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A Systematic Approach of Turbo Generators Performance Evaluation Maintenance for Continuous Power Generation

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ABSTRACT

Electricity demand in Nigeria far outstrips the supply which is epileptic in nature. The research presents to a systematic approach for maintenance of turbo generators to reduce power outages for continuous generation of electricity. Energy generated (MWH) is the summation of hourly MW generation on the turbo units multiplied by the number of hours the units are in operation. This is usually indicated on an energy integrator dependent on Unit Availblity (UA). UA is the ratio of the number of hours a unit is available for operation to the number of hours in the period considered. Plant evaluation data were collected to effect reduction in the power outages (downtime of the turbo generating unit) arising from thermal fatigue will be reduced through effective maintenance of heat exchangers, radiators and oil coolers. Vibration monitoring experiment will be used to reduce frequent high temperature arising from shaft misalignment of turbo generators for healthy operating condition.

Keywords: *Turbo generators, Unit Availability, Shaft Eccentricity, Operating Conditions, Optimal Power.*

1. INTRODUCTION

Turbo generators are designed to accommodate rise in temperature of the bearing oil and bearing pads when the generator is running. The heat generated on the bearing must be removed so that the oil temperature to be kept low by cooling water which must not torch the bearings (which are all self-lubricating and self-adjusting). The water temperature is kept low using six (6) shells and tube mixed flow heat exchangers. Each generating unit is fixed with eleven (11) radiators which help to cool the water. The cooling system consists of three lines: Line 1 - connected to the radiators, Line 2 - to the lower combined bearing (LCB) heat exchangers, and Line 3- to the upper guide bearing (UGB) heat exchangers. These lines form a network of protective circuit for the generator [3, 11].

Monitoring devices such as oil indicators, water flow and level indicators, mercury thermometers, thermostat and safety devices such as end switch and brake pads are incorporated into the circuit. As long as the water is kept cool, the bearing oil will be cool at normal working/operating temperature. Any rise in temperature causes an alarm signal on the control panel warning of the danger of running the generator. The generator is shut down and isolated for maintenance. Until the unit is synchronized back to the system there will be reduction in power generated and hence the efficiency of the hydropower station [5, 8 and14].

Leak tightness testing is a dynamic gas micro-flow measurement to detect the existence of one or more leak flow paths or micro-channels. In other words, it defines and detects the existence of “pinholes” in a radiator. In looking for pinhole or Equivalent Channel geometry, we define that geometry as a leak tightness specification [1, 12].

The traditional definition of leak testing parameters as flow parameters causes confusion for a variety of reasons: it requires an understanding of flow regimes and gas flow dynamics; tolerances and values cannot be calculated accurately for many applications; measurement units and gas type cause confusion; and leak-flow readings are strongly dependent on a specific setup, therefore, correlation is a major issue. Most of the time, during repetitive quality control production leak tests; the leak test system operates as go/no-go gage. Gage repeatability is important, but absolute leak flow values are not [7, 13].

In 1992, CIGRE presented Benchmark model for the analysis of torsion oscillations in the turbo generator shaft set. A rather tedious mathematical model was used to compute torsion oscillations of turbine shaft represented by several concentrated rotating masses. The level of accuracy required is ± 0.1 mm outside the stern tube bearing and ± 0.05 mm within the stern tube bearing. This level of accuracy has not been achieved [6, 9 and 13].

2.MATERIALS AND METHODS

The equipment and materials used for vibration monitoring experiment consists of a hydro turbine condition monitoring test rig was attached with Data Flow PCM 360 System, DAQ Card 6220; Transducers TM0110/120/60; Proximity probes TMO 180 (X, Y) for shaft radial vibration and shaft axial position phase reference. The materials and apparatus used for radiator leak tightness test and heat exchanger pressure testing includes: Manometer (device measuring pressure up to10 bar); High pressure washing machine; M6 Porker Brush; Air Compressor; Radiator trolley; Power house overhead crane; Halogen lamp, Bucket of soap water; Special service Special service tool box containing set of Allen keys, hammers, spanners and screw-drives; and Safety gadgets (overall, safety boot, hand gloves and nose fume proctor gloves).

