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Steam turbine overspeed protection

Overspeed protection systems and maintenance practices

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1 Executive summary

The scope and purpose of this paper is to provide contextual knowledge to the known risks and exposures associated with steam turbine overspeed protection systems. Overspeed protection systems have been on rotating machinery for decades, but their design over the years has changed from mechanical to electronic. However, their concept and function remains the same, aiming to safely shut down the turbine. Steam turbine overspeed events can be caused by mechanical failure of the steam admission valves and/or failure of the overspeed protection system. Turbine overspeed events can result in a severity type loss of the turbine. Overspeed events will cause severe vibrations, bearing failures, blade liberations, and lube oil pipe fractures resulting in a turbine fire. Damage to the rotor assembly and generator are likely to occur. Plants that experience an overspeed event can have significant business interruption impacts as catastrophic turbine repairs will often exceed 12 months or more.

2 Introduction

2.1 Standards used

The API Standard 670 5th Edition ("API 670")[1]-Machinery Protection Systems standard is the reference standard for rotating machinery electronic overspeed protection system design. New installations and retrofit system upgrades on existing equipment should also meet this standard. Section 8 of API 670 covers in detail the functionality, configuration, and verification of the electronic overspeed protection system. The API 670 is the standard applied in the US for minimum requirement for machinery protection. This standard is recognized globally, but other standards, such as VGB, may be utilized in other countries.

2.2 Overspeed protection philosophy

The purpose of a steam turbine overspeed protection system is to safely remove the driving energy being supplied to the steam turbine if the turbine attempts to exceed is rated design speed. The API 670 Machinery Protection Systems standard describes the minimum requirements for a machine protection system (MPS).

API 670 standard states that electronic overspeed detection shall be separate and distinct from the speed control system, with the exception of final control elements.

The two independent overspeed protection systems include the control system and the overspeed protection devices. The primary control systems (i.e., turbine governor, DCS, PLC) that operate the turbine have a level of protection built into the standalone electronic design. Mechanical overspeed protection devices, which are distinct from the control system, are further discussed in this document. The operation of the steam turbine protection system is often associated with the control system. However, it should be recognized that the two systems are entirely separate. The protection system operates only when the control system set point parameters are exceeded.

Overspeed protection systems monitor the speed of the turbines in Revolutions Per Minute (RPM). A turbine trip occurs when the turbine exceeds its rated RPM, which actuates immediate closure of the turbine's stop valves, isolating all motive energy to the turbine for a shut down.

Larger steam turbines operate at rated speeds of 3600 RPM for a 60 Hz design or 3000 RPM for a 50 Hz design. Overspeed events can occur during startup, shutdown, or from a disturbance that causes the generator breaker to open. When turbines are synchronized to the grid, the likelihood of an overspeed event is low.

However, when the turbine is not properly synchronized to the electric grid, rated speed can quickly accelerate to an overspeed condition. Protection systems are typically designed to trigger a trip between 108% and 112% of normal operating speed. For example, 3888 RPM to 4032 RPM for 60 Hz units or 3240 RPM to 3360 RPM for 50 Hz units.

The operation of the steam turbine protection system is often associated with the control system.

3 Types of overspeed protection systems

The two key, proven overspeed protection systems used today are the mechanical and electronic types. They are paramount to the safety and functionality of the turbine. It is important to note that the electronic control system governor (DCS or PLC) also has a form of overspeed protection recognized by API 670. This protection feature, however, is not meant to function as the primary overspeed protection system.

