International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-6, Issue-11, November 2020
ISSN: 2395-3470
www.ijseas.com

Modification and Performance Evaluation of Turbo Generator's Oil Coolers for Electricity Generation

Bernard A. Adaramola*[1] and Aminu Musa[2]

[1]*Department of Mechanical and Mechatronics Engineering, Afe Babalola University Ado-Ekiti (ABUAD), P.M.B 5454, Ado-Ekiti, 360101, Nigeria*

[2]*Department of Mechanical Engineering, Centre for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria.*

Abstract

Oil coolers are devices for transferring heat from oil to water. Oil coolers are used in Shiroro hydro station for cooling the turbo generators. Inlet and outlet temperatures of oil and shell of the turbine for 3-circuit oil coolers were persistently high resulting in overheating. Design modification to improve the Coefficient of Performance (COP) of oil coolers was focused on the pressure drop for the four oil coolers system to ensure that the operating pressure for both 3 oil coolers and 4 oil coolers system remains almost equal. Major and minor pressure loss as a result of the major and minor head losses were estimated using Bernoulli's equation. Major and minor losses equal zero there is no change in operating pressure for both three oil coolers systems and four oil coolers systems thus the operating pressure for both 3 oil coolers and 4 oil coolers systems remains equal. The fourth oil cooler was connected to the cooling water inlet line in front of the first oil cooler for the dynamic balancing of the oil cooling circuit system. The modified four oil coolers system brought about better cooling of the turbo generator to raise the power generated from a range of 120- 126 MW to a range of 145 – 150 MW.

Keywords: Oil cooler, turbo generator, overheating, modification, power generated.

1. Introduction

The results of experiments conducted for investigation of overheating reveals that the problem of overheating experienced in the power station majorly arose from the low performance of oil coolers Kowloon of the department of building services engineering, Hong Kong University, investigates how the condensing temperature serves to accurately determine the energy efficiency or coefficient of performance (COP) of air-cooled chillers under partial load conditions. An experiment on an air-cooled reciprocating chiller showed that for any given operating condition, the COP of the chiller varies, depending on how the condensing temperature is controlled (Liberman and Norman, 1995 and Kern, 1965). A lot of work has been done on sensitivity analysis to investigate the extent of COP response to changes in operating variables. Experiments show condensing temperature as an adequate variable to gauge COP under various operating conditions. The specifications of the upper limit for the condensing temperature to improve the energy efficiency of air-cooled chillers are discussed. The results of this work give designers and researchers a good idea about modeling chiller energy performance curves in the thermal and energy computation exercises (Yu and Chan, 2005).

Oil coolers are devices for transferring heat from oil to water. Oil coolers used in Shiroro hydro station are special cylindrical designed shell and tube heat exchangers. The shell is made from a steel material with a volume of nine (9) litres. Each oil cooler has 90 tubes made from copper material as shown in figure 1

