

Development of strategies for life cycle management of steam turbines and generators in aging fossil-fired steam power plants

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Many steam power plant operators are faced with the issue that, in order to support the energy transition, they are required to operate their plant longer than originally intended. To ensure continued reliable operation, it is important to update the plant asset management strategy for the remaining operating time horizon. In order to perform such an update, it is important to understand the present and expected future health condition of the main power generation components. A first step is a review of the historical maintenance findings and operational data. Based on this historical review, it is possible to evaluate the present condition and to predict the future risk progression. This can be done with lifetime models that are either based on design expertise or

on experience from similar units in the global fleet. The results of this assessment can then be used to define recommendations to manage future risks, based on the expected operational time and profile. In this paper, an overview of the main risks for the steam turbine and the generator will be provided, along with some of the methods available for monitoring and controlling those risks. The paper also discusses other risks potentially affecting aging plant that can be caused by interactions with the electricity grid, considering changes impacting grids in many countries linked to the ongoing energy transition.

1 Introduction

Most countries around the globe are in the process of transitioning from fossil-fired power generation to cleaner energy production. In the transition period, it is often not economical to continue to build new fossil-fired power plants. However, until there are enough cleaner energy sources, it is still required to run many of the existing fossil-fired power plants to ensure a reliable electricity supply. In many cases, this leads to

requests to run the plants longer than originally intended. Additionally, the future operational profile is different compared to the historical profile, because the plants need to adapt to the demand and the intermittent nature of power that is produced by renewable energy plants. It is therefore important to have a strategy and a plan to ensure that, during this extended operational period, the plants can continue to operate in a reliable manner.

In order to create such a strategy, it is important to have a good understanding of the unit specific operation and inspection history, and the expected future operational profile and expected grid characteristic changes. The focus of this paper is limited to the steam turbine and generator, which are the core power generation components of the power plant.

2 Asset lifecycle management strategies

The main components of the steam turbine and the generator typically have a few, dom-

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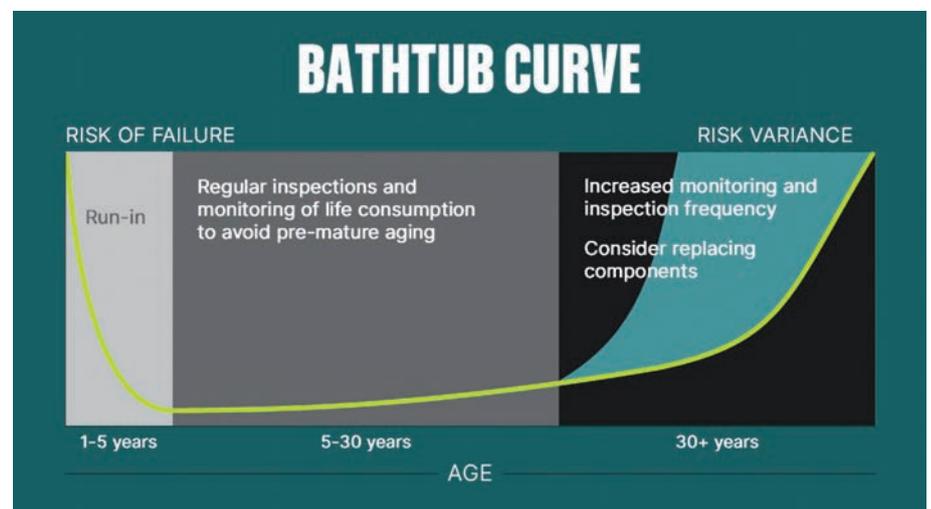


Fig. 1. Typical bathtub curve of component failure risk.