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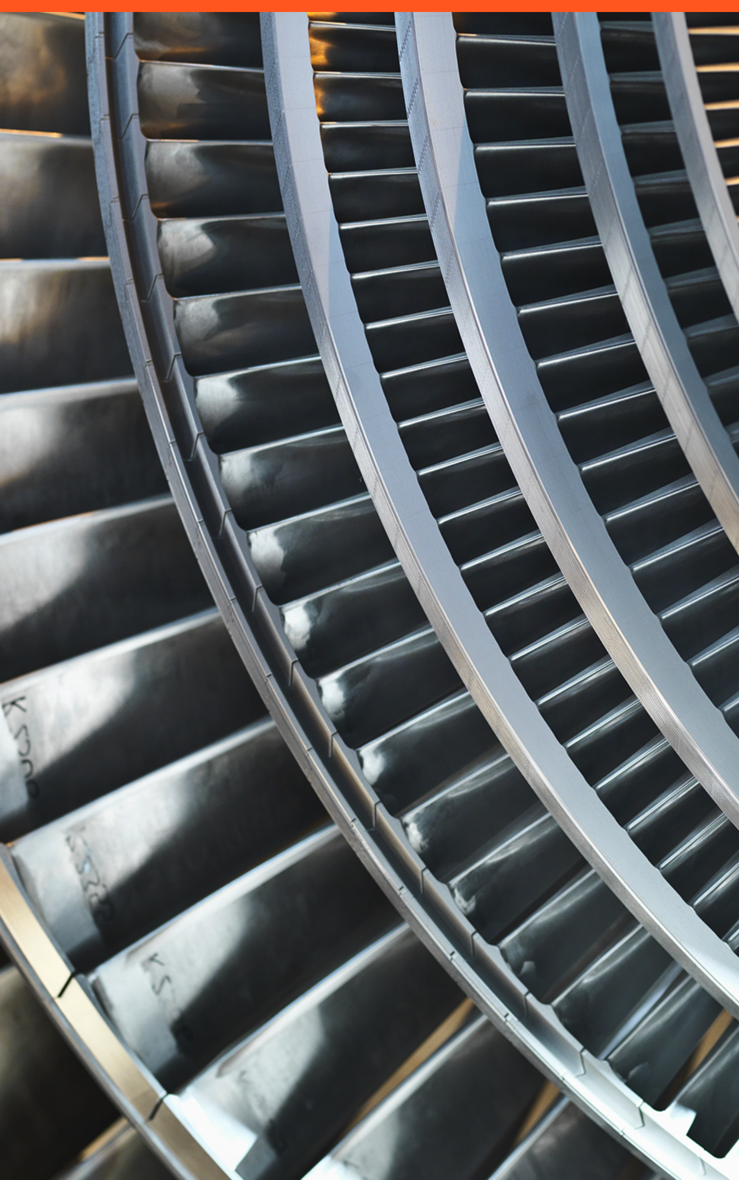

3.1 Mechanical overspeed trip protection

Mechanical overspeed trip protection, or a "bolt" type system (Figure 1), has a mechanical plunger (bolt) that is physically attached to the rotating shaft of the turbine. The bolt is held in a recessed position within the shaft via a mechanical spring. As the turbine spins, centrifugal force is asserted on the bolt. As the turbine spins faster, centrifugal forces increase, causing the bolt to start protruding outward. When the turbine reaches the predefined critical speed, the centrifugal force on the bolt is greater than the mechanical force maintained by the spring.

As a result, the bolt will then protrude significantly from the shaft and contact the trigger arm. The trigger arm will mechanically cause the trip header block port to open, resulting in turbine control oil (also known as EHC or Safety oil) to drain into a reservoir. Consequently, the oil is no longer being ported to hold the stop valve(s) open. The force of the valve spring causes the valve(s) to close, allowing the turbine to safely shut down.

Figure 1 - Mechanical overspeed trip protection

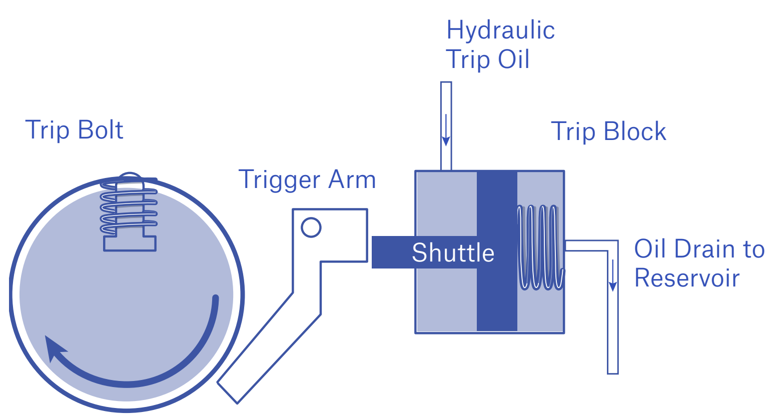

Figure 1: Example of the mechanical "bolt" overspeed protection. The mechanical trip protection as shown above is the original concept of this type of protection and has been commonly used for decades.

3.2 Electronic overspeed trip protection

The electronic overspeed protection system typically relies on a voting system to allow for a degree of fault tolerance and reduce a single point failure occurrence with a sensing device. Electronic overspeed trip protection consists of a 2 out of 3 voting configuration, where two of the speed probes need to sense an overspeed condition to trip the turbine.