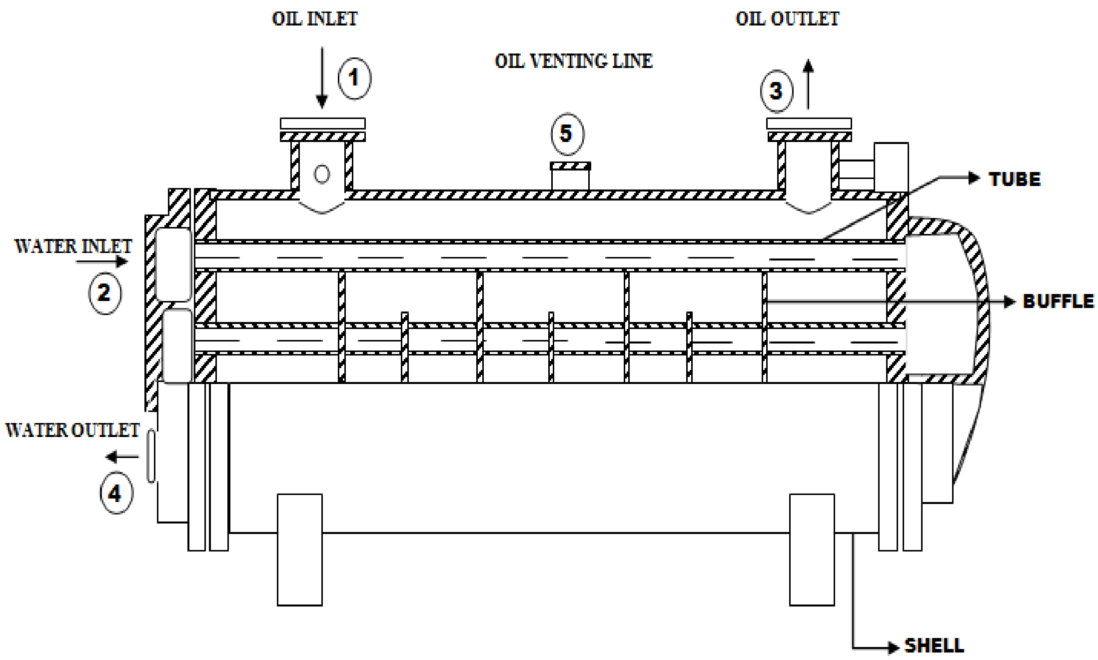

Figure 1: Block Diagram of Oil Cooler

The original design of Shiroro hydro turbine oil coolers is 3 No Oil coolers. Cooling water inside the tube takes away the heat from oil in the cooler of the turbine guide bearing (TGB) by convection. The operating pressure of the oil coolers is 7 bars. To monitor the temperature of the shell and the oil of the turbine guide bearing sensor equipment is attached to the TGB. The shell and oil cylinder is connected to the electronics governor. For any temperature above 70^0 C for shell and 55^0 C for oil, the sensor sends an alarm signal for onward action (Chas, 1995).

I. Coefficient of Performance (COP) Of Oil Coolers

The coefficient of performance (COP) is a measure of the energy ratio or thermal efficiency of oil coolers. It is also a measure of the conditions under which it is operating. The coefficient of performance of a given cooler will rise as the outlet temperature decreases.

Mathematically, $$COP = \frac{Q_H}{W_{net,in}} \quad (1)$$

Where Q_H, is the heat supplied to the hot reservoir and $W_{net,in}$ is the work input.

$$COP_{heating} = \frac{|Q_H + W_{net.\ in}|}{W_{net.\ in}} \quad (2)$$

$COP_{Cooling} = \frac{Q_C}{W_{net,in}}$ where Q_c is the heat supplied to the cold reservoir

$$COP_{heating} = \frac{T_{hot}}{|T_{hot} - T_{cold}|} \quad (3)$$

$$COP_{Cooling} = \frac{T_{cold}}{|T_{hot} - T_{cold}|} \quad (4)$$

Oil coolers the operating parameters inlet and outlet of oil coolers were measured for the determination of the coefficient of performance.

2. Materials and Methods

Coriolis flow meters and Magnetic flow meter, Precision Pt 100 Platinum Certified, Manometer Pressure gauges, Digital Thermometer, Hydrometer, Viscometer, Spectrophotometer were used to measure the operating parameters as presented in table 1 for determination of Coefficient of Performance of Oil Coolers

Table 1: Operating Parameters Measuring Instruments

Parameters	Symbol	Units	Instruments used
Fluid flow	ḿ	kg/h	Coriolis flow meters and Magnetic flow meter
Temperature	t	^{o}C	Precision Pt 100 Platinum Certified Digital Thermometer
Pressure	p	Bar g	Manometer Pressure gauges
Density	ρ	kg/m^3	Hydrometer
Viscosity	µ	cSt	Viscometer
Composition	%	%wt (or) % Vol	Spectrophotometer

Shell and tube exchanger's inlet and outlet temperatures of water and the shell and oil temperature were recorded. A manometer (Pressure gauge) was used to measure cold and hot fluid pressure. Samples of hot fluid and cold fluid density were measured with a hydrometer. Samples of hot fluid and cold fluid viscosity were measured with a viscometer. Composition by weight or volume was carried using a spectrophotometer.