I.Plant Evaluation Maintenance

Short time automatic data acquisition from a modern control room equipped with computer system and precision measuring instruments with high level of reliability were used for taking station evaluation performance data. The final check was carried out during plant operation and the fields measurement of the running hours, energy generated and dam volume of usable water were recorded for computation of reservoir operation analysis for optimal power and station efficiency.

II.Vibration Measurement Method

TM0105 (5mm) and TM0180 (8mm) proximity probes mounted inside the machine by probe clamp were used to measure shaft X, Y radial vibration. TM0393X was used to adjust the penetration depth ±13mm (0.512") for shaft dynamic motion at normal pressure or high pressure.

The thrust axial position was afterwards measured with TM0110 (11mm) and TM0180 (8mm) proximity probes to evaluate the movement of shaft in the axial direction with respect to a fixed reference (thrust bearing support structure or casing member to which the displacement probe is mounted).

III.Radiator Pressure Testing for Effective Maintenance

Three 3" gate valves (inlet and outlet) to the radiators were disconnected for 11 numbers of radiators. Radiators were removed from the generating unit using the power house crane and carried outside the power house with radiator trolley. Radiator top and bottom covers were opened on the trolley. Muddy particles and LX 188 hydraulic filter debris were forked (pushed) out of the radiator tubes using M6 Porker brush. Radiator tubes were flushed and washed with foaming water from a high pressure washing machine. Top and bottom covers were coupled back to the radiator with new gaskets installed. The 3" gate flange at the inlet to the radiator was blocked with a blind blocker. A 10 bar pressure measuring manometer was connected to the outlet of the radiator. The radiator tubes were first fed with water at the bleeding ½" ball valve until manometer pressure reading reaches 2 bars. As the pressure reaches 2 bars, the radiator was charged with compressed air until the manometer reads 4 bars. The pressure reading was monitored with the manometer pressure at 4 bars for about an hour. Manometer reading was observed and the pressure was recorded at intervals of 10minutes. The above procedures were carried out for the entire 11 radiators.

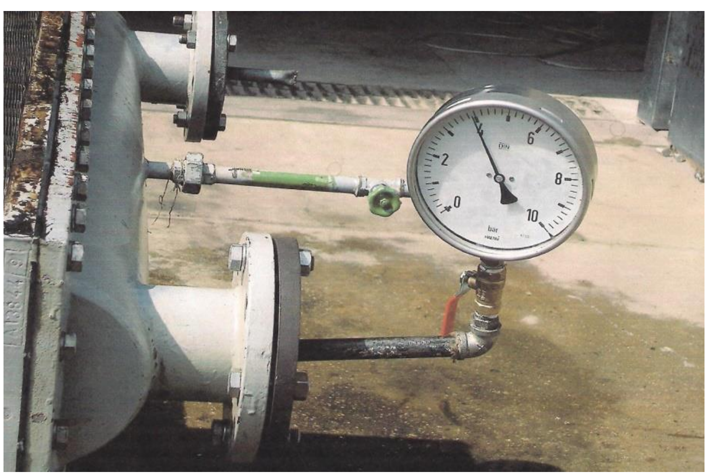


Figure 1: Radiator Pressure Test Experimental Setup (at Shiroro Power Station)

Heat Exchanger Pressure Testing

The 3" gate valves (inlet and outlet) to the heat exchangers were dismantled. The drain ½" gate valve was kept in close position. The 3" gate flange at the inlet to the heat exchanger was blocked with a blind blocker. A 10 bar pressure measuring manometer was connected to the outlet of the heat exchanger. At the bleeding ½" ball the air compressor hose was connected to the top of the heat exchanger. The heat exchanger was charged with compressed air until the manometer read 4 bars. Soap water was robbed at the bleeding ½" ball and manometer connections to detect any air leak. With the manometer pressure at 4 bars the pressure reading was monitored for 30 minutes. Manometer reading was observed and the pressure was recorded at intervals of 10minutes for all the 6 heat exchangers.

