Accelerated cool-down of backpressure steam turbines

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1 Introduction

Minimizing the duration of scheduled and unscheduled outages is becoming more and more important, especially for desalination plants. The turboset, with its hot components in the steam turbine, features long cool-down times of up to 12 days before the shaft can be put into standstill condition. Standard solutions like forced cooling used for condensing turbines cannot be adapted without major modifications.

Siemens has recently implemented a forced cooling procedure for backpressure turbines to shorten cool-down times by more than 50 percent. Test results will be presented in this paper.

By using this procedure, plant operators are able to have earlier access to areas of the steam turbines, generator, and auxiliary systems that require a shaft standstill, which increases the availability of the plant.

2 Forced cooling for condensing steam turbines

Forced cooling for condensing steam turbines was developed in the early 1990s for specific units, especially for the high number of newly built single-shaft power trains. In this application, the gas turbine is aligned with the steam turbine on one shaft with a generator in the middle. This configuration, with many advantages in a variety of areas (like compact civil arrangements), created challenges in terms of operation and maintenance. The gas turbine’s lighter design results in a much shorter cool-down period than that of its solid counterpart on the other end of the shaft, the steam turbine. That can cause situations where necessary gas turbine inspections are delayed simply because the steam turbine must first cool down in order to put it into standstill and so ensure a safe work environment with no rotating masses.

To avoid excessive thermal distortion and differential expansion of the steam turbine, maximum allowable cool-down gradients are determined using a finite element computer model and considering material strength limits and usage factors. Exceeding these steam turbine specific cool-down gradients could cause extensive damage. To monitor the cool-down gradients, existing temperature measurements of the steam turbine are used to help maintain the recommended temperature limits during a forced cool-down.

During forced cooling, the existing condenser-air removal system is used to draw air from the turbine hall through the blade path of the turbines into the condenser, where it is ultimately exhausted from the system. This flow generates a forced heat transfer from the hot steam
turbine components to the heated air, which allows the steam turbine to cool down much faster than through natural cooling.

Fig. 1: Cooling path in condensing steam turbine

Therefore, forced cooling is a reliable way of reducing cool-down times by more than 50 percent compared with natural cooling. The forced cooling process combines a modified software package, nozzle filters, and the mechanical analysis of permissible relative expansions. The permanent installation of additional hardware or modification of existing hardware is not required. In case of usage, the nozzle filters need to be installed on the existing flanges for the dehumidifiers between the emergency stop and control valves of HP and IP turbine.

Forced Cooling can be differentiated into two operational application areas, whether it is used for scheduled or unscheduled outages.
2.1 Procedure for scheduled outages

Prior to the plant shutdown, the main steam and reheat steam temperatures are reduced (Phase 1) to the minimum allowable values in accordance with allowable limits and protection criteria. Reducing the temperature during operation shortens the overall cool-down time due to the lower starting temperature of the forced cooling process. The on-load cool-down with steam allows higher gradients than later on with air. In addition, the steam turbine is available for the load dispatcher at that time.

In Phase 2, when steady-state temperature conditions have been achieved with reduced steam temperatures, the steam turbine is shut down. During turning-gear operation the turbine enters a so-called “natural cooling phase.” During this period the inner shaft and casing temperatures are equalizing throughout the entire steam turbine. As soon as the equalization has reached steady-state conditions, the forced cooling can be started.

During this period of “natural cooling,” the boiler is depressurized and isolated from the steam turbine. In addition, the nozzle filters are installed at the dehumidifier flanges between the emergency stop and control valves.

In Phase 3, the control valves are opened and the vacuum pumps switched on. This draws in ambient air via the nozzles through the turbine blade path and cools down the components.
smoothly. To maintain the allowable cool-down gradient, the air flow is regulated by changing the position of the control valve.

When reaching shaft temperatures below 100°C (212°F) the turning gear can be switched off, and the turbine is in safe condition for all required maintenance activities on the turbines, generator, and auxiliary systems.

2.2 Procedure for unscheduled outages
In the event of an unscheduled outage (for example, in case of a turboset trip) or if there are no desuperheating options for the steam generator, the on-load reduction of steam temperatures described in Phase 1 cannot be performed.

In this case, Phase 2 (natural cooling) and Phase 3 (forced cooling with air) will be extended for several hours to compensate the missing Phase 1.