The measured values of operating parameters of inlet and outlet temperatures of oil and shell of the turbine for 3-circuit oil coolers were persistently high. This necessitates design analysis for modification to improve the Coefficient of Performance (COP) of oil coolers following three steps listed below.

i. Inlet and Outlet temperatures of water reading as shown in figure 2.
ii. Inlet and Outlet temperatures of oil reading as shown in figure 3.
iii. Design analysis and evaluation of parameters for the modification process.

Figure 2: Water temperatures regulation

Figure 3: Oil Test Temperatures Reading

I. Design Analysis

Pressure losses occur in internal flows as a result in pipe diameter, velocity, length, viscosity, density, and wall roughness. These losses occur in straight pipes or ducts (major losses) or sudden expansion, valves, elbows, etc (minor losses). The cooling medium (water) is an incompressible fluid thus the energy equation was applied for a control volume between two points in a flow channel.

Applying Bernoulli's equation or energy equation

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 \quad (1)$$

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + H_L \quad (2)$$

where H_L is the head loss, P_1 and P_2 are the pressures at points 1 and 2, V_1= inlet velocity and V_2= outlet velocity, Z_1 = top elevation and Z_2 = lower elevation.

Equation 3.6 becomes $$\left[\frac{P_1}{\rho g} - \frac{P_2}{\rho g}\right] + \left[\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right] + [Z_1 - Z_2] = H_L \quad (3)$$

$$\frac{P_1 - P_2}{\rho g} + \frac{V_1^2 - V_2^2}{2g} + [Z_1 - Z_2] = H_L \quad (4)$$

In determining the major losses, the analysis was restricted to a fully developed incompressible flow in a constant diameter pipe with no change in the head level where V_1=V_2 and no elevation change $Z_1 = Z_2$.

∴ Equation (4) becomes $H_L = \frac{P_1 - P_2}{\rho g}$ (5)

For dynamic similarity, the forces of flow were made identical and to bear the same ratio in both the model and the prototype

$$H_L = \frac{U_1 - U_2}{g} \quad (6)$$

The pressure change Δp in a pipe of diameter *D* and length *l* due to turbulent flow depends on the velocity V, viscosity μ, density ρ and wall roughness k.

From dimensional analysis, using Buckingham's $\pi - theorem$, an expression for Δp was obtained.

The pressure difference Δp is a function of D, L, V, μ, ρ and k.

Mathematically, $\Delta p = \mathrm{f}\,(\mathrm{D, L, V}, \mu, \rho, k)$ (7)

Or $\mathrm{f}\,(\Delta p, \mathrm{D, L, V}, \mu, \rho, k) = \mathrm{n}$ (8)

Hence the total numbers of variables, $\mathrm{n} = 7$.

The friction factor f depends on 3 primary variables (ρ, V, D) pipe diameter D, density ρ, and the velocity V; and 7 variables.

Hence the number of $\pi - terms = 7 - 3 = 4\pi - terms$.

Taking ρ, V and D as repeated variables

$$\mathrm{f}\left(\frac{\Delta p}{\rho V^2}, {L}/{D}, \frac{\mu}{\rho v D}, \frac{k}{D}\right) = 0 \quad (9)$$

Therefore $$\frac{\Delta p}{\rho V^2} = \emptyset\left({L}/{D}, \frac{\mu}{\rho v D}, \frac{k}{D}\right) \quad (10)$$

This is an expression of the pressure head, H. From experiments, Δp is a linear function of ${L}/{D}$ i.e. $\emptyset\left(\frac{\mu}{\rho v D}, \frac{k}{D}\right)$

$$\frac{\Delta p}{\rho V^2} = H = ({L}/{D}) V^2 \frac{f}{2g} \quad as \quad \frac{\mu}{\rho v D} = \frac{1}{Re} \quad i.e. \quad \frac{1}{Reynold'sNumber}$$

Thus elbow lows H_L is computed using values obtained from experimental data

$$H_L = k\frac{V^2}{2g} \quad (11)$$

Where k= $({L}/{D})$ is the function loss coefficient that varies with different types of pipe