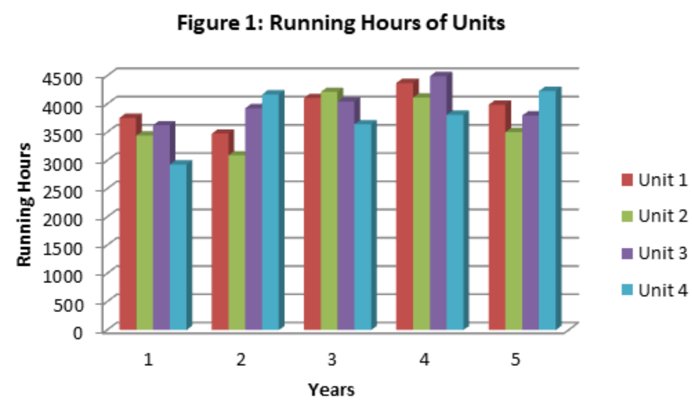
RESULTS AND DISCUSSION

The result of Shiroro hydro station evaluation performance data running hours for each unit is presented in table 1.

Table 1: Running Hours of Units

Turbo Generator	2013	2014	2015	2016	2017
Unit 1	3756.2	3478.1	4107.6	4375.3	3989.7
Unit 2	3444.3	3092.6	4217.6	4118.3	3504.9
Unit 3	3626.4	3928.3	4046.9	4495.2	3797.8
Unit 4	2931.6	4172.7	3644.3	3812.4	4232.2

Fluctuation in the running hours of units is clearly shown in figure 1 which gives the prediction of unit availability presented in table 2.



UNIT AVAILBLITY (UA) is the ratio of the number of hours a unit is available for operation to the number of hours in the period considered. This is independent of whether or not the unit is actually in operation.

$$UA= \frac{No\ of\ Hours\ Unit\ was\ Available\ for\ operation}{No\ of\ Hours\ in\ the\ period} \times 100\% \quad (1)$$

For Unit 1 in 2013,

UA=(No of Hours Unit was Available for operation)/(No of Hours in the period) ×100

UA=(3756.2)/8760 ×100%

UA = 42.9%

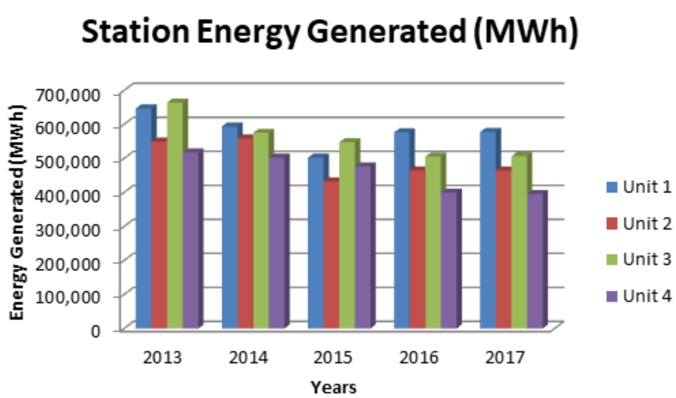
Table 2: Station Unit Availabilty (UA) in %

Turbo Generator	2013	2014	2015	2016	2017
Unit 1	42.9	39.7	46.9	50.0	49.7
Unit 2	39.3	35.3	46.9	47.0	44.9
Unit 3	41.4	44.8	46.2	51.3	47.8
Unit 4	33.5	47.6	41.6	43.5	42.2

The power generated increases yearly for the units 1, 2 and 3 but decreases with unit 4 as shown in table 3 and figure 2 suggesting problem that must be rectified through predictive maintenance.

Table 3: Station Energy Generated (MWh)

Turbo Generator	2013	2014	2015	2016	2017
Unit 1	646,723	594,066	502,292	576,260	577,330
Unit 2	549,744	558,739	432,585	464,006	464,716
Unit 3	664,059	575,129	547,383	505,104	506,124
Unit 4	517,204	502,110	476,327	399,455	395,356
Total	2,377,730	2,230,044	2,058,587	1,944,825	1,944,825



