Stressing Turbine Generators beyond their Established Thermal Limits
Report on Questionnaire Working Group A1.01.03

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PURPOSE

Synthetic resin based insulation systems were introduced over 40 years ago. Originally, manufacturers outside Europe made full use of the temperature class in applying the insulation. However, in the late 1970's it became the established practice for turbine generators to have the insulation system qualified for class 155 (class F) and be utilized according to class 130 (class B). In view of a changing power market, Equipment Group A1.01 in 1998 launched a questionnaire to provide an overview of the thermal stressing practice beyond this established thermal limit and to collect the related experience on operating units. The questionnaire includes the topics new equipment, upgrades, and condition assessment and maintenance. The aim is to reach conclusions on operational risks and opportunities for established and new technologies.

INTRODUCTION

Power delivery payments in liberalized/deregulated grids can be very progressive with demand. The known practice of peaking may thus become increasingly beneficial for the operator. Peaking corresponds to a temporarily increased thermal utilization of the generator beyond the established rated continuous class 130 operation limit. In fact, IEC standard 60034-3 and ANSI standards C50.14 and C50.15 provide guidance and cautions regarding peak capability and the temperatures acceptable under these conditions. Also, when considering the excellent behaviour of the established insulation systems at class 130 operation and to achieve more economic designs, the continuous operating regime may have been extended, at least to a certain extent, into the class 155 region.

The concern in doing this is primarily about the electrical insulation. A related deterioration may affect availability and unit lifetime. This concern is reflected in the present discussions on generator condition assessment as part of a reliable risk management for the power plant.

On the other hand, insulation technologies with enhanced performance have been announced, allowing higher operation temperatures, increased electrical stress, or improved thermal conductivity, which can be of interest for both upgrading of existing plants, and for providing more economic generator solutions for new plants.

QUESTIONNAIRE AND SCOPE

The questions relate to turbine generators driven by steam and gas turbines and especially to the topics: operating practice, experience, new equipment, condition assessment and maintenance. The questionnaire applies to generators having rated voltage 10kV and higher, rated power 40MW and above, and having a stator winding based on a mica-synthetic resin based stator insulation.

Responses and Evaluation

Upon the call for responses eight countries have responded with 9 answers (CA, CH, CN, CR, IT, FI, JP, US (2)). The cumulated answers on operating experience cover the impressive amount of 535 air-cooled units, 358 hydrogen-cooled units and 265 water-hydrogen cooled units. New equipment is represented by 345 air-cooled units, which are sold for operation beyond class 130. However the answers were given quite selectively, rendering a representative statement rather difficult. Due to this situation EG A1.01 in its 2002 meeting requested that the coordinator establish a draft summary conclusion to be again submitted to all members of EG A1.01 for review and comment.

CONCLUSIONS

Operating practice

The majority of units operate strictly according to class 130. This means that the detectable temperatures are kept within the values which are specified by the relevant standards. Regarding the standards:

1) In accordance with IEC 60034-1, hot-spots at rated operation of the generator are not required to be within 130°C. They are allowed to be inside the insulation system class, which in practice is usually the next-higher class 155. Two design philosophies have grown over the years: manufacturers keeping hot-spots at 130°C, and manufacturers, using the full range of temperature covered by the standards, allowing hot-spots approx. 10K beyond the 130°C. A resulting difference in peaking practice is obvious, because of different continuous operation temperature base, and the allowed hot-spot rise being limited by the fixed insulation system class 155.

2) This discussion above is valid for rated condition. IEC 60034-3 allows surpassing of the class limits for operation outside rated condition (e.g. operating in voltage tolerances, superimposed negative sequence loading, etc.)

A couple of responses relate to experience with elevated temperature limits for peaking of air-cooled units. The specified increase +10K and +15K is inside the limit of IEC 60034-3, which specifies an increase of max. +15K, this considers that the allowed hot-spot at rated condition may go to some degree into class 155. One response describes a continuous operation in class 155-10K (=130+15K), this relates to a series of 10 units, all of them equipped with a class 155 insulation system. One answer is about 35 units sold for rated operation in class 155, all of them also equipped with a class 155 insulation system.