II. Design Calculations

The focus of the design calculation was on the pressure drop for the four oil coolers system. Major and minor pressure loss as a result of the major and minor head losses were estimated using equation (16) $H_L = \left(\frac{L}{D}\right) V^2 \frac{f}{2g}$

(12)

Where, L= length of pipe =18m; D= Diameter of pipe=0.042m

g = acceleration due to gravity= 9.8m/s^2; f=64/ N_R

N_R =2000 for laminar flow; change in velocity, ν=0 as $\nu_1=\nu_2$

H_L= (18/0.042)(0^2/2×9.8)(64/2000)

H_L = 428.6×0×0.032 = 0

The minor pressure loss, which occurs at elbows and T-connection, was computed using equation (3.10) $H_L = K\nu^2/2g$

where K is the loss coefficient for various types of minor loss.

For minor loss at T-connection, K=0.25; $H_L = 0.25(0^2)/2\times 9.8=0$

For minor loss at elbows, K=0.42

$H_L=0.42(0^2)/ 29.8=0$

The total head loss for both major and minor losses is equal to zero.

From the above calculation, both major and minor losses tend to be negligible; therefore, there is no change in operating pressure for both three oil coolers system and four oil coolers systems. The operating pressure for both 3 oil coolers and 4 oil coolers system remains almost equal.

III. Modification Process

An extra outlet pipe was provided to the 3-oil coolers system of the guide bearing for the fourth oil cooler. The outlet pipe of the fourth oil cooler was connected to the sump. The cooling water pipe from the main inlet pipe was connected to the inlet of the fourth oil cooler; and the cooling water outlet pipe of the fourth oil cooler connected to the main outlet cooling water line. Thus, all oil cooler water outlet pipes have been connected to the main outlet pipe.

A water discharge pipe was created from the inlet of each of the oil coolers. The discharge pipes were interconnected using Φ42mm union connector and 42mm flexible hose to form a common discharge pipe. The common discharge pipe was directed to the turbine pit main drain pipe Φ100mm wide for flushing or backwashing of the oil coolers. All oil piping networks including the oil coolers were painted with yellow gloss paint. All cooling-water piping networks are painted with green gloss paint.

3. Result and Discussion

The result of the monitored reading of steady-state parameters of the turbogenerator with 3- Oil coolers are presented in table 2**.**

Table 2: Unit 411G 3 Guide Bearing Temperature Reading with 3- Oil Coolers.

Shell Temp [°C]	Oil Temp [°C]	Inlet Water Temp [°C]	Outlet Water Temp [°C]	Cooler Pressure [Bar]	Power Generated [MW]
72	61	23	24	6.5	125
71	60	18	23	6.7	136
73	62	19	24	6.1	130
72	62	18	20	6.8	128
74	63	17	18	6.0	125
71	60	18	20	6.9	130
72	61	18	19	6.5	128
72	61	20	21	6.6	120

The measurement of operating parameters inlet and outlet of turbo generator with 3- oil coolers in table 1 reveal persistent high temperature of oil and shell of the turbine. This necessitates design analysis for modification to improve the Coefficient of Performance (COP) of oil coolers.

Pressure losses occur in internal flows as a result in pipe diameter, velocity, length, viscosity, density, and wall roughness. These losses occur in straight pipes or ducts (major losses) or in sudden expansion, valves, and elbows (minor losses). The cooling medium (water) is an incompressible fluid thus the energy equation was applied for a control volume between two points in a flow channel. Major and minor pressure losses as a result of the major and minor head losses were estimated to be zero. The minor pressure loss, which occurs at elbows and T-connection, when computed was found to be zero. This implies that the total head loss for both major and minor losses is equal to zero.

Since both major and minor losses equal zero there is no change in operating pressure for both three oil coolers systems and four oil coolers systems thus the operating pressure for both 3 oil coolers and 4 oil coolers systems remains equal. The modified four oil coolers system brought about better cooling of the turbo generator to raise the power generated from a range of 120- 126 MW as shown in table 2 to a range of 145 – 150 MW reflected in table 3 below.

