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GENERATION PERFORMANCE EVALUATION OF THE KAINJI HYDRO POWER STATION, NIGERIA

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ABSTRACT

The Kainji hydro power initially conceived as the nucleus of the Nigerian power system was rated at 960MW to be supplied by 12 x 80 MW Kaplan turbines. The station was commissioned in 1968 with two 80 MW Kaplan turbo-alternators. Subsequently, other types of turbines and of varying sizes were installed. By 2010, six additional units consisting of two 80MW and two 100MW Kaplan turbines as well as two 120MW Francis turbines were installed bringing the installed capacity to 760 MW. This paper examines and evaluates the performance of the facility of Kainji hydro power generating source. In order to study the performance of this power station, the inflow and outflow data, as well as the generated energy were collected over the period from 1992 – 2008. Various analyses were then performed. Analysis of the inflow data indicates that whilst there was a drought period in the late 70's and 80's, the reservoir appears to have recovered sufficiently in the new millennium enough to provide a reliable source of energy. A stochastic model of the station realized as a 128 state Markov process was solved to calculate the gross failure probability for the station. The failure probability of the plants still manifest a behaviour that gives the impression of performance but which when compared to what is expected of such turbo-alternators is unacceptable. An assessment of unit performance was then performed using an index defined as the ratio of the mean-time-between-failures and the mean-time-to repair. These results reveal a performance not entirely dependent on the age of the plants. Indeed the aggregate performance of the Francis turbines despite being the newest was poorer than the aged start-up plants. It further revealed that most of the plants require on the average two days servicing for every five working days. This situation points at an urgent need to refurbish the plants, upgrade the maintenance capability and acquire a good supply of spares for the future, so as to be able to increase the available power generation in Nigeria through a renewable means – hydro.

KEYWORDS: Power Systems, Hydro Power, Installed Capacity, Generated Capacity, Availability.

INTRODUCTION

Power generation in Nigeria dates back to 1895 when preliminary investigations and planning carried out by the Public Works Department resulted in the construction of the first power station in Lagos in 1896 – a mere fifteen years after its introduction in England (NPR, 1985). At independence, the majority of Nigeria's power was generated by isolated coal-fired thermal plants sited in close proximity to the loads. After independence efforts were made to expand the power network of the country. When the need arose for reliable, efficient and cheaper power supply, it was decided then that a hydroelectric plant was the most feasible alternative and the Kainji Dam Project on River Niger was conceived.

The river Niger is the third longest river in Africa, 4100km long, after Nile and the Congo / Zaire Rivers. It traverses two humid catchments separated by a wide expanse of semi-arid environment and four countries of Guinea, Mali, Niger and Nigeria in that order from the source at Fouta Djallon mountains to the Gulf of Guinea in Nigeria where it enters the Atlantic ocean through its delta (Alayande and Bamigboye, 2003). As a result two distinct floods occur annually on the river in Nigeria, the river exhibits a seasonal flood regime, which is responsible for the annual flood characteristics of the river. Balfour and Nedeco, (1961) described the seasonal hydrology of River Niger with two major features. During the months of May to October, rainfalls in the northern parts of Nigeria south of Niamey produce floods that quickly reach Kainji. This floodwater with a peak flow of between 4,000 to 6,000 m s^{-1} occurring sometime in September or October is laden with silt/clay sediments and is of high turbidity. Due to its color, it is locally referred to as the "White Flood"

The second flood originates from the river's headwater region of high annual rainfall in the Fouta Djallon highlands in Guinea, and passes through the sub-arid region and deltaic swamps around Timbuctu. In these areas it loses much of its silt load and water to evaporation and infiltration and very little water is added to the flow before it reaches Kainji in

November with a peak flow of about 2,000 $m^3\ s^{-1}$. The water is relatively clear due to its low silt load and is thus locally called the "Black Flood"

