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Onshore and offshore turbo generators preventive maintenance program

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Abstract

The aim of this article is to suggest a common preventive maintenance program for large turbogenerators used on onshore or offshore, the objective is to be generic, under the intention to allow owners of different turbo generators brands a level of standardization. It motivation derives from lack of literature under this approach, either publication from the own manufacturers or old literature were found, in the time where industry 4.0 productivity and availability needs to work together, and the suggest preventive maintenance program works to collaborate on this direction

Keywords: Turbogenerators; Large synchronous generator; Onshore and offshore preventive maintenance; Standardization; Availability; Turbines; Generators

1. Introduction

As Machado (2022) commented on his book, it is constant present in the oil and gas environment, the trade-off between availability (related to maintenance) and operational effectiveness (which has to do with productivity); The aim for properly coordinate and synchronize production and maintenance goes certainly beyond the oil fields and, as stated by Vatn (2018), it can be considered one of the key elements of the 4.0 industry. This article presents one standard preventive maintenance approach that could be applied on different turbo generators used in the oil fields onshore or offshore. It does collaborate therefore, to facilitate obtaining success confronting this constant ambition and challenge between high productivity and high equipment availability in the industry.

It may be therefore quite useful for managers, engineers and technicians, planners, and even vendors in the oil field; in short, it may aggregate to everyone involved somehow with turbo generator availability directly or indirectly.

Objective

The objective of this article is to suggest a common preventive maintenance program for large turbo generators used onshore and offshore, normally driven by gas turbines, to be generic, the intention is that the ideas listed could be suitable to different synchronous brands or manufacturer.

2. Methodology

The current proposition is done after the author scan the preventive maintenance program from three different manufacturers manuals pinpointing communalities. This document is NOT intended though to override, supersede or question any manufacturers manual, the idea purely and simply to observe and present similarities towards what a vessel operator owner or a power generator plant onshore could somehow use to standardize its maintenance practices.

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The manufacturers know how, experience and site presences during the interventions is recommended as well as read specific manuals on its entirely.

2.1. The need for preventive maintenance programs

As Klempner & Kerszenbaum (2004) suggested, the predictive maintenance approach initially came as something that would eliminate the preventive maintenance program. The first as conditional driven, maximizing the intervals between repairs (Keith, 2002), including either simple monitoring (instrumentation connected with fix alarms and trips), dynamic monitoring (when alarm and limits varies following load variations) or diagnostic systems (with machine learning, expert systems providing early-stage diagnosis) (Klempner & Kerszenbaum, 2004), versus the second; Time-based, utilizing more statistics and MTTF (mean between failure) or MTBF (main time between failure) than real data, sometimes questioned about if the maintenance intervals were too short or too long (Mobley, R. Keith, 2002). Wang (2016) in what was called intelligent predictive maintenance industry 4.0 scenario, as well as Nazmus & Wuest, (2018) defended though, that over the years both systems demonstrated its advantages and disadvantages, both altered the way the other is performed and, in the end, statistical based and conditional based maintenance, or better saying predictive and preventive maintenance programs coexist. Dekker (1996) and Machado (2022) reinforced it, mentioning the need for develop a generic modelling including both as an adequate way to collaborate resolving the maintenance dilemma between equipment availability and site productivity. Based on this context, it is possible to mention that content and the interval of preventive maintenance have will continue to be questioned and readjusted, nevertheless there is a clear need and applicability in the field for preventive maintenance programs.

ISO 14224:2006, defines preventive maintenance as actions carried out at predetermined intervals or according to prescribed criteria, all intended to reduce the probably of failure or degradation of the functioning of an item. If we stick to this definition, the criteria considered to listed activities are considered manufacturers intellectual property, the article does not question the suggestion, it describes the recommended tests, inspections, maintenance interventions and components exchange within the given time frame periods. Despite easy writing and ambitious of clarity, the article does also require readers with some familiarity and knowledge about large synchronous turbogenerator. Complementary, IEC 50 calls the attention to the administrative aspects related to maintenance, which includes but is not limited to resource sizing, scheduling and consumables listing, in the end of the article, beside the technical activities itself, an overall suggested overview is presented, but we start with the interval and quantities, which relates with the maintenance philosophy, as can be seen in the next subject.

