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Operational Optimization of Turbo Generator Units and Auxiliaries in Large Run - off the River Hydro Power Plants

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This paper presents the operational optimization to be implemented, based on the energy performance evaluation study carried out in a few large run off the river hydro power plants. The design parameters are compared with operating parameters and the deviations are analyzed. The various operational optimization opportunities available are described in this paper.

Keywords: *Hydro power plant, Operational optimization*

1.0 INTRODUCTION

The installed electrical power generation capacity in India is 200 GW (as on year 31-03-2012), out of which hydro-power generation system account for 39 GW (19.5 %). Hydro power sector offers lot of research opportunities for performance improvement. A decision support system which will interest utilities to maximize the value of water resources by providing rapid and informative recommendations based on current data and dynamic forecasts of hydrology, energy prices and loads at individual hydro plants is developed [1]. The system recommends quickly how to maximize hydroelectric benefits while meeting non-energy aspects of water management, such as effects on the river downstream and on the fore bay upstream. A nonlinear programming model has been formulated [2] and applied to the Brazilian hydropower system, one of the largest in the world with an installed capacity of 70 GW is extreme useful for setting up guidelines for real-time operation and for planning purpose. A methodology is developed [3] to serve for optimization of the maintenance intervals and to minimize the performance losses between two subsequent maintenance programs. This paper presents the various operational optimizations possible to be implemented for overall performance improvement of hydro power plants.

2.0 POWER GENERATION SYSTEM

The schematic of a typical power generation process in a hydro-power station is depicted in Figure 1. As shown in the Figure, water from the Dam enters the spiral casing of the hydro-turbine through the head race tunnel, surge shaft and penstock. The surge tank takes care of the surges caused due to the variation in electrical power demand. Guide vanes, actuated by servomotors, regulate the water flow to turbine. The mechanical rotational power produced by the turbine, due to the reaction of water on the turbine blades, is converted into electrical power by the generator. The generated voltage is stepped up to higher voltage level through the power transformer and fed to the grid.

The computed energy loss (at rated load) from various equipment of a typical hydro power plant [4] is shown Figure 2. It is seen that the hydraulic head loss across the head race tunnel (HRT) and penstock amounts to significant power loss. This loss occurs due to the friction head caused by the flow of water.