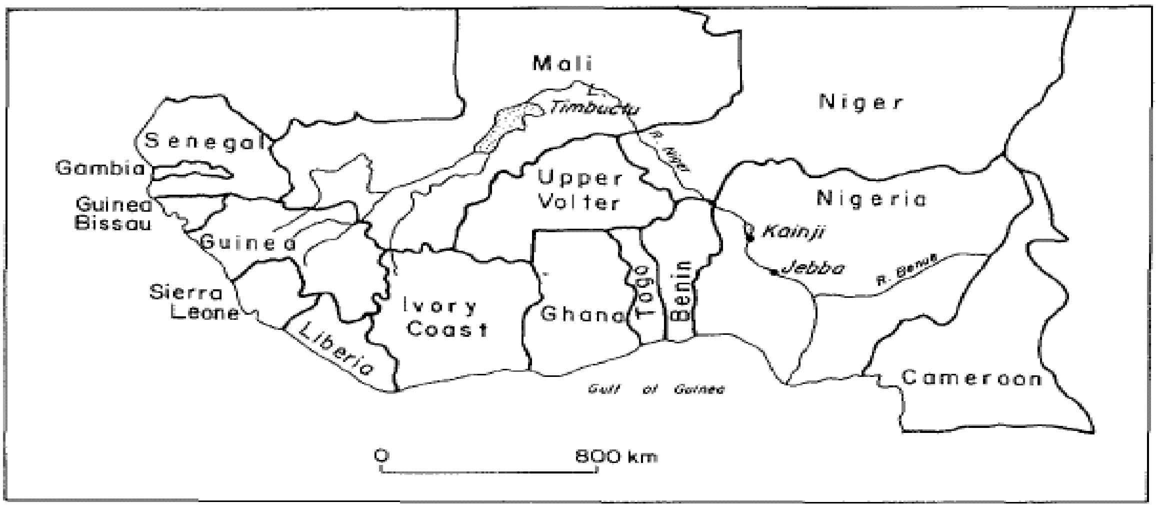

Figure 1: Map of West Africa Showing River Niger Route (Sarkar, 1985)

Since the mid-twentieth century, there has been a move to establish other dams on the Niger River especially in the semi-arid areas between its headwaters and Nigeria. Presently, the Niger Republic is in the process of constructing a multi-purpose dam on at Kandaji. This is in addition to the Fomi dam in Guinea, Mekrou dam in Benin Republic and Tossaye dam in Mali. All these in addition to climate change impacts; desertification and water diversion activities for irrigation purposes by peasant farmers along the river course are pointers to an impending reduction of inflow due to the black flood waters into Kainji reservoir (Ale *et al*, 2011). Intensified use or diversion of water for other purposes in the Sokoto-Rima basin can also reduce the white flood into the Kainji Lake so that the power generating potential of the Kainji power station may be greatly reduced in the near future.

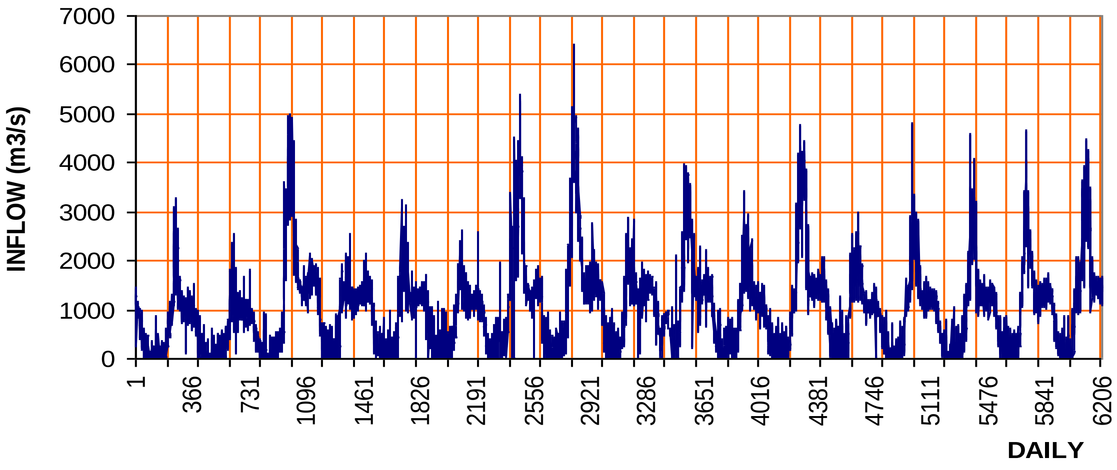

Figure 2: Time Series Of Kainji Inflow (1992-2008)

Presently, three hydro-power stations contribute 36.14% of the power generated in Nigeria. The Kainji plant generates 33.58% of hydro energy production, which is equivalent to 12.14% of total energy produced by both hydro and non-hydro power plants between 1992 and 2008. Clearly there is a need to ensure that full benefits are derived for the investment made in the dam and its equipment.