inant, age-related failure modes, which follow an aging approach that is often represented by a bathtub curve (see Figure 1). The bathtub curve displays the failure rate over the lifespan of the different components and is used in reliability engineering to model the lifecycle of the different components [1]. The curve consists of three different phases. After an initial run-in period, there is a relatively long “mid-life” period, with a low, constant or slightly increasing probability of failure. During this phase, it is important to perform inspections to see if the actual aging rate is in line with the expected aging rate. It is also important to monitor the leading indicators, such as steam temperatures, generator end-winding vibrations, steam chemistry, generator winding temperatures, etc. This is important because it is often difficult to monitor the symptoms of aging, such as creep damage or loss of generator winding insulation. If the aging is properly managed in the mid-life phase, pre-mature aging can be avoided. If not, it will only be observed when it is too late to do something about it. Depending on how the aging is managed and how the plant is operated, the third period can start earlier or later (see Figure 1). The third period is referred to as the wear-out phase. When this phase is reached, the strategy should shift from preventing pre-mature aging, to shorter term prediction of possible “end-of-life” failure situations. The most risk averse approach is to replace or recondition the components, in order to reset the lifetime. For a larger extension of the operational life of the plant, it is often worth replacing or reconditioning the components to reduce risks and improve the usage of the new or reconditioned components. In case a shorter extension of the operational life is planned, it is often difficult to justify such an investment. If this is the case, it is important to increase the monitoring effort and inspection frequency.

The first step to develop an updated Asset Lifecycle strategy is to create a high-level understanding of which phase of the bathtub curve the different components are in. To support plant operators with this effort, GE Vernova has developed an offering called Risk-based Health Assessment (RBHA). This assessment is based on the Risk-based Inspection (RBI) methodology, which is being used increasingly in many industries, mainly for static equipment. GE Vernova uses its OEM fleet experience to model the bathtub failure rate curves. Fleet data is used to create quantitative failure rate curves, based on two parameter Weibull distributions. More details can be found in a previous GE Vernova paper [1]. The result of the assessment is a high-level overview of the historical and future evolution of the lifecycle phases for the most important, life limiting components (see Figure 2).

Figure 2 shows an overview of the complete lifecycle. The green color represents

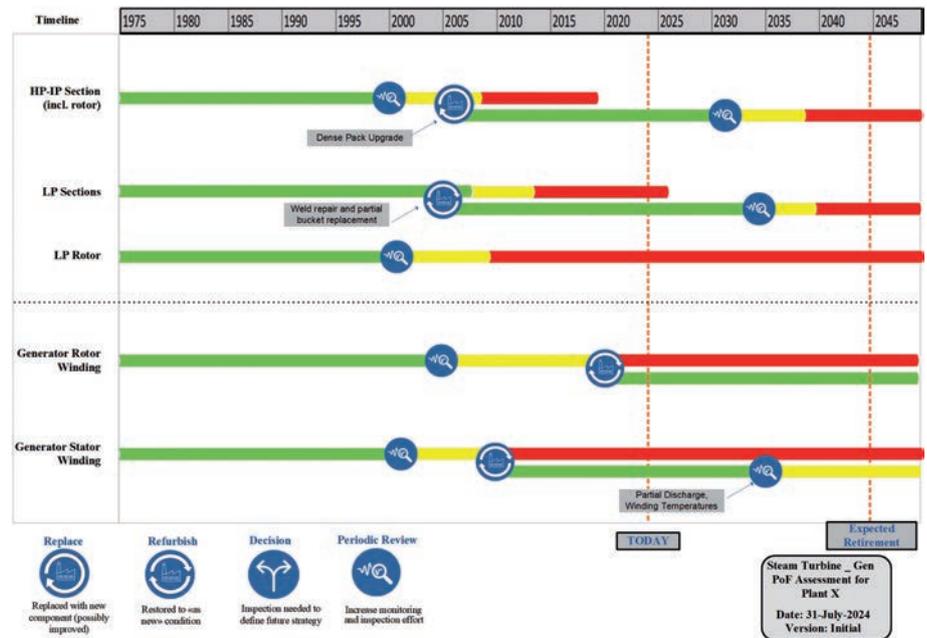


Fig. 2. Lifecycle Assessment for most important ST and Generator components.

the mid-life period of the bathtub curve. The yellow phase is the start of the wear out phase, and the red color represents the more advanced period of the wear out phase. When components have been replaced or planned to be replaced, a second line is added, where the used lifetime is reset.

3 Steam turbine

The main life limiting failure modes of the high temperature components are creep and LCF lifetime consumption of the HP and IP rotors, and also other components such as the inner and outer shells and the steam inlet valve casings. Operation above 400 °C leads to a finite component life. In order to quantify the remaining lifetime of these components, it is recommended to perform a remaining lifetime assessment (RLA). Further details can be obtained through NDE of the critical locations identified in the RLA. The RLA and the NDE results can then be used to plan further actions, e.g. repair or replace, as required. For more details, see an earlier paper by GE Vernova [2]. The main leading indicators to monitor here are the steam temperature levels and variations and the number of start/stop cycles.