3 Forced cooling for backpressure steam turbines
In 2010 the first idea for a forced cooling process for backpressure steam turbines surfaced and a general concept was developed. The pilot implementation was performed in a desalination plant on the Arabian Peninsula and was finalized in 2012. The crude-oil fired desalination plant consists of three turbosets with an electrical power output of approximately 430 MW per unit. The total plant is capable of producing 880,000 m³ of drinking water per day. Each turboset comprises a high-pressure turbine (150 bar, 510° Celsius), a two-flow intermediate pressure turbine (40 bar, 460° Celsius), and a 500-MVA hydrogen-cooled generator with static excitation.

Due to the high water and electricity demand in the region, it was the customer’s goal to shorten the plant outage times. The fact that the steam turbine required more than 12 days to reach a standstill condition of below 100° Celsius shaft temperature when cooling down naturally needed to be addressed. Basically, the forced cooling procedure for condensing steam turbines can also be applied for backpressure steam turbines. The challenge is to provide a suitable external suction blower unit (instead of the not existing evacuation system of the condenser) that has sufficient capacity and is capable of processing hot air, especially at the beginning of the procedure. Another requirement was the mobility of the suction unit and its installation, because it should be used for all three units. Due to the design of high (HP) and intermediate (IP) pressure turbines at the pilot plant, two suction units were required.
Each suction unit had to ensure that the required vacuum was achieved so that appropriate cooling flow in the turbine was established.

For the suction unit, the choice was made to use a rotary blower with high energy efficiency, low pulsation characteristics, a robust design, and a long service life. With a motor power of more than 70 kW and its speed-controlling capability, the suction capacity was sufficient for the application purpose. The blower was built in an encased, fan-cooled skid design, which allows easy mobile handling and reduces noise emissions when in operation.

Each rotary blower must be easy to connect to the operational piping, taking into account the calculated cross-sections of the piping, structural stiffness against the vacuum, and process temperatures during the procedure. The connection points must have been selected to provide fast accessibility and adequate space for the blower skid.

![Fig. 3: Forced cooling concept for backpressure steam turbines](image)

For the HP turbine, a flange access on the HP dump line was chosen, with the advantage of being able to install the blower skid on the 0 m plant level without the need of cranes.
Unfortunately, it was not possible to gain access in front of the HP dump valve, simply because it is positioned in between the 6 and 12 m floor and no flanges are available. The skid can be brought into position with a simple jack lifter. The connection is still relatively close to the HP turbine and ahead of the cold reheat flap, which itself builds up a “vacuum barrier” to the rest of the reheat piping.

The HP dump line ends in an atmosphere opening for dumping purposes in case of a steam turbine trip. In order to create the vacuum, the atmospheric end of the HP dump line must be closed. For safety reasons, it was decided to not simply cover the exhaust on the machine hall roof, because the cap might be forgotten when the plant is restarted. Instead, a dummy piece was installed in the HP dump line farther upstream at an easily accessible position close to the 12 m turbine floor. When the forced cooling occurs, the dummy piece will be removed from the HP dump line, and the consequent opening in the pipe will be covered with the flange from 0 m at the downstream side. In this way it is guaranteed that vacuum can be pulled without openings to the atmosphere and the safety aspect is fulfilled not to forget the cover plate in a case of restarting the plant in places like the roof, where it could be easily overlooked.

An access point to the IP turbine was selected close to the process steam line that connects the IP turbine with the desalination units. The access point uses a seal steam connection line, which was easy to modify for the forced cooling purpose. This access position is close to the IP turbine and therefore permits a close and thus an efficient evacuation of the IP turbine. The large process steam flap in closed position acts as a barrier to the enormous volume in the process steam line and it’s connected desalination modules. The start-up and safety valve that connects the process steam line with the atmosphere can be easily closed for this purpose to avoid air ingress. The existing platform of the left-side IP control valve needs to be extended marginal, but offers a close position of the rotary blower and therefore short connection pipes.

The power supply and control cabinet for the blower units were installed in a fixed position close to the blower operating positions. Due to the mobility concept involving all three turbosets, six power and supply cabinets in total were installed in the plant. The air-cooled cabinets provide the 380-V power supply via a frequency converter. The power supply itself is fed by the plant’s low-voltage distribution. It is possible via the frequency converter to regulate the speed of the rotary blower. This is necessary because the blower can only be operated in certain temperature limits before its motor protection will be actuated. The
exhaust temperature is used for a control loop. If it exceeds a certain limit, the speed is throttled to allow a decrease in temperature. To handle the high temperatures at the suction blower inlet, especially at the beginning of the forced cooling procedure, the up-heated air coming from the turbine is mixed with ambient air via a manually operated valve. This ensures an admissible inlet temperature for the blower at all times. In addition, the rotary blower is protected by a differential pressure measurement.