2.2. Preventive maintenance philosophy

The revised turbogenerators preventive maintenance programs include commonly at least one specific annual intervention on year-by- year basis, starting simpler to more complex. The table 1 below present an overall view of the maintenance cadence.

Table 1 Preventive maintenance intervals

Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year12**
8000 h	16000h	25000h	33000h	41000h	50000h	58000h	66000h	75000h	83000h	91000h	100000h
L1	L1	L2	L1	L1	L3	L1	L1	L2	L1	L1	L4
A	A	B	A	A	C	A	A	B	A	A	C

One can observe on table 1, what some manufacturers list as yearly or hourly based maintenance. The term is not operational hours but equivalent running hour, normally attributing operation life degradation factors to each start compared to the standard operational hours. Someone says 1 starts equal to 20 running hours, other 30, etc., there is no commonalities in terms of how much to add on each start, now all off them consider some degradation factor to be added. The name attributed to those programs may vary as well, it is possible to find the 8000, 25000, 50000 & 100000 hours, or terms like L1, L2, L3 & L4 or A, B, C & D, to mention a few, in the end, they all indicate the necessity of one structured preventive maintenance intervention per year. As a last comments, worth to observe the scalability in terms of complexity between the levels from the first to the last, meaning the L1 is the simpler and the L4 the more complex, another detail is that the next level encompasses the previous, this is, one L2 includes all activities from L1 as much L3 will add on the activities from L2. Complementary, should sound a bit obvious but is useful to mention that, have a preventive maintenance program in place, does not imply that other unplanned intervention will never be demanded, users and operations are called to raise their concerns to the manufacturers as if any abnormal situation occur such as increase in temperature, noise, abnormal smell, trip or alarms.

Another general observation from an operational and maintenance standpoint, as indicated Klempner & Kerszenbaum, generator parameters should be kept within design limits, or in another words, should always run under normal operation conditions, if we respect IEC 62368-1:2010 definitions. Sounds obvious in the theory and is a common in the literature that respect performance limitation increases availability and longevity of the equipment, or more, there are authors or manufacturers suggestion that the turbogenerator life spam can even be prolonged respect its operational conditions.

Concluded the general philosophy and first consideration we start with general preparation guidelines.

2.3. Preparation

Klempner & Kerszenbaum classify preparation as the first significant activity to be carried out before inspecting the generator, pointing out that negligence here can have serious safety, integrity and duration consequences, based on that, the next table explores the points captured:

Table 2 Preparation steps

Preparation – general aspects				
Description	**L1**	**L2**	**L3**	**L4**
Scaffolding		X	X	X
Bearing opening tools			X	X
Lifting ~250kg (validate with the manufacturer)			X	X
Rigging plan ~11 Ton (validate with the manufacturer)				X
Replaceable spares available		X	X	X
Foreigner material exclusion (need for protective covers, hot-air, insulation area, protection against mechanical objects)		X	X	X
Familiarization with manufacturer given lifting procedures		X	X	X
Manufacturer specialist presence		X	X	X
Manufacturer recommended sheets	X	X	X	X
Plan/ execute maintenances as from previous reports or recommendations	X	X	X	X
Safety precautions (warning signs, tags and lock-out, groundings, insulations, heaters off)	X	X	X	X
Main plate data	X	X	X	X
Prime mover general data (type of combustible, model, general notes)	X	X	X	X
Operating hours	X	X	X	X
Number of starts	X	X	X	X

It is necessary to make the remark that, despite table 2 compile guidance from different manufacturers, site conditions shall be observed, and operation and maintenance people shall be listened, interviewed, to allow turbogenerator and site characteristics specifics to be captured allowing a more effective preparation. Once preparation step is over, next has to do with maintenance initials.