Kainji Dam

The Kainji Dam, a multipurpose project intended for power production, improved navigation of the river, flood control in the Niger Valley and fishery production of over 10 000 tons annually was constructed between February 1964 and August 1968.

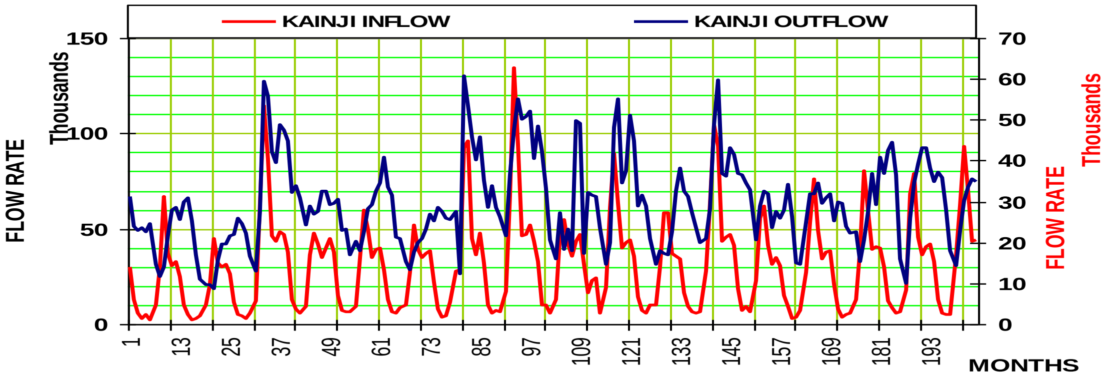

Figure 3: Time Series Of Inflow And (Tail Race) Outflow At The Kainji Dam (1992 - 2008)

The Niger River has a total drainage area of 1.12 x 10^6 km^2 and passes through two humid catchments which are separated by a wide expanse of semiarid environment. The lake formed by the impoundment has an area of 1280 km^2 at its maximum elevation (Oyebande *et al*, 1980).

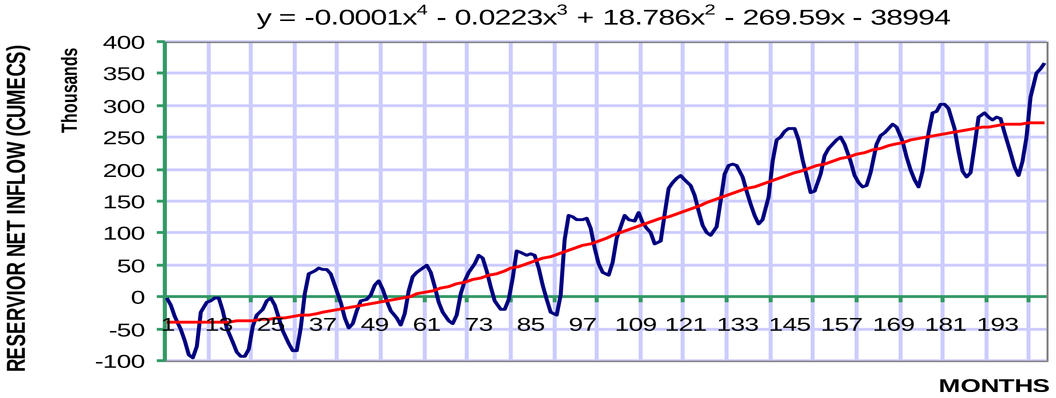

Figure 4: Cumulative Reservoir Inflow At Kainji Dam

Using data obtained from the station and the National Control Center, Osogbo, the daily inflow pattern from January 1992 till December 2008 is shown in Figure 2.

Figure 3 present the inflows and outflows observed over the period from 1992 to 2008. The inflows exhibit distinctive periodic twin peaks consistent with the features of the two widely separated catchment areas from which the waters originate. It can also be observed that while the tailrace outflow varies, the minimum level seems to be consistent even when the inflows appear to have almost tapered off. This is indicative of the measure of control that is being provided by the dam. These results can form the basis for a systematic exploitation of the water resources in a manner that may be used to extract more benefits for the national economy.