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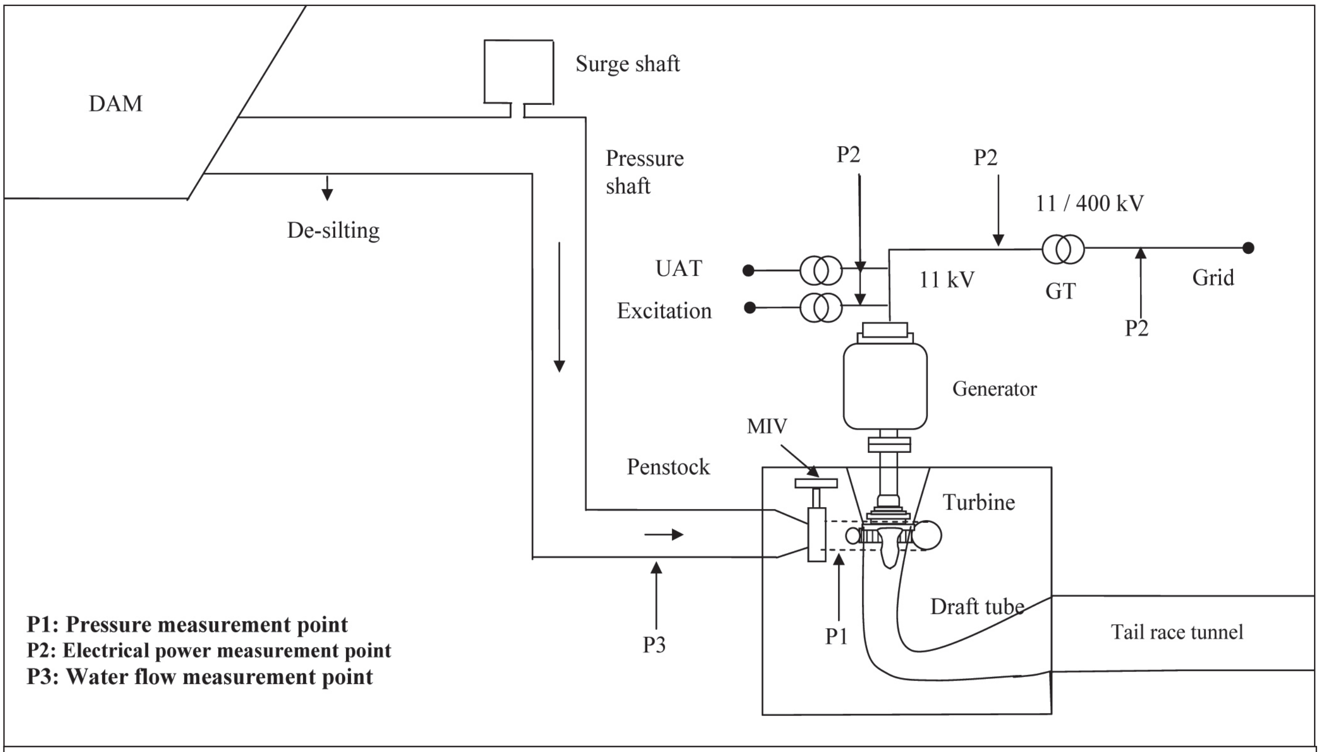
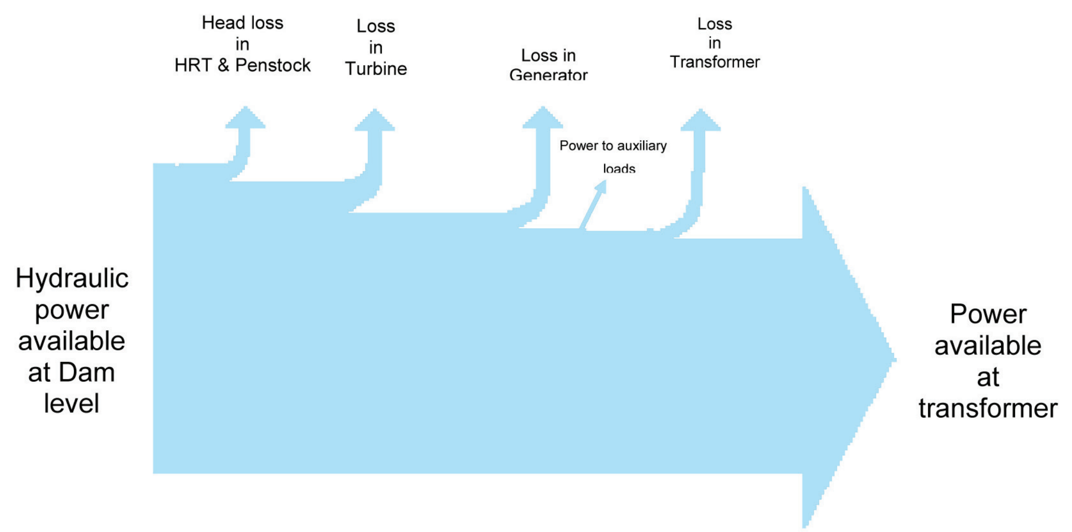


FIG. 1 SCHEMATIC OF A HYDRO POWER GENERATION



Equipment	Hydraulic power at dam	HRT and penstock	Turbine	Generator	Transformer
Efficiency, %	–	93.53	89.2	97.6	99.34
Power output, MW	73.69	68.92	61.48	60.0	59.61
Loss, MW	–	4.77	7.44	1.48	0.39
Loss, %	–	6.47	10.8	2.4	0.66