Table 3: Unit 411G.3 Guide Bearing Temperature with 4-Oil Coolers.

Shell Temp [°C]	Oil Temp [°C]	Inlet Water Temp [°C]	Outlet Water Temp [°C]	Cooler Pressure [Bar]	Power Generated [MW]
68	58	17	20	6.9	148
67	56	18	22	7.0	150
69	59	19	21	6.8	146
65	52	18	22	7.0	150
68	57	17	19	6.8	147
68	56	18	24	6.8	145
67	56	18	24	6.8	145
66	53	18	22	7.0	150

Figure 4 shows the diagram of the turbogenerator with 3 - Oil coolers connected in series to the cooling water inlet line to cool the oil. It is worthy of note that the number 4 oil cooler was connected to the cooling water inlet line in front of the number 1 oil cooler for dynamic balancing of the oil cooling circuit system as shown in figure 5.

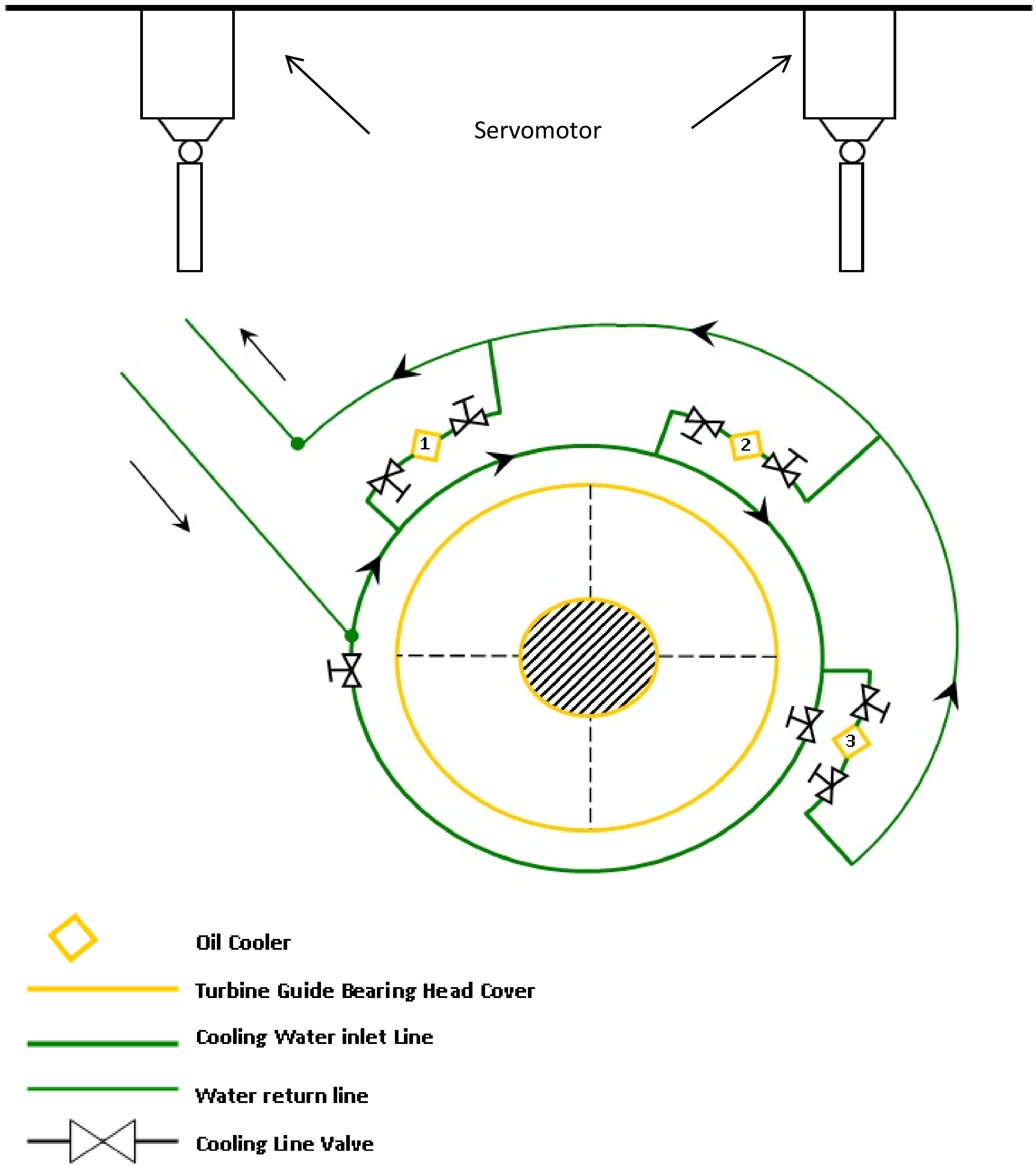

Figure 4: Cooling System with Three (3) Oil Coolers

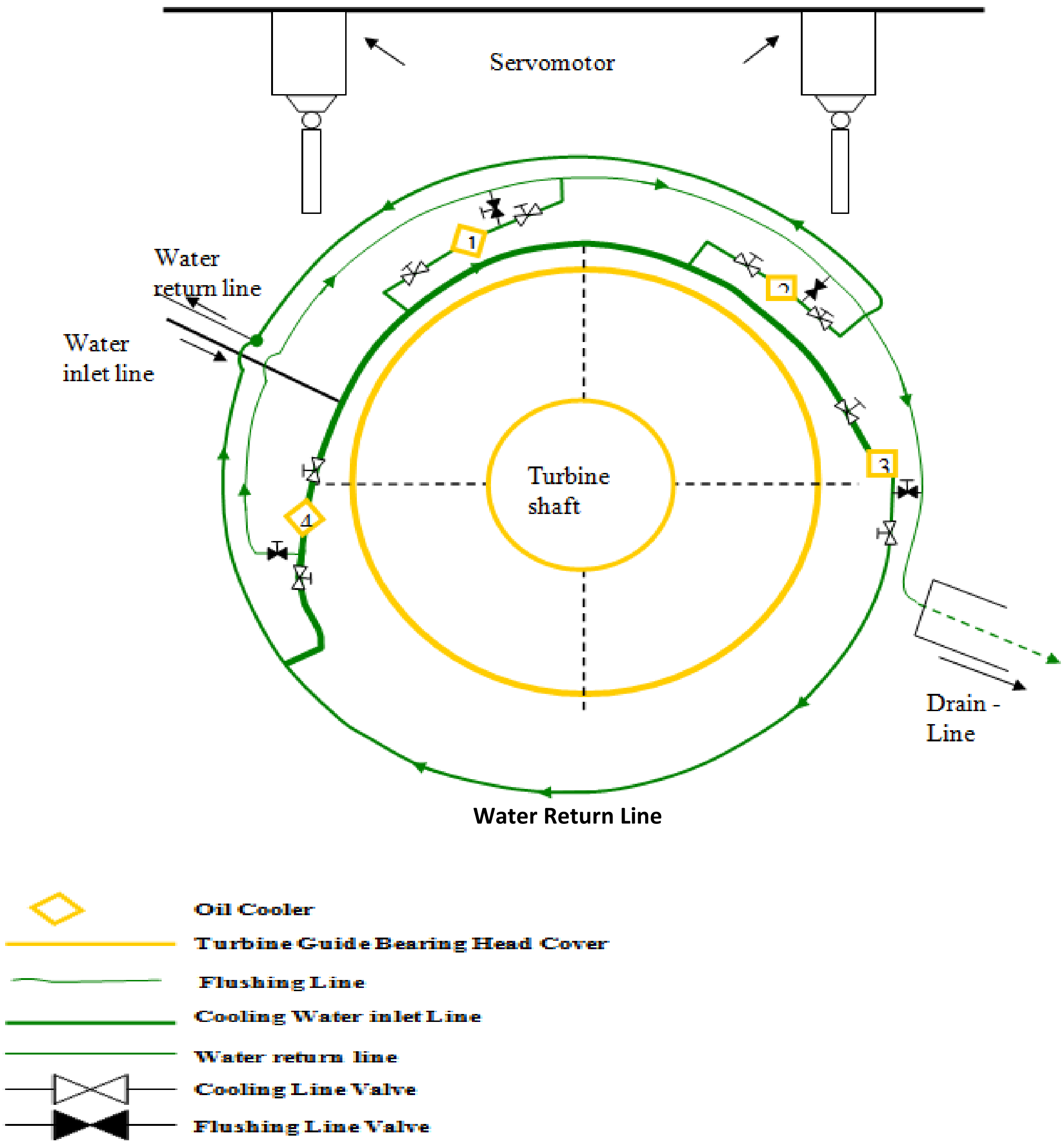

Figure 5: Cooling System with Four (4) Oil Coolers

4. Conclusion

The oil cooling system was modified from a 3- oil cooling circuit to a 4- cooling circuit system to achieve better cooling of the turbo generator unit 411G..3. With four oil cooler circuit system the power outages (the number of times the hydro units are shut down for repairs and minor maintenance) reduces. There was no change in operating pressure for both three oil coolers system and four oil