It is not too surprising that all answers relate to air-cooled units. This reflects the operation of gas turbine sets with peaking specifications and the common upgrades, which for air-cooled generators are likely to be done by extending temperature regimes. With regard to peaking practice, hydrogen-cooled units are generally not (yet) involved. These units also have other means to cope with the overloading, e.g. the hydrogen pressure adjustment. Water-hydrogen cooled units are also described as operated inside class 130. This is probably because the direct-cooled stator winding usually has margins in cooling, the limits given by the temperature of the coolant at atmospheric pressure and the flow rate of the coolant. Thus primarily the rotor field temperatures being involved, here again other means, such as hydrogen pressure increase, are the convenient solution.

Experience

Forced outage rate and availability numbers are not available either from the members or from the manufacturers for elevated thermal utilization. It seems these values in the past years have become increasingly of commercial value and are thus confidential. Thus no conclusion can be drawn on any specific numbers, and conclusions must be based on the reported endangered generator components.

The stressing of generator components is the result of a combined influence of temperature, electric field, ambient conditions and mechanical stress. The stressing by temperature is often not only the result of the inevitable chemical aging of insulation material, contributors may also be thermally induced mechanical stress and wear resulting from thermal expansion and contraction.

The most endangered components were designated as stator end winding support and rotor winding. Regarding stator end winding the ground wall insulation is of secondary importance, the surface grading coatings are of more concern. The air-cooled units are submitted to a high number of start-stop cycles, even up to two or three starts per day. This thermal cycling at higher temperatures, is inherently leading to higher mechanical movement, or in the case of hindrance of movement (fully restrained stator end windings), to elevated mechanical stress. An elastic attachment to the core or a gliding arrangement, allowing the support to follow thermal "breathing" of the winding, is a mandatory prerequisite of higher operational temperatures in the opinion of many experts. When uprating existing units, it is of great importance to carefully check the suspension system to be sure that it meets the increased duty, and refurbish if needed.

Turning to the rotor winding two aspects need close attention. One is the very highly stressed interturn insulation layer. The stress is produced by purely mechanical reasons. The two most important reasons reported are: stress peaks due to uneven conductor faces leading to punching of the insulation and shear stress produced by non-even temperature and centrifugal load in the slot combined with varied friction coefficients at material interfaces, leading to ratcheting-creeping at every start-stop cycle. Such an insulation migration/creeping although not seen on all high temperature rotor windings has been observed on some generators in all parts of the world. The combination of fading mechanical properties of the insulation material and higher cycling elongations at elevated temperatures may lead to an unacceptable probability of interturn shorts. Higher cycling applies also to the end regions; here interturn insulation may be pressed out of the space between the conductors. Spacers/blocking should be arranged in such a way not to hinder thermal "breathing" of the conductor bundles; however they should separate the conductor bundles without gap, to avoid any slipping out of the conductors. Again here, machines to be uprated should be checked for the design margins before going to a higher operation temperature. Excellent behaviour at class 130 is no guarantee for a reproduction at class 155. In fact, the evaluation of the stator and field insulation must be performed in a coordinated manner as upgrading one does not assure the increased capability in the other.

No mention is made of any incident/failure produced by operation beyond established thermal classes. One reason is that it would likely be too difficult to correlate these clearly to elevated temperatures; the other, as mentioned before, is the commercial value of such information. In that context, no news should not be taken as good news. However, it is referred to the above mentioned case reporting delivery of 35 units for class 155 utilization and the units having a class 155 mica-tape synthetic resin system. Even though these units were sold seven to twenty years ago there is no feedback from the plants about the amount of duty (time and temperature) in the class 155 region, but also no report has been received about any incident/failure.

No mention was made in the responses to any superimposed electric loading.

New equipment

There is an impressive amount of nations reporting modifications in insulation systems to cope with the continuous operation beyond class 130. These may be minor changes in the well-experienced insulation system, or even a re-certification to the true limits (inter-class values), which allow the temperature range to be gradually extended. One challenge is to avoid delamination in the taped ground wall stator bar insulation, which at the final stage might endanger the heat transfer (indirect cooling), especially in the unclamped end regions. An adaptation of materials is also needed for the field winding insulation. Here the challenge is to define materials which are resistant to creep at elevated temperatures.

