Guide on economic evaluation of refurbishment/ replacement decisions on generators

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In the new economic environment involving deregulation and globalization of electric energy supply, the reliability and financial aspects of system operation have become extremely important. In addition, the increasing share of renewable energy forces fossil power plants to change the operation regime into peak load operation with significantly decreased on-line hours, accelerated aging of materials and less revenue. Power plant owners endeavor to reduce the cost of plant life management. With that background, this guide provides essential information that will help in making sound refurbishment or replacement decisions for generators and their critical components. It will be particularly useful to electrical power plant managers, engineers and other maintenance decision makers, who are faced with repair or replace decisions on their generator equipment. The information in the guide will also help with planning for essential maintenance actions, providing advice on investing in monitoring and diagnostic systems to help optimize maintenance activities based on financial risk assessment.

The guide will also help generator asset managers perform economic evaluations of proposed solutions. A list of key parameters has been established covering technical, operational, economical, environmental and other strategic aspects. Some approaches, models, flowcharts, and examples have been included to illustrate the criteria and steps used in the decision-making processes. The focus is on the incremental impact of maintenance/replacement strategies, up-front investments, and monitoring and diagnostic systems on the economic evaluation.

Major chapters are briefly introduced below.

Risk management and financial models

Demands for higher rates of return and cost of service reductions together with increased operation flexibility are resulting in increased equipment utilization, deferred capital expenditures and reduced maintenance allocations in many areas. The immediate cost savings of postponing investments and reducing budgets are readily quantifiable. However, the costs associated with the consequences of these actions such as increasing maintenance, repairs and failure rates can only be approximated using risk analysis techniques. Methods and approaches for managing the risk for a single generator and a number of generators are discussed in this section.

The following two methods are proposed in this guide:

1. Increasing the technical lifetime of a generator or a group of generators where the associated average anticipated risk is acceptable. This method is called: “The increased lifetime method”.
2. Identifying the components that need increased condition monitoring or other actions to be within an acceptable risk level according to a ranking system. This method is called: “The ranking method”.

If a utility decides to increase the service period for one or several generators, the utility must also expect that future failure rates for these components will increase. This means increased future costs for maintenance and repair. Therefore, the decision criteria for a utility, whether or not to postpone reinvestments in the generators, will be the minimization of overall costs related to reinvestment, maintenance, and repairs. The basis of the method is first to perform a risk management analysis that introduces a linkage between cost savings from postponed reinvestments and the losses or consequences for maintenance down time andrepairs

The Net Present Value (NPV) is used here as a decision criterion. This criterion insures that there will be a maximum return for the invested corporate dollar when decisions are being looked at over multiple years. Aging equipment includes timing, and the time value of money is an important consideration in any decision analysis. Sometimes engineers use reliability as a criterion for decision-making. Reliability has to be tied to financials. Reliability and NPV analysis can produce the same or very similar results when the equipment of concern is in demand a high percentage of the time. However, for not-highly-utilized equipment NPV will guide the decision toward highest value, rather than highest reliability, since highest reliability is not always needed. In the case of maintenance, the Net Present Value is created by looking at the choice between two maintenance decisions.

The main concern the decision makers have is not whether a component will fail, but what the failure will mean to the business •••

profit. This risk is the product of probability of occurrence and the consequence of occurrence of failure. This same formulation is called the "expected value of the consequence" in financial terms.

Operation impact on generator risks

Generator abnormal operating conditions can cause risks that may not necessarily involve a fault in the machine, but likely will affect its normal life expectancy. This section includes descriptions of some of the most typical operational issues and their impact on the generator.

This section includes discussions on the following topics: Reactive capability curve limits, Unbalanced armature currents, Loss of synchronism, Loss of field, Over-excitation (over-fluxing), Motoring, Abnormal frequencies, Inadvertent energization, High-speed reclosing, Improper synchronizing, Load cycling and repetitive starts, Extended turning-gear operation and System emergency conditions.

All are important operational risks, but cycling (load and speed), in particular, is a risk that is typically ignored. The effects on the generator and the potential to shorten the life of the generator, however, are very real.

Major component risk areas

An excellent summary of the risk to major generator components is provided in this section including a discussion on the major failure mechanisms that can occur during operation. The referenced papers are extensive, providing a resource of information not readily found in other documents. All major components of the generator are included: stator core, stator winding, rotor shaft, and rotor winding. Also included are some smaller specialty components including retaining rings, fans, slot wedges and generator auxiliaries.

Specifically, the following components and failure modes are discussed:
Stator Winding: Loose bars in slots, Insulation thermal deterioration, Thermal (load) cycling, Semi-conductive / grading coating, Inadequate Insulation Impregnation, Winding contamination, Inadequate end-winding spacing, End-winding vibrations, Stator coolant water leaks, Poor electrical connections and Bushings;
Stator Core: Thermal deterioration, Electrical degradation and Mechanical degradation;
Casing/Frame: Stator frame and support and Bearing insulation;
Rotor Winding: Insulation thermal deterioration, Thermal (load) cycling, Abrasion due to unbalance or turning gear operation, Winding contamination, Pole connector and Main lead (J-strap) failures;
Collector and Brushes: Slip / collector rings and related parts and Shaft grounding brushes / copper braids;
Other Rotor Parts: Central shaft bore, Teeth area, Pole area / retaining rings seats and Unbalance / vibrations, Retaining rings, Fans;
Cooling System: Air cooling system, Hydrogen cooling system, Water cooling system;
Auxiliaries: Seal-oil system, Bearings and lube-oil system and Excitation system.