Station Utilization Factor (SUF/SLF)
Station Utilization Factor or Station Load Factor is defined as
SUF/SLF=(Total Station Energy Generated (MW))/(Total Station Installed Capacity (MW))
SUF/SLF=(2,377,730)/(365 ×24 × 150 × 4) ×100%
SUF/SLF = 45.2 %
Reservoir Operation Analysis for Optimal Power
There was no spillway of water throughout. The live storage is the water available for power generation.
Maximum pool elevation (lake level) = 382 m
Corresponding volume of lake = 5.72 × 109 m3
Lake level at the end of Oct 2013
(maintenance period) = 381.83 m
Corresponding Lake level = 4.7432 × 109 m3
Difference in volume (5.72-4.7432) x109 m3
= 0.9768 × 109 m3
Volume at dead storage (Elevation 360m)
= 1.4860 × 109 m3
Volume of usable water = V381.83 –V360
= (4.7432 –1.4860) × 109 m3
= 3.2572 × 109 m3

Percentage volume of H_2O available for generation = $\frac{V_{usable}}{V_{382}} \times 100\% = \frac{3.2572 \times 10^9}{(5.7200 - 1.4860) \times 10^9}$

$$= \frac{2.6902}{4.2340} \times 100\% \quad = 76.9\%$$

Using 77% available water Average turbine discharge for each month per day the optimum load generation

$$= \frac{V_{month}}{No\ of\ days \times\ Hr \times\ Min\ \times Sec}$$

For October 2013, $= \frac{0.9768 \times 10^9}{31 \times 86400} = 364.7\ m^3/s$

Energy loss as a result of in flow,

$E_{loss} = \frac{V_{DM} \times P}{V_{TD} \times Hr \times Min}$ where

$$V_{DM} = Difference\ in\ volume\ for\ month$$
$$V_{TD} = \ Rate\ of\ discharge\ by\ turbine\ /sec$$
$$P = \ Rate\ of\ machine\ power$$

Average $E_{loss} = \frac{(5.72-4.7432) \times 150 \times 10^9}{156 \times 3600}$

$$= 2.61 \times 10^5\ \text{MWh}$$

Percentage Energy loss for the year (% loss)

$$= \frac{E_{loss} \times 100\%}{E_{382}}$$

$$E_{382} = \frac{(V_{382} - V_{360}) \times P}{V_{TD} \times 3600}$$

$$= \frac{(5.72-1.486) \times 150 \times 10^9}{156 \times 3600}$$

$$E_{382} = 11.13 \times 10^6\ \text{MWH}$$

Percentage loss $= \frac{E_{loss} \times 100\%}{E_{382}}$

$$= \frac{2.61 \times 10^5}{11.13 \times 10^5} \times 100\%$$

$$= 23.1\%$$

Efficiency of operation =100 - 23.1 =76.9 %

E_G=77%

The result of vibration experiment is presented in table 1 shows the natural frequencies of the turbine shaft rotation speed with blade vibrations registered in vertical, horizontal and axial planes with three measuring points at positions 1 - motor drive and non-drive end bearing, 2- pump outboard bearing next to the coupling, and 3 -pump outboard bearing away from the coupling.

Table 1 Vibration Amplitude (in Frequency Domain)

Motor Drive and Non Drive End Bearing (Vertical)	**50 Hz**	**100Hz**	**195Hz**
Acceleration[mm/s^2]	26	5	7
Velocity [mm/s]	70	7	6
Displacement[nm]	124.4	17	10
Pump Outboard Bearing Next to The Coupling (Horizontal)	**50 Hz**	**100Hz**	**195Hz**
Acceleration[mm/s^2]	1	11.8	9
Velocity [mm/s]	5	17.5	8
Displacement[nm]	13	27	6.5
Pump Outboard Bearing Away from The Coupling (Axial)	**50 Hz**	**100Hz**	**195Hz**
Acceleration[mm/s^2]	25	7.5	18.5
Velocity [mm/s]	75	12	16.5
Displacement[nm]	125.5	3.5	1.5

The blade bending vibration displacement at 50Hz appeared dominant 124.4nm and 125.5 nm for vertical position 1 depicted by yellow line and axial position 3 by blue line, but as low as 13nm for horizontal position 2 depicted by pink line. The amplitudes at 100Hz for horizontal position was high 27 nm and drops to as low as 6.5 nm implying in the shaft torsional vibration signals for all blade vibration frequencies undulates from 50Hz and 195Hz. For frequencies higher than 60 Hz, less of the torsional vibration to the blade vibration was observed for acceleration and velocity measurement at all positions. This signifies the best position of shaft eccentricity for good operating temperature within the turbo generator