coolers systems. The operating pressure for both 3 oil coolers and 4 oil coolers system remains almost equal with the number 4 oil cooler connected to the cooling water inlet line in front of the number 1 oil cooler for dynamic balancing of the oil cooling circuit system.

Since the number of outages predicts the station availability and overall plant efficiency; the power generated rose significantly from a range of 120 to 136MW before modification to a range of 145 to 150MW as shown in tables 2 and 3 respectively.

5. References

1. Chas, T.M. (1995), "Shiroro Hydro Electric Project'': Published Journal, Torno Millano, and Vol. 1 pp. 5-7
2. Garn, D. (1998), "Thermo analytical methods of investigations" Academic Press Incorporation, New York, 395 pp.
3. Campos J.G., Guide for Preliminary Design and Specification of Hydro Stations with HVDC Unit connected Generators CIGRE JWG 11/14-09, HVDC Unit Connected Generators 1997.
4. Guilherme A. C, Duarte M. S, Helena M. Ramos, "Small scale hydropower: generator analysis and optimization for water supply systems" World Renewable Energy Congress-2011, 8-13 May 2011, Linkoping Sweden.
5. *Gustavsson, R , "Modeling and Analysis of Hydropower Generator Rotors"* Licentiate thesis: The Polhem Laboratory, Division of Computer Aided Design Department of Applied Physics and Mechanical Engineering Lulea University of Technology, SE-97187 Lulea