One out of 2 electronic overspeed protection systems are not recommended as per API 670 but are accepted by other international standards, and therefore, we believe, are widely implemented in the designs of major Original Equipment Manufacturers (OEMs). The speed probes are mounted to the bearing pedestal. The speed probe most often used to detect turbine speed is the magnetic pickup (MPU). When a magnetic material (usually a gear tooth driven by the prime mover) passes through the magnetic field at the end of the magnetic pickup, a voltage is developed.

The frequency of this voltage is translated by the speed control into a signal that accurately depicts the speed of the prime mover. Said frequency is configured in their respective control cards for specific turbine alarm and trip parameters. The overspeed speed card will control a solenoid on the turbine dump manifold (TDM) (see Section 2.3.3). When the rotating speed of the turbine exceeds a pre-defined limit, the control card will then de-energize to actuate the respective trip solenoid.

The de-energization triggers a "fail safe" turbine trip. Note, that if a complete loss of power (wire cut, system failure, etc.) were to occur, the electronic solenoids will also trigger a trip. When the TDM solenoids are de-energized, the control oil is released or dumped to a drain. Consequently, oil hydraulically can no longer maintain pressure to hold the stop valves open.

The electronic overspeed protection, when configured and evaluated properly, may be considered to have a higher degree of reliability than the mechanical overspeed bolt design. The expected response time from when an overspeed condition is detected to the trip of the turbine TDM can be less than 50 m/s. Per API 670, overspeed reaction time should be less than 50 msec.

Electronic overspeed protection systems must be maintained as separate from the turbine governor control system per API 670 and other industry standards. All plants that have a Distributed Control System (DCS) and electronic overspeed protection system typically have multiple layers of overspeed protection.

The primary overspeed protection system is a standalone system, typically with separate speed probes isolated from the turbine governor control system. While the turbine governor system has a form of overspeed protection and can trip the unit, the turbine governor system is not considered the primary overspeed protection system.

An electronic overspeed protection system combined with the main control system (turbine governor control, DCS, or PLC) may be considered the primary protection system. However, an additional independent protection overspeed system is also required per API 670. Both systems must be evaluated at least annually. To assess the trip function within the governor control, a plant technician may adjust the trip speed setpoint. This is not considered a test of the independent overspeed protection system. While the turbine may in fact trip and display the event in the alarm historian, the test is not considered an adequate test of the overspeed protection system. This test is only a test of the turbine governor control logic. The OEM should professionally train plant staff to ensure proper testing of the overspeed protection systems both in the governor controls and the independent protection system.

Figure 2 - Overspeed protection controllers

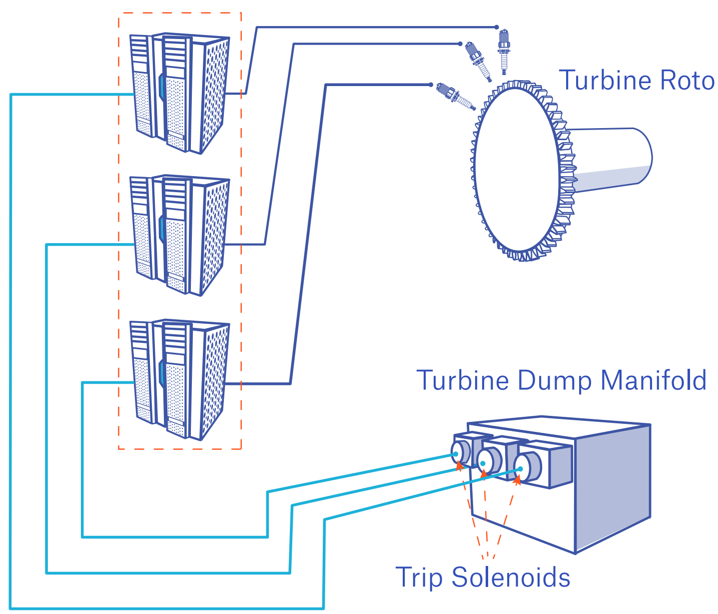

Figure 2: Typical configuration for an electronic overspeed protection system. This is a standalone system, separate from the governor controls and operates independently. The system monitors speed of the rotating shaft and sends that signal to speed cards, which then de-energize to trip solenoids located at the TDM or Trip Block. When two or more (in the example above) are de-energized, the oil is drained, and the pressure in the trip header is removed, thus closing the steam stop valve.