2.4. Maintenance - Initials

Until now were more about preparation and checks, Kerszenbaum, 1996 calls the attention that the maintenance initials allows enhance effectiveness in execution as well as appropriate preparation for further intervention, here it is hence about the maintenance itself, worth to remember that all data shall be noted, protocoled, reported and storage properly as part of the generator historical.

Table 3 Maintenance initials

General – Initials				
Description	**L1**	**L2**	**L3**	**L4**
Logged temperatures Historical (windings, bearings, inner and outer air, inner and outer water)	X	X	X	X
Logged electrical parameters historical (terminal voltage, phase current, MW, MVA, MVar, Hz, field current, field voltage, V/Hz, Negative sequence current (i2t) and shaft current, alarms and protections activated from the last intervention	X	X	X	X
Confirm environmental aspects (humidity, altitude, salinity or other air contamination)	X	X	X	X
Logged mechanical historical (vibrations, orbits)	X	X	X	X
Interview maintenance and operational people trying to obtain any abnormal behaviour, experience, problems, actions taken.	X	X	X	X
360 degrees walk through collecting pictures from outside, special attention to leakage, rust, painting work, visual cracks, and general deterioration conditions.	X	X	X	X
Observe if there are ventilation obstructions to the machines	X	X	X	X
Observe if there are fluids (oil and or water) obstruction to the machines	X	X	X	X
Execute disassembles and opening of the covers and air ducts to be able to access the winding overhangs		X	X	X
Generator and ancillaries´ protection and monitoring devices are connected and operational (no jumps, nothing disabled)	X	X	X	X
General parameters reviews/ updated, in the generator control panel (AVR, excitation, protection and control panel)			X	X

Table 4 Stator

Stator frame				
Description	**L1**	**L2**	**L3**	**L4**
Check for instrumentation and other connections tightness	X	X	X	X
Check for general tubes or pipping tightness	X	X	X	X
Check grounding	X	X	X	X
Check for inspection windows/ doors/ coverage general conditions and tightness	X	X	X	X
Heaters functional tests	X	X	X	X
Purging system visual inspection	X	X	X	X
Visual conditions of the jacking oil		X	X	X
Check foundation and anchor bolts tightness		X	X	X
Replaced recommended gaskets		X	X	X
Inspect for cleanliness in the interior of the frame		X	X	X
Inspect the winding connections to the cubicles		X	X	X
Visual inspect winding overhang bracings and insulations		X	X	X
Observe if there is any discolour, dirty, movement or wear of winding overhangs		X	X	X
Measure and record the insulation level		X	X	X

Measure and record polarization index		X	X	X
Observe RTD´s functionality		X	X	X
Borescope between stator and rotor			X	
Check for corona activities			X	X
Purging system functionality test (as applicable)			X	X
Wedges visual			X	X
Inspect the winding connections and bracing ropes interior			X	X
Inspection pressure fingers			X	X
Visual inspect the winding core			X	X
Execute frame interior cleanliness where accessible			X	X
Jacking oil functionality check			X	X
Execute wedges tightness map check				X
Check inner case conduits				X

Once completed the table 4, one more experience maintenance engineer could potentially question about the absence of remaining life test; Reading about stator winding life is quite interesting, there are different theories and methodologies trying to predict the winding remaining life, from our observation, none of the manufacturers consider these tests as part of their preventive maintenance program. In the other hand, both authors like Klempner & Kerszenbaum, as well as manufacturers agrees though, that properly maintained stators run for decades, somewhere beyond 25 to 30 years. After having explored the stator frame, now we look sequentially at the cooler, the cubicles and stator terminal boxes.