Repair vs. replacement considerations

Besides the substantial technical and financial data specific to the generator in question; other factors such as demographics, condition of the unit, utilization and performance of the generator population should be taken into consideration. These decisions cannot be made in a vacuum and, therefore require a good understanding of corporate risk tolerance, current investment strategy, and regulatory environment. Repair versus Replacement decisions also need to consider possible life extension, performance and capacity improvements due to progress in design and new materials. Major components of the generator are discussed in this chapter with respect to repair versus replacement considerations, Key discussions are presented on the following components and topics:

Generator Stator Winding: Specific repair on individual failure mechanism, Cutting out stator coil,s Repair of bar insulation, Partial rewind, Complete rewind, Full rewind following winding or core failure, Full rewind for reliability improvement / life extension, Full rewind for capacity increase (uprating) and Full rewind towards operation regime change;
Generator Stator Core: Minor core repair, Damage beneath the core surface, Partial Core Restack, Laser cutting cost advantage, Improved inter-laminar insulation, Improved material hardness, Improved core losses with new steel.

Whole generator replacement as an alternative.

Rotor Field Winding: Soft Copper, Excessive Distortion due to End Turn Elongation or Foreshortening, Excessive Copper Fatigue as Evidenced by Cracking.
Rotor Shaft Forging: Effects of speed cycling versus load cycling, Starts and fatigue, Low cycle and high cycle fatigue – the differences, Rotor bore cracking, Snap ring groove cracking and Recommendations to minimize rotor shaft fatigue cracking, Tooth top cracking as shown in the photo below.
Retaining Rings: Ring-off inspection, Ring-on inspection and visual examination, Underlying causes of stress corrosion and Remaining life estimates.

On-line monitoring for risk assessment

On-line monitoring is a risk mitigation tool and can be helpful to improve reliability and improve decision making on •••

repair versus refurbishment actions. It enables early indication of up-coming defects and better planning for specific maintenance work to be done at future outages. The challenge is being able to quantify the benefits and payback of such systems. The guide reviews some examples of on-line monitoring, including discussion on cost and benefits.

Multiple component maintenance replacement decisions

With large utilities managing more than one generating unit, a number of maintenance projects are competing for the maintenance budget simultaneously. Some maintenance optimizations use decision analysis process to maximize Net Present Value (NPV) for a number of maintenance projects simultaneously. Net Present Value is defined as "the value in the present of a sum of money, in contrast to some future value it will have when it has been invested." This will be discussed.

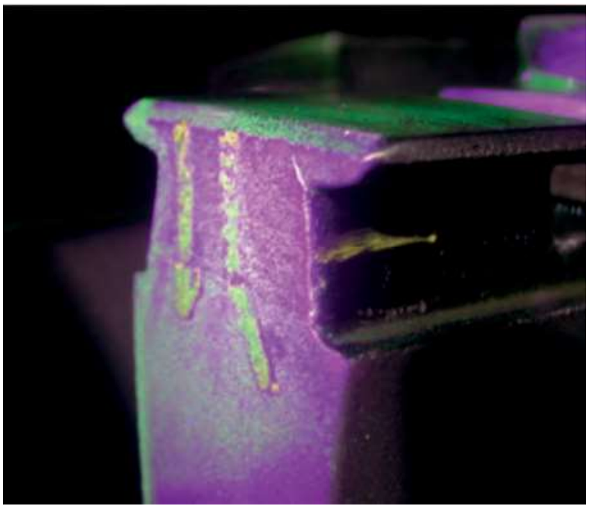
Conclusions and recommendations

Providing a guide for large turbo-generators refurbishment or replacement decision represents a clear necessity of the industry, nevertheless a difficult challenge. This document discusses the various demanding aspects that have to be taken into consideration when dealing with such costly decisions. It is intended to help power plant managers, engineers and maintenance decision makers; however, it doesn't pretend to offer an absolute solution.

The guide mentions financial tools useful in the decision process, and discusses the insurance impact on risk management including statistical/quantitative examples. On the other hand, there are many aspects that cannot be easily quantified but have to be considered. One of them is the obvious impact of the operation mode - therefore most common abnormal operation regimes are briefly discussed. Another decision influence is the presence of various on-line monitoring devices, and their cost-benefit evaluation.

Based on a wide technical literature survey, the guide reviews most known deterioration mechanisms of large turbo-generators and their major component risk areas. The failure mechanisms discussed cannot be totally comprehensive and particular unusual failures are always possible in such complex machines. For each major generator part, the most typical essential maintenance is described, emphasizing again the replacement versus repair available solutions.

The attempt to concentrate the various aspects of refurbishment vs. replacement dilemmas of large turbo-generators in one self-contained material, covering various technical, operational, economical, and other strategic aspects, may hopefully cover an existing literature gap and contribute to better asset management in the electricity generation industry.



Rotor tooth top crack visible by fluorescent penetrant test
(Courtesy of National Electric Coil)

Finally, this guide should be seen as a live tool, with an opportunity to update regularly as new machine designs and new failure modes become known. The on-line monitoring methods are continuously being refined, the machine operation regimes are more and more challenging as required by new grid codes, while at the same time, manufacturers are trying to reduce generator costs using narrower design margins, and in the present deregulated world, the utilities have reduced in-house maintenance capabilities. All these factors (and additional others) can dramatically influence refurbishment vs. replacement decisions. ■

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