FIG. 2 TYPICAL ENERGY LOSS IN VARIOUS EQUIPMENT OF A 60 MW HYDRO UNIT

The hydraulic head loss through HRT and penstock of a power plant where there are 3 generating units is provided in Figure 3. It is seen that the head loss is about 37 metres when the three units are run at full load and it is only 18 metres when one unit is run at full load. Whenever the water available in the Dam is low and 2–3 units are run for short time (say 2–4 hours/day), it is recommended to run only 1–2 units for longer time since more energy can be generated using the same quantity of water due to the reduced friction head loss across the HRT.

The energy performance parameters of hydro turbine system in three different stations are given in Table 1. It is seen that the operating net head is lower than the design net head. The operating efficiency of the turbine is lower than

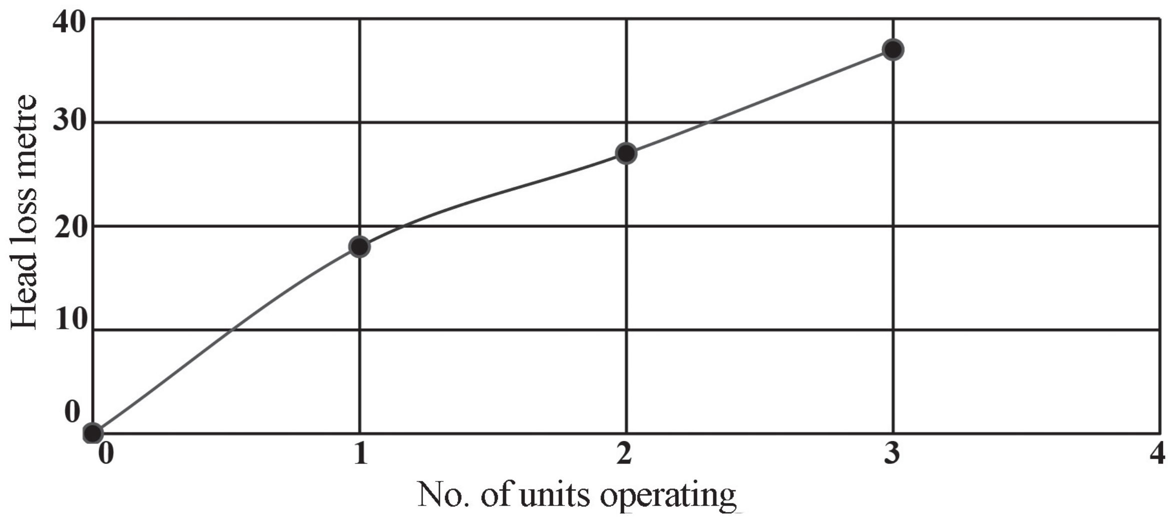


FIG. 3 HYDRAULIC HEAD LOSS THROUGH HRT AND PENSTOCK

TABLE 1

ENERGY PERFORMANCE PARAMETERS OF WATER CONDUCTOR AND HYDRO-TURBINE GENERATOR SYSTEM

Sl. No.	Unit	Unit load factor, %	Average water flow, m^3/s	Pressure head, m	Velocity head, m	Elevation head, m	Net head, m	Gross head, m	Head loss in penstock, m	Energy input, MWh/h	Turbine efficiency, %
I. Francis turbines rated for 115 MW, 137.3 m^3/s flow, 94.5 m net head and 92.5 % efficiency											
1	Unit # 1	89.0	135.2	95.2	4.1	–9.9	89.5	92.0	6.6	118.6	88.1
2		96.5	150.3	92.9	5.1	–10.1	87.9	91.7	8.9	129.5	87.4
3		101.4	167.2	90.8	6.3	–10.2	86.9	91.6	11.0	142.5	83.5
4	Unit # 2	87.7	130.6	93.8	3.9	–9.8	87.9	91.9	7.9	112.5	91.4
5		96.3	150.0	91.9	5.1	–10.1	86.9	91.7	9.9	127.7	88.4
6		99.9	161.3	91.0	5.9	–10.3	86.7	91.5	10.7	137.1	85.5