Table 5 Cooler

Cooler				
Description	**L1**	**L2**	**L3**	**L4**
Visual inspection for obstruction	X	X	X	X
Cooling system visual inspection (rust, leakage)	X	X	X	X
Check louvres or protection general conditions	X	X	X	X
Replace air filters (if applicable)	X	X	X	X
Request last available water analysis (if applicable)	X	X	X	X
Leakage detector and RTDs functionality check		X	X	X
Replace air cover sealing and applicable gaskets		X	X	X
Clean air and water sides (as applicable)		X	X	X
Replace protection anodes (as applicable)		X	X	X
Remove and clean air ducts (as applicable)			X	X
Pressure Test			X	X
Remove water box and access tube plates				X
General cleaning				X
Replace cooler gaskets between water boxes and the tube plates nest				X

Table 6 Cubicles and terminal boxes

Cubicles and Stator terminal boxes				
Description	**L1**	**L2**	**L3**	**L4**
Check line and neutral connections	X	X	X	X
Observe sealing and general conditions inside		X	X	X
Test instrumentation functionality			X	X
Check tightness torques			X	X

Undoubtedly, the second main component from a turbogenerator is the rotor, specially by the fact that its spin at up to 3600 RPM and is where all dynamic efforts play a rule demanding high attention to allow obtain proper availability. Rotor is explored on table 7.

Table 7 Rotor and its rectifier

Rotor and its Rectifier				
Description	**L1**	**L2**	**L3**	**L4**
Observe rotor overhangs or retaining rings without rotor pull out	X	X	X	X
Instrumentation cleanliness (including rectifier)		X	X	X
Measurement of main field insulation		X	X	X
Inspect fan blades		X	X	X
Confirm air gap		X	X	X
Replace gaskets and wear parts like earthing brushes and its holders			X	X
Instrumentation functionality			X	X
Confirm rectifier, fire unit and fuses (as applicable) functionality			X	X
Confirm rectifier bolts and fasteners			X	X
Check internturns			X	X
Check connections and interconnections for cracking			X	X
Check for discoloration			X	X
Cleanliness where accessible			X	X
Shaft voltage or current leakage signals			X	X
Detail inspection of rotor overhangs and retaining rings after rotor pull out				X
Inspect coils supports, screws, bolts and washers (as applicable)				X
Check insulation displacements (as applicable)				X
Rotor wedges map				X
Rotor Cap non destructive tests				X
Closer check of axial fans, welds, balancing weight				X
Overall cleanliness				X

As from above, until the first 50000 hours the rotor is mostly exposed to minor intervention, cleaning and components swap until it's come the time of pull it out, in what is also called major overall, at 100.000 hours. There are debates about whether the site environment, been it on or offshore are the most suitable for such an intervention; Certain experience maintenance people and manufacturers suggest a properly equipped workshop, where a more in deep and effective work could be executed, the procedures suggested are applicable in both scenarios. A complementary note, insulation measurement is quite often present, on the above and following tables, IEEE 2000 and EPRI 1991, both provide good guidance about insulations resistance measurement and evaluation.

Observe please also, that the brushless exciter stator and rotor have not been covered yet and will follow after the next critical component, due its tolerances in the round of millesimal, heavy weight and high speed to withstand, the bearings.

Table 8 Bearings assessment

Bearings				
Description	**L1**	**L2**	**L3**	**L4**
Visual check for cleanliness, leakage	X	X	X	X
Lube oil analyse	X	X	X	X
General piping and tubing fixation	X	X	X	X
Verify instrumentation functionality		X	X	X
Parts for replacement		X	X	X
Check knife edges seals		X	X	X
Air pipes, gaskets, sealing assessment/ replacement		X	X	X
Bearing insulation		X	X	X
Oil and filter replacement			X	X
Bearings opening and bush or liner removal			X	X
Bearing housing damages, leak signals			X	X
Bush white metal conditions			X	X
Bush white metal clearances			X	X
Jacking oil hoses access/ replacement			X	X
Equalization pressure hoses access/ replacement			X	X
Inner and outer seals access/ replacement			X	X
General bearing housing, gaskets and seal cleaning			X	X
Verify shaft surface free from corrosion and wearing			X	X
Oil ring access/ replacement			X	X