The main life limiting modes in the LP section rotor are aging due to LCF, stress corrosion cracking (SCC) in the blade root or rotor groove area, erosion and pitting. To reduce the risk of corrosion, it is important to monitor the water/steam chemistry. There is also the risk of cold-end corrosion during stand still periods if the recommended preservation procedures are not followed. This may result in pitting, which will become an area of potential crack initiation (corrosion fatigue).

A common change for the aging plant fleet is that they are no longer used as base load units and instead they are only used to sup-

ply power when there is a supply shortage. This means that the plants are often changing between maximum and minimum load, with more time spent at low load operation than was historically the case, or that they experience an increasing number of start/stop cycles. This must be taken into consideration when evaluating the future life consumption.

Depending on the situation, there are also many plants that only run a low number of hours, and that are on standby for most of the year. In this case, there is only a very limited life consumption. The main affected system in this situation is the shaft turning system. It is important to regularly inspect the shaft turning components, because an outage of the shaft turning system would mean unavailability of the unit. In order to limit operational costs and wear of turning gear and oil systems, it is not recommended to run the shaft turning system continuously for long periods. Continuous shaft turning will have a degrading effect on the turbine and generator rotors. It is however recommended to start the shaft turning system once a week for a short time (e.g. 1 hour), to limit rotor bending, ensure that the system operates properly and to provide a fresh oil film on the bearings to prevent surface corrosion.

Another issue when units have limited operation is that they will not reach the operating hours or starts limits to perform inspections. GE Vernova generally advises that if the operating limits are not reached after a period no longer than 12 years, it is recommended to perform a major overhaul of the steam turbine and generator.

4 Generator

The main life limiting failure modes of the generator are winding failures. An unexpected stator or rotor winding failure can

lead to extended equipment unavailability and long forced outage periods. It is therefore important to increase the monitoring when the components reach the wear-out phase, and the expected remaining operation time is insufficient to justify a re-wind or replacement of the rotor or stator. A very good way to perform such monitoring is to use the GE Vernova generator health monitoring system (GHM). Most important modules to monitor the aging of the stator and rotor winding are:

– Partial discharge monitoring:

Partial discharges (PD) are localized electrical discharges that partially bridge the insulation between conductors in high-voltage insulation systems. Insulation deterioration, through the aging process will cause PD to increase significantly and accelerate failure mechanisms. PD monitoring with sensors installed on all three phases and on the neutral point helps to identify the main stator winding failure modes, such as insulation aging, loose stator bars or contamination (Figure 3).

– Rotor flux monitoring:

Rotor flux probes are designed to accurately detect, localize and track rotor

winding inter-turn short circuits in real time. The flux probes allow operators to identify generator rotor winding failures at an early stage and take adequate actions for extending operation of the generator (Figure 4).

Other GE Vernova GHM modules are rotor shaft voltage measurement, stator end-winding vibration measurement, stator bar cooling water distribution monitoring, stator leakage monitoring and brush monitoring for static excitation systems to avoid flash overs.

5 Grid issues

The energy transition is also causing changes to the grid conditions, which may affect the life consumption of turbine-generator shaft line components. The power grid includes more and more equipment that can interact with the turbine-generator shaft line and cause torsional vibrations at the shaft natural frequencies. The amplitude of these vibrations can be large enough to cause cumulative fatigue damage to turbine-generator shaft components. In some cases, interactions with the grid have led to sustained or growing shaft torsional vibrations

that caused severe damage (cracks, etc.) to rotors, rotating blades or generator retaining rings at shrink fit surfaces, resulting in long forced outages for the affected units.