II. Kaplan turbines rated for 40.5 MW, 188.6 m³/s flow, 24.3 m net head and 92.4 % efficiency											
1	Unit # 1	20.4	66.7	27.7	0.2	–5.5	22.4	22.5	0.2	14.6	61.1
2		40.3	102.9	27.4	0.4	–5.5	22.3	22.3	0.4	22.5	75.8
3		62.6	146.6	26.7	0.8	–5.5	22.0	22.9	1.7	31.6	82.7
4		74.6	196.6	26.3	1.4	–5.9	21.8	22.1	1.7	42.0	73.9
5	Unit # 2	21.3	58.4	27.8	0.1	–5.8	22.2	22.3	0.3	12.7	73.4
6		40.4	88.3	27.7	0.3	–5.7	22.3	22.4	0.3	19.3	88.6
7		59.8	128.7	27.3	0.6	–5.8	22.2	22.3	0.7	27.9	89.5
8		78.6	176.4	26.2	1.2	–6.0	21.4	22.0	1.8	36.8	88.5

III. Francis turbines rated for 35 MW, 14.0 m³/s flow, 298 m net head and 88.0 % efficiency											
1	Unit # 1	26.2	5.0	295.5	0.7	–3.6	292.6	310.2	18.2	14.2	70.0
2		48.4	8.1	290.5	1.8	–3.6	288.7	310.2	23.3	22.8	77.7
3		67.5	10.7	288.0	3.2	–3.6	287.6	310.2	25.8	30.2	81.1
4		90.3	14.4	282.9	5.8	–3.6	285.1	310.1	30.8	40.1	81.0
5	Unit # 2	24.8	4.9	292.0	0.7	–3.8	288.9	309.9	21.8	13.9	67.8
6		42.3	7.4	287.0	1.5	–3.9	284.6	309.9	26.7	20.6	75.8
7		60.3	10.0	279.9	2.8	–3.9	278.7	309.8	33.8	27.2	80.6
8		79.5	13.0	274.9	4.7	–4.0	275.6	309.7	38.8	35.0	82.1

the design value due to the erosion of the guide vanes and runner blades caused by silts. The water flow through the penstock was measured using an ultrasonic flow meter. Coating of guide vanes and runner blades could aid the turbine in restoring the design profile. There are varieties of coatings like *High Velocity Oxy Flame (HVOF) Plasma Nitride (PN)*, etc. These coatings need to be tried on runner blades and guide vanes and suitable one may be chosen for large scale application. Renovation of the runner and draft tube through *3D computer modeling* needs to be carried out to improve the efficiency.

3.0 AUXILIARY POWER SYSTEM

The various operational optimization for the major auxiliary loads in a hydro power plant is discussed below.

3.1 Cooling Water System

The cooling water (CW) flow to various purposes in a typical hydro-power unit is given as pie chart in Figure 4. It is seen that the CW flow to lower guide bearing (LGB) and upper guide bearing (UGB) is 2.9 % each. About 53 % flows to the