Table 9 PMG

PMG				
Description	**L1**	**L2**	**L3**	**L4**
Visual inspection	X	X	X	X
Insulation resistance measurement		X	X	X
Air gap check		X	X	X
Confirm AVR responses haven't demonstrated any de-magnetization aspect				X
General cleaning				X

Table 10 Exciter stator and rotor

Exciter stator and rotor				
Description	**L1**	**L2**	**L3**	**L4**
Visual inspection of the rotor	X	X	X	X
Visual inspection of the stator	X	X	X	X
Visual inspection of general connections	X	X	X	X
Visual inspection of the frame specially looking for rust	X	X	X	X
Confirm slip-ring conditions (if applicable)		X	X	X
Replace gasket and sealing		X	X	X
General stator and rotor cleaning		X	X	X
Heater check		X	X	X
Replace brushes and holders (if applicable)		X	X	X
Replace oil pumping coupling (as applicable)			X	X
Insulation measurement			X	X
Air gap check			X	X

One manufacturer report more incident failure in the exciter than others, indicating that there are design or construction characteristics which may be the rational to this condition in the background, nevertheless all of then recommend the points presented in the table 10.

From a management and planning perspective, it is common to be questioned about an overview perspective of the whole preventive maintenance program, with than in mind, the next subitem was created.

3. General preventive maintenance overview

Table 11 Preventive maintenance program overview

Maintenance level	L1	L2	L3	L4
Interval	8.000 equivalent hours	25.000 equivalent hours	50.000 equivalent hours	100.000 equivalent hours
Activity	- Historical data review - Visual inspection	- All previous +electrical test +replace consumables +general bearing inspection	- All previous + Bearings opening + longer parts swap list + PMG and exciter more detail assessment	- All previous + Rotor pull out + Wedges map + Rotor and stator cleaning
Preparation	- Open inspection covers - Open cubicles	- All previous - Scaffolding - Spares on sites - Megger - Surge test equipment	- All previous - Bearing open kit - Borescope - PMG, cooler opening	- All previous - Rigging plan for rotor pull out -
Machine On/Offline	Offline	Offline	Offline	Offline

Typical spare lists	- 2 years parts list - Commissioning list	- All previous+ Brushes and holders + Gaskets (bearings, covers) + Seals + Air filters + Bearing hoses	- All previous + bearing liners + Rectifiers	- All previous + stator wedges + rotor wedges
Typical Duration (estimated/ offshore)	1 -2 days/ 12 hours each	5- 7 days/ 12 hours each	12-15 days/ 12 hours each	15-25 days/ 12 hours each
Team	1 From the manufacturer 1 helper	1 From the manufacturer 1 – 2 helpers	1 From the manufacturer 2-3 helpers	1 From the manufacturer 3-4 helpers

The general preventive maintenance program planning overview addresses the key elements on the process of maintenance and decision-making in the offshore operational environment listed by Machado, 2022, which does include the preventive maintenance intervals, the number of planned interventions, required spares and consumables and complementing it, the estimated duration, human resources and special tools. FPSOs are environment where logistic aspects have a great impact on production costs, becomes therefore of natural importance that those items are carefully observed, discussed and validated between the involved stakeholders.

With the preventive maintenance program overview we believe we have covered the objective of suggest a common preventive maintenance program for large turbogenerators used on offshore and onshore installations, normally driven by gas turbines, generic, but suitable to different synchronous brands or manufacturer, again, it is a complementary literature and the original manual and manufacturer shall be consulted and used to allow address the specifics contributing to standardization and to the dilemma of high productive and high availability.

4. Conclusion

With the suggested program and overview we expect to have collaborated presenting a preventive maintenance program suitable to different brands of large turbogenerators onshore and offshore, which facilitate planners, managers, maintenance engineers and service vendors to coordinate their activities toward the constant challenge between high productivity and high availability.

Compliance with ethical standards

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