![Fig. 4: Suction blower concept](image)

In the initial phase of evacuating the HP and IP turbine with the suction blower units, the forced cooling procedure is basically the same as described in the standard forced cooling for condensing turbines in Chapter 1.

The cooling air mass flow is controlled by the position limiter of the control valves in the plant control room to keep the maximum allowable cooling gradient. The solution for backpressure turbines also offers the option of influencing the cooling gradient through the ingress of bypass air – within the limits of the operating range of the rotary blower.

### 3.1 Test results

The tests were performed in the pilot plant’s scheduled yearly outage. The prefabricated piping was welded and adapted to site requirements during this time. The installation of the cabinets and their cabling was already complete when the units were still in operation. The commissioning of the blower units was carried out without major problems, and several tests
were performed. Diagram 1 shows the test results from the cool-down during the pilot implementation.

Diagram 1: Test results

The blue line (HP nat) symbolizes the natural cool-down of the HP shaft recorded during the initial commissioning. Compared to the natural cooling, the red line (HP FC) represents the result from the forced cool-down of the HP shaft. The green line (IP FC) illustrates the forced cool-down of the IP shaft. The binary information of the blowers’ operation (HP/IP Fan On) can be seen by the grey lines, where 100 percent represents “On” and 0 percent ”Off.” The position of the control valves is also shown by the orange (HP CV) and light green (IP) lines.

The required natural cool-down phase of at least 12 hours after shutdown was used effectively to prepare for the tests and to install the air nozzles between the emergency stop and control valves. Due to manpower restrictions during the tests, the installation and successive operation of the blowers took place sequentially, starting with the HP blower due to the higher temperatures.

During the first tests it became obvious that maintaining the maximal allowable cooling gradients could be influenced most effectively by adjusting the manual bypass valve upstream of the blowers – which explains why both the HP and IP control valves in Diagram 1 were opened fully when starting the HP and later the IP blower.
3.2 Conclusion

The measured cool-down times were very impressive. The HP shaft achieved temperatures below 100° Celsius within 76 hours, and the IP shaft within 82 hours due to the later startup of the suction blower. Taking the total process of a natural cool-down into account, Diagram 2 illustrates the achievement in a more tellingly way.

![Diagram 2: Test results compared to natural cooling](image)

Compared to the 12 days of natural cooling, the benefit of forced cooling is obvious, with 3.2 days for the HP shaft and 3.4 days for the IP shaft. These results still show room for further optimization: All participants in testing process were convinced that it will be possible to cool down all shafts in less than three days.

With “forced cooling for backpressure turbines,” it is possible to easily reduce cool-down times by 50 percent at the minimum. The test results show that a reduction down to 25 percent of the normal cool-down time can be achieved. In this scenario, the customer would be able to avoid nine days of outage time and profit from this advantage, whether by fulfilling more demand for electricity and drinking water.

With this example, Siemens has proven once again to be a reliable partner for plant optimization.
This is not just the case for standard plant configurations, but also for individually designed plants with special design features like the desalination plants described in this paper.
4 Disclaimer

These documents contain forward-looking statements and information – that is, statements related to future, not past, events. These statements may be identified either orally or in writing by words as “expects”, “anticipates”, “intends”, “plans”, “believes”, “seeks”, “estimates”, “will” or words of similar meaning. Such statements are based on our current expectations and certain assumptions, and are, therefore, subject to certain risks and uncertainties. A variety of factors, many of which are beyond Siemens’ control, affect its operations, performance, business strategy and results and could cause the actual results, performance or achievements of Siemens worldwide to be materially different from any future results, performance or achievements that may be expressed or implied by such forward-looking statements. For us, particular uncertainties arise, among others, from changes in general economic and business conditions, changes in currency exchange rates and interest rates, introduction of competing products or technologies by other companies, lack of acceptance of new products or services by customers targeted by Siemens worldwide, changes in business strategy and various other factors. More detailed information about certain of these factors is contained in Siemens’ filings with the SEC, which are available on the Siemens website, www.siemens.com and on the SEC’s website, www.sec.gov. Should one or more of these risks or uncertainties materialize, or should underlying assumptions prove incorrect, actual results may vary materially from those described in the relevant forward-looking statement as anticipated, believed, estimated, expected, intended, planned or projected. Siemens does not intend or assume any obligation to update or revise these forward-looking statements in light of developments which differ from those anticipated. Trademarks mentioned in these documents are the property of Siemens AG, its affiliates or their respective owners.