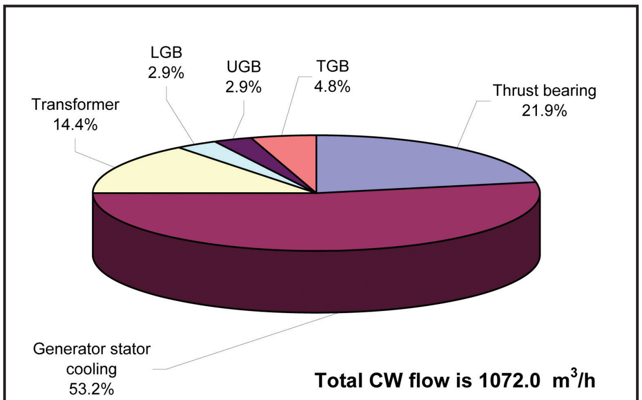


FIG. 4 TYPICAL COOLING WATER FLOW PATTERN

generator stator cooling and 4.8 % to turbine guide bearing (TGB). The optimum (general design) temperature difference across the heat exchanger (water side) is about 4–5°C and pressure drop is about 0.5–0.7 bar. The lower value of temperature difference indicates more cooling water flow and higher pressure drop indicates chocking of HX and throttling of valves. As per the design data, the cooling water inlet and outlet temperature for each application is 30°C and 35°C respectively. Generally, the rise in CW temperature across various heat exchangers is measured to be in the range of 0.8–2.5°C. This indicates that the CW flow to various purposes is high. Hence, the water flow to each application can be optimized through use of AC variable frequency drives (VFD) and power saving upto 40–50 % can be achieved. In many of the plants, the CW is available in the temperature of 8–20°C throughout the year.

Through the VFD, the motor can be run at reduced frequency (say 30–40 Hz) to ensure that 5ºC rise is there across the heat exchanger. The pressure reducing devices like orifices need to be removed and globe and gate valves are to be kept 100 % open in the cooling water circuit. In other CW lines also, the gate valves are to be kept 100 % open. Generator stator air cooling line may be kept as the reference. In other CW lines, the gate valves needs to be operated slightly, if required for flow regulation.

The energy performance parameter of the cooling water pumps (CWP) is given in Table 2. It is seen that the efficiency of some of the CWP is low since the operating pressure is lower than the design. The efficiency of pump is highest at the rated head and flow only. Generally low head and high flow pumps are more efficient. Hence, during new procurement, the pumps need to be sized optimally such that it *operates close to the rated head and flow most of the times*.

In some of the plants, suction valve is partly closed for flow control. In such cases, use of AC VFD for flow control provides better operational optimization.

3.2 Air compressors

The high pressure (HP) air compressors are used for the operation of turbine and spherical valve oil pressure unit (OPU). The average running time is about 800 hours/compressor/year. The performance parameters of the compressors are given in Table 3. It is seen that the capacity of HP #1 have come down by 44.34 %. Hence, it is suggested to overhaul the compressor to improve the present capacity.

TABLE 2

ENERGY PERFORMANCE OF COOLING WATER PUMPS

Sl. No.	Particulars	Unit	Design	Unit #1		Unit #2	
				CWP1	CWP2	CWP1	CWP2
1	Motor output rating	kW	30.0	30.0	30.0	30.0	30.0
2	Operating input power	kW	28.1	25.37	24.85	26.56	26.09
3	Measured flow	m^3/h	340.0	320.0	339.2	333.0	288.5
4	Velocity inside pipe	m/s	1.73	1.63	1.73	1.69	1.47
5	Suction pressure	kg_f/cm^2		0.90	0.89	0.88	0.88
6	Discharge pressure	kg_f/cm^2		2.29	2.41	2.26	2.00
7	Total pressure developed	kg_f/cm^2	1.9	1.39	1.51	1.38	1.12
8	Motor + pump efficiency	%	62.7	47.7	56.2	47.0	33.7
9	Motor load factor	%	81.4	73.6	72.1	77.0	75.6