6. Guthrie, J. B. (2003), "Hydro-Electricity Engineering Practice", Blackie and Sons Limited, New Jersey, Vol. 7 (1, 2 and 3), 740pp.
8. Lialitha, S. "Micro-Generation of Electricity from Tap Water *"International Journal of Emerging Technology and Advanced Engineering*, Vol. 3, No 10, 2013
9. Nhut-Quang, D., and Harmonic D. (1998), "Modelling of Direct Connected Generator and HVDC Converter Units in Electrical and Electric Engineering 1998, University of Canterbury: Christchurch
10. Rade Koncar (1996), Torvonica Generator Maintenance Handbook", Zagreb, Press, Auckland, 734 pp. 13-17
11. Schudler, A.E. (1997). "Transportation Energy and Power Technology", Glencoe, Mc Graw Hill, U.S.A, pp. 221-255
12. Sukhatine, S.P (2006), "Heat Transfer" Universities Press, India.
13. Tuve, G.L and Denldoldt, T.C. (2006), "Engineering Experimentation", Mc Graw Hill Incorporation, New York, 451 pp
14. Wilson, D. G (1988), "Design of High- Efficiency Turbo machinery and Gas Turbines", MIT Press, Cambridge, 47 pp

15. Yang X., Yue C., Yao, D., Yuan, C. (2013) "Hydro Power Integration with DC Power Plant Technology" The International Conference on Electrical Engineering (ICEE2013)-, Xiamen 14-17 July, 2013.