3.2.1 Turbine dump manifold (TDM)

The (TDM), depending on the manufacturer, may be identified as a trip block or emergency trip device (ETD), but all function similarly. The TDM is a critical part of the electronic overspeed protection system. TDMs utilize a hydraulic trip block to port control oil to the turbine stop valve(s). The block is equipped with three dump solenoids that are each wired to a dedicated overspeed control card. These solenoids are wired for failsafe operation, which means an energized solenoid is for normal operation and a de-energize solenoid occurs for the turbine to trip. In the event of a wire break or a power loss, the solenoids will de-energize to protect the turbine from overspeed.

The TDMs can be tested through the turbine control system independent of a full function overspeed test. The TDM system will typically de-energize one trip solenoid at a time. During the test, pressure transmitters located on the trip block monitor chamber pressures for a pass/fail result. A failed test means a hydraulic trip issue resides in the block. This test can be performed both online and offline with typically no risk to the unit.

For mechanical devices, a bench test will prove system functionality.

4 Testing and system reliability

Both mechanical and electronic overspeed protection systems shall undergo system testing for reliability - this is typically required by an insurance carrier. There are many ways to complete a function test of the system. For mechanical devices, a bench test will prove system functionality. It is important to note that the adequacy of this test relies on the function testing of the entire loop, from the sensor to the trip valve. Additionally, before the plant conducts any online testing, it is especially important that the manual trip push buttons are inspected and reliability tested. A system inspection should be performed and checked on both mechanical and electronic systems to ensure that the control oil drain returns to an unpressurized reservoir. The drain lines must be free, direct, and without isolations such as hand valves (even if locked open).

4.1 Mechanical bolt testing

Mechanical overspeed bolt testing can be performed two ways. The first is bench testing and the second involves an actual overspeed of the unit. Bench testing of the overspeed bolt involves removal of the bolt from the rotor and installation into a test stand. While this does prove the functionality of the overspeed bolt and centrifugal forces acted upon it, this method will leave gaps in evaluating the protection, such as reinstallation complications. Bench assessing the bolt, while mitigating the associated risk of an actual overspeed of the turbine, does not functionally evaluate all the mechanical components involved with a turbine trip, such as the centrifugal forces acting on the bolt. Additionally, the disassembly and reassembly of the bolt poses a human element risk during installation.

The second method of evaluating the mechanical overspeed protection system is the more commonly used method; however, it poses more risk and is the least preferred. This method involves physically overspeeding the turbine to trigger the mechanical bolt. Physically overspeeding the steam turbine causes mechanical stress on the physical components of the turbine, presenting increased risk. Actual overspeeding testing typically is performed when the turbine rotor is hot prior to a planned shutdown for an annual outage. The turbine generator breaker is opened, and the unit's speed is manually raised to overspeed; in some cases, protections in the control system need to be bypassed as this is not a normal operation of the turbine. Once the centrifugal forces acting on the bolt overcome the spring retention force of the bolt, the bolt should eject, resulting in a trip of the unit. Because this is a mechanical action, the overspeed trip speed is not exact and could be slightly below or above the 108% to 112% overspeed trip setpoint.

It is generally recommended the frequency for assessing the mechanical system should be performed on an annual basis and would consist of a physical overspeed test. While this is the less preferred method from an insurer standpoint, it is important, it is important to test the system. If the unit is unable to be tested at rated overspeed, the unit should be replaced with an electronic overspeed protection system. Should a unit be equipped with electronic overspeed that meets the API 670 standard as described in this document and mechanical overspeed protection, testing only the electronic protection system is adequate for insurance purposes. As a reminder, the turbine governor controller (DCS or PLC), while it has a form of overspeed protection, it is not considered a primary means of overspeed protection as it does not meet API 670 standards.

4.2 Electronic overspeed testing

Electronic overspeed testing can be performed a variety of ways either online or offline without causing undo stress to the machine, mitigating risk. While there are multiple ways to functionally evaluate an electronic protection system, this section will cover the key components of the test to ensure reliability and functionality of the system as a whole.
The preferred method for online testing is by lowering the overspeed trip setpoint during operation with the unit at synchronous speed or upon startup. With the lower setpoint, the protection will cause the trip valves to open, draining oil from the TDM. This results in immediate closure of the steam stop valve(s). From an insurance standpoint, it is not recommended to perform an actual overspeed test of the unit, which is at setpoint of 108% to 112% of maximum rated speed. According to OEMs, the induced stress on the turbine can be destructive.