The following are typical causes of grid disturbances that may cause torsional vibrations of the shaft line [3]:

- Switching of series capacitors in transmission lines
- Negative phase sequence currents, which can be continuous or intermittent, caused by, for example, ground faults, unbalanced loading, slow fault clearing
- Short circuits and line switching
- Oscillations from power electronics such as large industrial drives, AC or DC converters, steel mills with arc furnaces
- Vicinity of (AI) data centers, especially if the unit operates in island mode to deliver power to the data center

Some of the most critical transient disturbances are sub-synchronous resonances (SSR) caused by switching of series capacitors used to compensate the high inductive reactance of long transmission lines. Sub-synchronous and super-synchronous torsional vibrations can also occur where turbine generator units are closely interconnected with AC-DC power converters such as those used in some industrial plants (e.g. steel mills) or DC power transmission systems.

The most critical steady state response is usually caused by negative phase sequence currents caused by phase imbalance. This causes a stimulus at twice the grid frequency. The effect therefore depends on the amount of separation of the torsional natural frequencies from the stimulus frequency (twice the grid frequency).

In case the turbine-generator is exposed to any of the mentioned potential sources of torsional vibrations, it is important to perform a rotor dynamic study to calculate the sub-synchronous vibration modes and the natural frequencies in the vicinity of 1X and 2X grid frequency. In case the results are close to twice grid frequency (within 2Hz), it is important to confirm the results of the study with an actual torsional vibration measurement on the turbine-generator unit.

When upgrading or replacing turbine-generator sections, it is important to consider whether these changes could adversely influence the torsional duty experienced by the machine [3].

In case there is a potential for high levels of torsional interactions with the power system, it is recommended to install a permanent Torsional Vibration monitoring system, such as the GE Vernova TTVA system. Examples of plants that could require such a system are those connected to series capacitor compensated transmission lines and plants electrically close to steel mills with large AC and DC power converters or (AI) data cent-

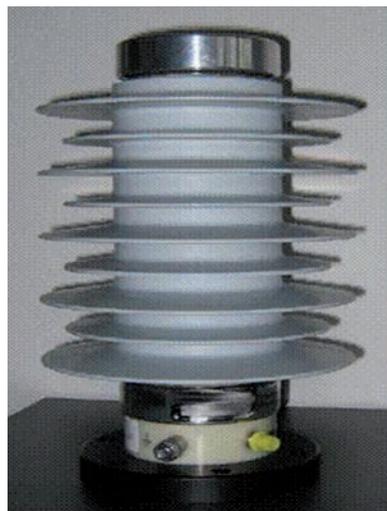


Fig. 3. PD sensor and pattern.

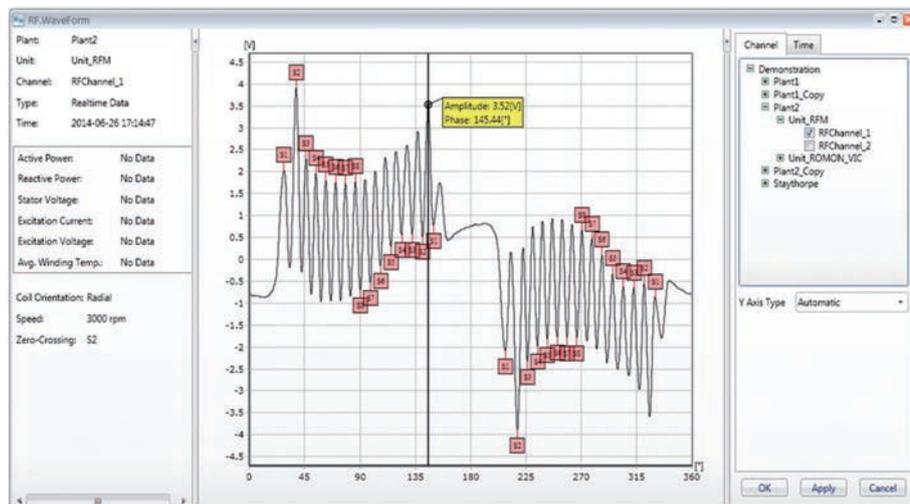
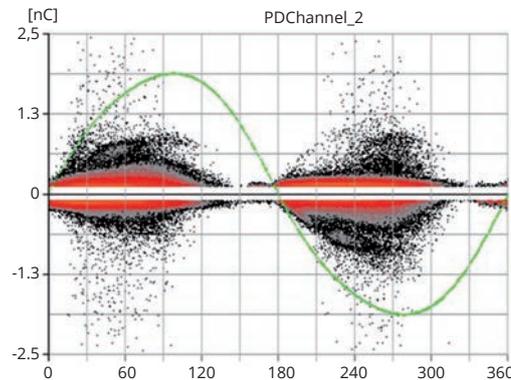