One nation reports the introduction of a class 180 insulation system for stator and field winding, the new system bases on an established class 155 system. With this new system, the aim is to operate the generator according to class 155, also the hot spots kept inside this limit, and thus to keep the established reserve of a temperature class for peaking. The application is anticipated for both new generators and for upgrading of older units.

Today, a novel technology introduction, such as a substitution of the mica-tape-resin system, seems to be beyond the horizon.

Some remarks on the insulation qualification:

The majority of responses focus on long term qualification tests for insulation systems. It is referred to the related international standards now existing and covering the field, such as IEC 60216, IEC 60505 and IEC 60034-18 and the equivalent ANSI/IEEE standards. There are a large number of nations confirming and accepting insulation systems by operating experience, as described as "reference insulation system" in IEC 60034-18. This means for example, an insulation system is accepted as a class 155 system, when there is a long-time cumulated positive operation experience at (with peaking to) class 155.

The benefit of thermal uprating is mainly described to be of the economic type. Weight and footprint contribute to lower first costs. For larger air-cooled units the gain in efficiency is mentioned as an operational cost benefit.

Upgradings

According to the responses the demand for upgrading existing generators seems moderate. In some countries, this may be the result of needing to meet new environmental and emissions requirements for upgraded plants that are not required for modifications that keep the original rating. From the remaining positive statements no difference is visible between active and reactive power demand and also no preference for a specific plant/generator type. Overall it seems that a temporary overcapacity in the western world has damped the upgrading demand (and temporary demand peaks are coped by peaking existing units).

Upgrading is not without initial cost. Most nations support a thorough assessment before any upgrading (see assessment). One nation reports about a consequential rewind of rotor and stator when thermally upgrading, causing initial costs. Preferably the rewind does implement the experienced achievements of insulation technology. It is to be considered if such a method might be the one with the highest overall benefit. It is highly beneficial to check in such a case if the stator endwinding support needs refurbishment at the same time (see experience).

Regarding upgradings of existing units by temperature, the benefit lies in an unchanged footprint of the generator, requiring considerable less redesign and throughput time. This of course applies primarily for air-cooled units since they are coupled to gas turbines, and since hydrogen-cooled types possess other means (hydrogen pressure) to cope with higher output requirements.

Condition assessment and maintenance

The majority of responses do not react to higher temperature utilization by introducing additional diagnosis and maintenance systems, and prefer to rely on the existing systems. Two nations report experience with remaining life assessment (for > class 130) by assessing the state (off-line) and concluding periodically on the remaining life. It is known from international activities, which the market is pressing for reliable and transparent generator condition assessment systems. Today the manufacturers and some specialized companies are sharing the market with different systems, in the end each relying on databases and person-bound expertise. The precise assessment of remaining life may come in the far future, however the condition assessment for today's practiced condition based maintenance is progressing rapidly. Partial Discharge (PD) monitoring has become a widely accepted tool. Prior to upgrading many responses require an assessment of the condition of the generator, and despite all the sensor-based assessment methods visual inspection is still suggested as a must.

So far no nation has changed maintenance practice due to thermal upgrading. In case of scheduled maintenance this is based on the experience that the peaking or continuous running at a higher class might not result in a dramatic change of degradation of components and will be detected within the regular intervals (provided a thorough condition assessment at upgrade). In the case of condition based maintenance this is based on the experience that the condition assessment method reliably triggers a maintenance recommendation. The division between these two philosophies is unknown, since no nation has reported on condition based maintenance, although it is known as being increasingly practiced.

For new units beyond class 130 the picture looks a bit different. It seems customers are relying on condition based maintenance since they suggest taking an initial state assessment in the new condition (fingerprints on PD and air-gap search coil). Regarding time based maintenance it seems that here also the maintenance intervals should not be adapted. This is reasonable since measures taken by the manufacturers are to be expected to keep availability and life time at existing levels.

Disclaimer