Testing offline is the preferred method, which can be performed a few separate ways. For example, by connecting a frequency generator, a signal can be injected into the speed probe. This method will prove that the circuitry from the sensing unit to the control card is acceptable. When equipped with a 2 out of 3 voting system, the two signals required from the trip system will generally cause the trip valves to open, draining oil from the TDM. This results in immediate closure of the steam stop valve(s).

Another method involves testing while the turbine is rotating at turning gear. Typically, a rotation greater than 25 RPM is required to perform an overspeed test. This is accomplished by lowering the overspeed trip setpoint. This will allow a full function test of the overspeed protection system from the sensing probes to the TDM without motive steam to the turbine. This method poses the least stress and risk to the turbine.

Furthermore, a simulated speed test has been designed into modern overspeed systems equipped with control cards that permit a self-test feature. There are three overspeed protection cards designed into the overspeed controller. This allows the operator to trigger an artificial signal similar to an external frequency generator mentioned above. An internally generated speed signal is used to evaluate the module's overspeed trip setpoint and trip output function. When the overspeed trip signal satisfies the pre-established setpoint, 1 of the 3 trip valves should allow oil from the trip valve leg to open and partially drain oil from the TDM. This testing feature can typically be performed at any time to evaluate the functionality of the trip system but without tripping the unit, as only 1 of the 3 circuits is evaluated at a time. This method proves the system’s full function capability.

4.3 Maintenance practices

Both mechanical and the electronic protection systems require planned routine maintenance. The mechanical overspeed protection system requires the bolt to be inspected and assessed on an annual basis. At this time, all the mechanical components of the overspeed protection system should be inspected for wear and freedom of movement.

Electronic overspeed protection systems have specific areas of maintenance and inspection that are often overlooked. At a minimum, inspection and testing of the electronic overspeed protection system should occur at least annually or if the electronic protection system is disturbed. The speed probe distance should be properly gapped from the speed wheel mounted on the turbine shaft. The speed probe utilizes a generated voltage signal as the speed wheel teeth spin by the sensing probes. The voltage signal is transformed into a frequency speed signal, which is needed for the turbine control display. If the probe is too close to the speed wheel, the probe may become saturated with voltage, resulting in a poor reading. Conversely, a probe that is too far from the speed wheel will result in a poor voltage signal and an inaccurate reading.

In addition, the electronic overspeed protection system circuit is often energized by power relays. While it is unlikely that these relays may fail, they should be inspected and evaluated annually. The electronic overspeed protection system is designed to control the TDM, which is the key component of the overspeed protection system. This hydraulic control block is equipped with failsafe solenoids that direct port oil through the hydraulic block to actuate the turbine stop valve(s) or drain. The failsafe solenoids are energized while the unit is in operation and will tend to get hot during normal operation.

It is especially important to adhere to the manufacturer’s recommendations for planned reliability maintenance and testing. Some manufacturers recommend a replacement at five-year intervals. From an insurer perspective, the best practice is to perform an online test of the TDMs on a weekly basis. TDM testing will prove proper solenoid valve actuation (open and close), identify an unacceptable response time, and identify signs that block ports may be obstructed. The solenoids can be evaluated as part of the online TDM testing at any time.

Both systems have hydraulic trip blocks that require planned maintenance. TDMs have small oil ports inside of them and some of them have small orifices. While these systems sometimes have their own oil filtration system, it is important that they are inspected annually and replaced at manufacturer recommendations by the manufacturer or a competent engineer. There have been known severity turbine events in the industry due to poor maintenance practice of the TDM and failsafe solenoids.

5 Loss control

Loss potential of the rotating machinery is addressed by properly following technical standards such as the API 670, OEM recommendations, and industry best practices for maintenance and testing for overspeed protection systems. There are typically many layers or forms of overspeed protection in place for rotating machinery; however, history has shown that during certain circumstances, losses have occurred; typically, the loss root cause stems from poor system maintenance, testing, or installation.

6 Conclusions

Operators should have good working knowledge for the type and configuration of the overspeed protection system installed. Operators have the responsibility to ensure the reliability of their protection systems and maintain adequate documentation that they are being routinely assessed. A well-developed written functional test procedure should be in place.

It is the responsibility of the asset owner, operator, and engineer to review and ensure that the systems are being assessed and the rotating machinery has a dependable overspeed protection system installed. Regardless of the type of overspeed and trip protection systems provided, the system needs to be regularly evaluated by simulation and by actual testing of the complete system.

[1] API Standard 670, 5th Edition, 11/14.