TABLE 3					
ENERGY PERFORMANCE PARAMETERS OF HP AIR COMPRESSOR					
Sl. No.	**Particulars**		**Unit**	**Power House**	
				HP #1	HP #2
1	Motor rating		kW	11.3	11.3
2	Compressor rating	Pressure (gauge)	kg_f/cm^2	35.0	35.0
		Capacity (design)	cfm	30.9	30.9
		Capacity (design)	m^3/min.	0.88	0.88
		Displacement	m^3/min.	1.25	1.25
3	Compressor detail		–	Ingersoll-rand, Type 30, Model 15 T2, 3 stage reciprocating	
4	Design specific power consumption		kW/m^3/min.	10.93	10.93
5	Tank capacity		M^3	1.6	1.6
6	Pipe volume (before and after tank)		M^3	0.003	0.006
7	Total volume		M^3	1.60	1.61
8	Operating power		KW	12.7	11.5
9	Final test pressure (gauge)		kg_f/cm^2	41.5	41.5
10	Time taken to charge the tank		Sec	8625.0	6120.0
11	Present capacity		m^3/min.	0.49	0.69
12	Operating specific power consumption		kW/m^3/min.	26.0	16.7
13	Atmospheric pressure (absolute)		kg_f/cm^2	0.95	0.95
14	Volumetric efficiency		%	38.96	55.02
15	Iso-thermal power: compressor		kW	2.87	4.06
16	Iso-thermal efficiency		%	24.30	37.88
17	Load factor of the motor		%	112.47	101.88
18	Capacity reduction due to wear		%	44.34	21.40

3.3 Air conditioning system

The air conditioning (A/C) load of hydro power plant is generally 50–70 TR. For underground plants, the A/C load is as high as 300–500 TR. Since cooling water at 8–15°C is available throughout the year in many of the hydro power plants, it is suggested to circulate the cooling water through a coil inside the air-handling unit (AHU) there by the power consumption of compressor, condenser pump and cooling tower fan can be saved. The specific power used by best chiller is 0.6–0.7 kW/TR. By using only CW for A/C, this can be brought down to 0.1–0.12 kW/TR, resulting in huge savings.

3.4 Drainage pumps

Lot of leakage is observed from turbine top and bottom seals in some of the plants and drainage pumps are run continuously. By sealing the leaks, there is twofold savings. One is additional power can be generated if the water pass through the turbine and the running hours of drainage pumps will come down drastically. In a typical power

TABLE 4

SUMMARY OF OPERATIONAL OPTIMIZATION MEASURES

Sl. No.	Operational optimization measure	Envisaged energy savings, MWh/year	Annual cost savings, Rs. Lakhs	Capital investment, Rs. Lakhs	Pay back period, months
1	Optimizing the number of units running when water availability is low in Dam	432.0	3.46	–	–
2	Replacement of inefficient CW pump with an efficient pump	41.8	1.25	2.2	21
3	Installation of *AC variable frequency drive* for CWP motor	98.9	2.97	5.5	22
4	Overhauling of HP air compressor to improve the capacity	5.9	0.18	–	–
5	Use of low temperature CW for air conditioning purpose	109.2	3.27	1.5	6
6	Arresting of water leaks in turbine top and bottom seals	0.67 MW			

plant, the addition energy generation possible if seal leak is arrested is 2.1 MW/(m^3/s) of water flow and the drainage water pumping power is 0.57 MW/(m^3/s). In some of the plants, the discharge valve of drainage pump is throttled to avoid the over load and burning of motors. It is suggested to use AC VFD so that the motor can be run at reduced frequency.

The summary of operational optimization measures are given in Table 4.

4.0 CONCLUSIONS

The main conclusions from the study are as follows:

(i) Coatings of runner blades and guide vanes with high velocity oxy flame (HVOF) or plasma nitride (PN) will optimize the water used for power generation.

(ii) Renovation of the runner and draft tube through 3D computer modeling will improve the energy efficiency.

(iii) Optimizing the number of units running when water availability is low, will result in increased energy generation (by reducing the frictional head loss).

(iv) Optimizing the cooling water flow to various application, Introduction of AC variable frequency drive for CW pump-motor, replacement of inefficient pumps, Overhauling of worn out air compressor and use of CW for air conditioning, will reduce the auxiliary energy consumption.

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