Fig. 4. Rotor flux probe user interface.

ers. In case of high risks for sub-synchronous vibrations, it is recommended to also install a Turbine-Generator Torsional Stress Relay (TSR). A TSR is a digital protective relay designed to continuously monitor the shaft line for torsional vibrations and provide trip output contacts when the vibration reaches predetermined levels. The torsional vibration measurement is typically done by proximity probes observing a toothed wheel on the shaft line that generate pulses every time a tooth passes. Depending on the shape of the vibration modes, one or more measurement planes will be required.

Many generators are equipped with a Power System Stabilizer (PSS). A PSS is a controller that modulates the generator field voltage to dampen generator rotor angle swings. In addition to damping of the low frequency modes in the power system, which are of primary importance, it is possible that a PSS can also introduce undesirable effects at the characteristic modes of the turbine-generator mechanical torsional system. Such interaction must be strictly limited. In the GE Vernova PSS designs, there are filters to reduce torsional signal levels. The settings for the filters are determined as part of the PSS tuning study when needed [4].

6 Conclusion

In cases where a plant owner decides to extend the operational lifetime of their turbines and generators beyond the original planned time period, it is important to understand the lifetime phase of the different main subcomponents. Once these components have reached their wear-out phase period, it is necessary to decide to either replace or repair them to reset the life of the components, or to continue operation. In the latter case, it is important to have a strategy to mitigate the related risks, consisting of spare parts and increased condition monitoring. For the steam turbine, it is important to monitor the trends of performance,

temperatures and other leading indicators. For the generator, it is important to monitor winding temperatures, cooling water distributions, vibrations and perform GHM monitoring of the rotor and stator winding. If there is an increasing risk of torsional vibration excitation from interaction with the grid, it is recommended to install a torsional vibration monitoring system and in case of a high risk of sub-synchronous resonances, also a turbine torsional vibration protective relay.

Publication and event notice

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Kurzfassung

Entwicklung von Strategien für das Lebenszyklusmanagement von Dampfturbinen und Generatoren in alternden fossil befeuerten Dampfkraftwerken

Viele Betreiber von Dampfkraftwerken stehen vor dem Problem, dass sie zur Unterstützung der Energiewende ihre Anlagen länger als ursprünglich vorgesehen betreiben müssen. Um einen weiterhin zuverlässigen Betrieb zu gewährleisten, ist es wichtig, die Anlagenmanagementstrategie für die verbleibende Betriebsdauer zu aktualisieren. Um eine solche Aktualisierung durchzuführen, ist es wichtig, den aktuellen und den erwarteten zukünftigen Zustand der wichtigsten Komponenten der Stromerzeugung zu verstehen. Ein erster Schritt ist die Überprüfung der historischen Wartungsergebnisse und Betriebsdaten. Auf der Grundlage dieser historischen Überprüfung ist es möglich, den

7 References

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aktuellen Zustand zu bewerten und die zukünftige Risikoentwicklung vorherzusagen. Dies kann mit Lebensdauer-Modellen erfolgen, die entweder auf Konstruktionskenntnissen oder auf Erfahrungen mit ähnlichen Anlagen in der globalen Flotte basieren. Die Ergebnisse dieser Bewertung können dann verwendet werden, um Empfehlungen für das Management zukünftiger Risiken auf der Grundlage der erwarteten Betriebszeit und des erwarteten Betriebsprofils zu formulieren. In diesem Beitrag wird ein Überblick über die Hauptrisiken für die Dampfturbine und den Generator gegeben, zusammen mit einigen der verfügbaren Methoden zur Überwachung und Kontrolle dieser Risiken. Der Beitrag diskutiert auch andere Risiken, die sich möglicherweise auf alternde Anlagen auswirken und durch Wechselwirkungen mit dem Stromnetz verursacht werden können, unter Berücksichtigung der Veränderungen, die sich in vielen Ländern im Zusammenhang mit der laufenden Energiewende auf die Netze auswirken.

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