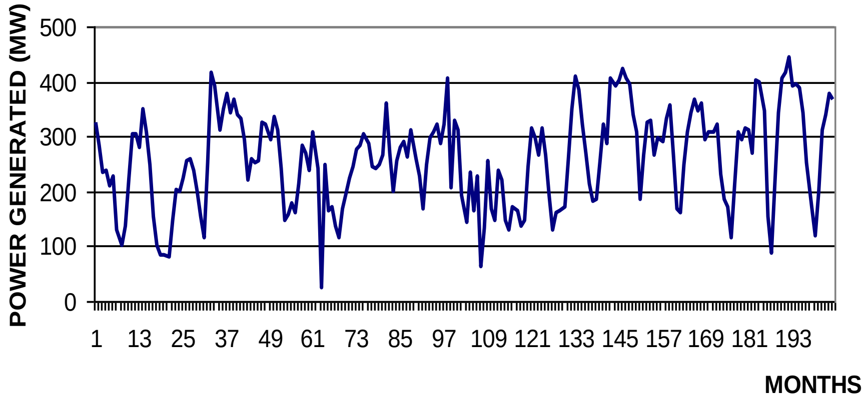

Figure 5: Time Series Of Kainji Power (1992-2008)

The state of the reservoir has often been a cause for alarm over the years. In order to determine the condition of the lake, an upper bound on the cumulative flows was computed. The result is as shown in Figure 4. This variable, which is virtual one, can be seen to exhibit a monotonic trend modulated by the seasonal floods and ebbs. On the other hand the actual head in recent years varies slightly almost in sympathy with the seasonal modulation of the cumulative flow.

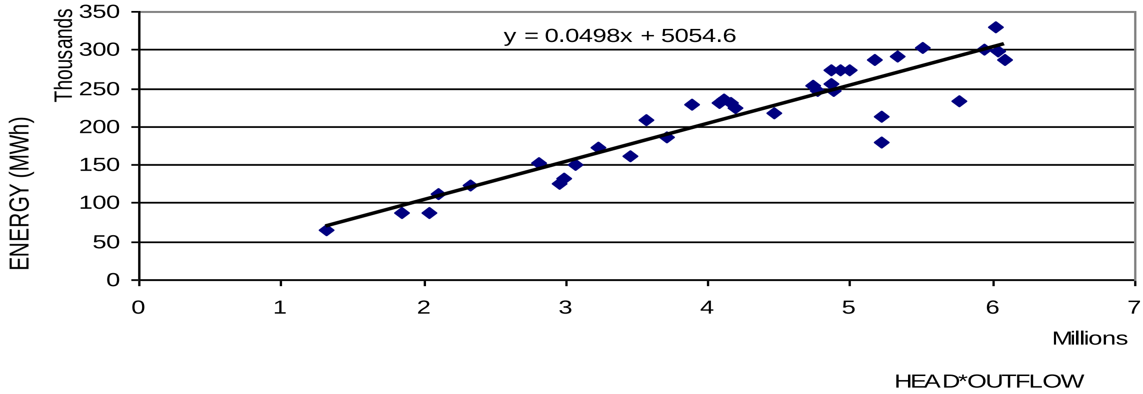

Figure 6: Energy Vs (Head*Outflow) – 2006-2008

The average value of the head is around the high point set by the designers – 40 meters. This result suggests that despite various activities upstream of the dam that the reservoir is recovering from the effects of drought once evapo-transpiration and discharge through the spillways are taken into account. There is, however, a further need to study the phenomenon and establish appropriate guideline for reservoir management.