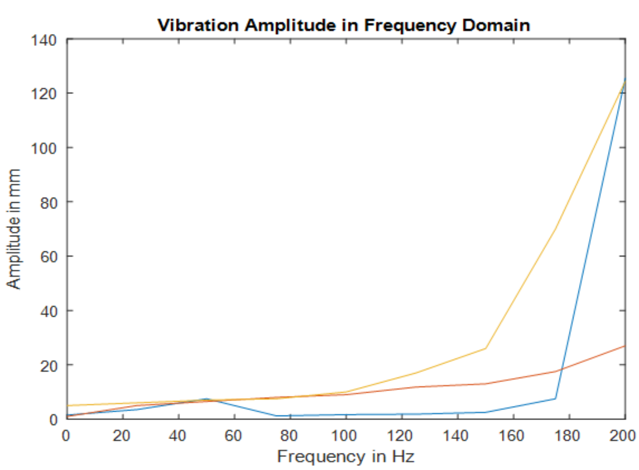


Figure 1: Vibration Graphical Spectrums

The outages were usually due to problems arising from the turbine, the generator excitation panels and electrical transmission problems within the switch yard. Emergency outages are problems arising from temperature and pressure rise within the turbo generating units. The efficiency of turbines decreases if proper maintenance and repairs are neglected. Safe operation of the generator is ensured by periodic (daily, weekly and monthly) inspection and overhauls. The maintenance comprises of regular checking during operation, occasional shut down and short overhauls. During short overhauls, the unit is not completely dismantled. Large overhauls is the one in which generator is completely dismantled from the Lower Combined Bearing (LCB) to the Upper Guide Bearing (UGB) and is carried out after 5 to 7 years of operation.

On-line vibration monitoring improves plant safety by mitigating the risk of catastrophic machine damage, improve production throughput by reducing unscheduled outages via early failure warning alerts, and allow a modern condition-based maintenance approach. Investments in on-line monitoring offer a marked reduction in the cost of operating and maintaining the overall process facility. Maintenance is very critical for continuous and effective plant operation. The efficiencies of generator and transformer are practically permanent if insulation is not allowed to deteriorate. Transmission lines efficiency changes only by reason of damage to wire or insulation. Reduction in the efficiency with age would be minimized for great potential for efficiency improvement in the hydro plant with better cooling system if there is thorough inspection at frequent intervals and proper maintenance is carried out.

CONCLUSION

Reducing power outages (reducing downtime of the turbo generating unit) arising from thermal fatigue through effective maintenance of heat exchangers, radiators and oil coolers. Programmed schedule maintenance of all power stations whereby hydro units are released for annual maintenance during dry seasons while thermal and other stations are scheduled for maintenance during rainy seasons to ensure continuous power generation.

Cooling lines, fittings, valves and seal joints should be checked from time to time for leakage. Oil coolers should be inspected for possible condensation of oil vapour. Possible leakage points are oil coolers connections, bearing pots, joints, thermometer entries, oil drainage bearing pot and seal joint of the inner ring of the bearing pot. It must be ensured that the turbo generator is not operated below a draw level of 360m to avoid cavitation and excessive water discharge with no appreciable increase in power output. There must be enough water in lake within the range of 360.81 to 363.81m to run the units. Partial loading of turbo generator within the range of 70 to 120MW should be avoided to forestall excessive vibrations and increased banging noise of the draft tube which may result in cavitation.

Then number of outages of the hydroelectric plant can be reduced using effective and properly planned annual maintenance. During annual maintenance, all loosen bolts and nuts should be tightened. In case of fault in oil and water piping, individual elements should be dismantled from the cooling circuit and replaced accordingly. Broken supports and loose flanges should be replaced to prevent excessive vibration sometimes witnessed in the hydro stations. Heat exchangers and radiators should be pressure tested for leak tightness. All burnt brushes and insulators should be changed to improve transmission efficiency. In order to ensure safe and reliable operation of the Upper Guide bearing (UGB), it should be periodically changed together with its elements and fittings. The number of starts and stops (i.e. number of times the hydro unit is switched on/off) must be drastically reduced to prolong the life of the turbo generator and to improve the efficiency level of the hydro station.

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