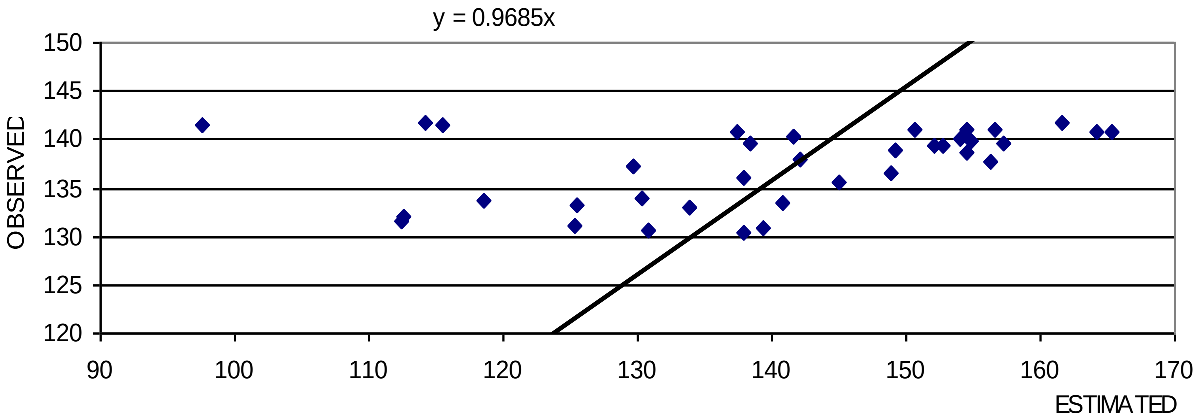

Figure 7: Actual Average Head Vs Estimated

Kainji inflow and power generation potentials
An average daily discharge of $2280m^3/sec$ was estimated as necessary to sustain a full generating capacity of 760MW or 3m/sec per unit Mega Watt of electricity (Alayande and Bamigboye, 2003). This estimate was determined using an average head and near ideal operating conditions for all the plants. The actual energy generated during the period was studied. The monthly energy produced by the station is as shown in Figure 5. Theoretically the energy developed is a function of the flow and the head but the information for all these variables were not captured until very recently. As a result the performance of the plants could not be comprehensively determined. Nonetheless, some conclusions can still be reached.

Using the available head information (daily from January 2006 – December 2008) but averaged to provide a monthly equivalent, it was possible to determine the relationship between the energy developed and the product of the flow rate and the head in meters. This result is shown in Figure 6 with the best line of fit as shown having a correlation coefficient of 0.8634. This confirms the result forecast from the theory although the aggregate efficiency of conversion is much less than the 90% theoretically forecast for Kaplan type turbines (Peter *et al*, 2008).

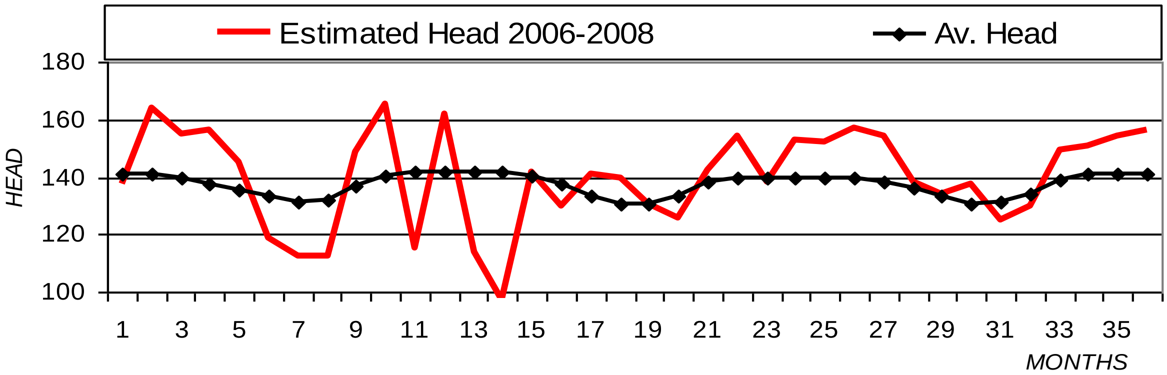

Figure 8: Average Head: Estimated Head (Jan. 2006 – Dec. 2008)

Using the head characteristics available from the data, estimation of the head for the period from 1992 to through 2005 was carried out. The result is as shown in Figure 7 and the plots for the available period as shown in Figure 8. The result here indicates a relative insensitivity to the head which may be not unrelated to the activity of the runner vane regulators that are designed to optimize the energy conversion of the plants. There is also the matter of the efficiency of conversion which is an unknown but which may be estimated from the results of Figure 8. The exact situation would require more detailed data of the plant. The problem can be eliminated by requiring the station authorities to capture all the necessary information on a daily basis so as to facilitate a better monitoring and assessment process.

Assessment of the Performance of the Plants

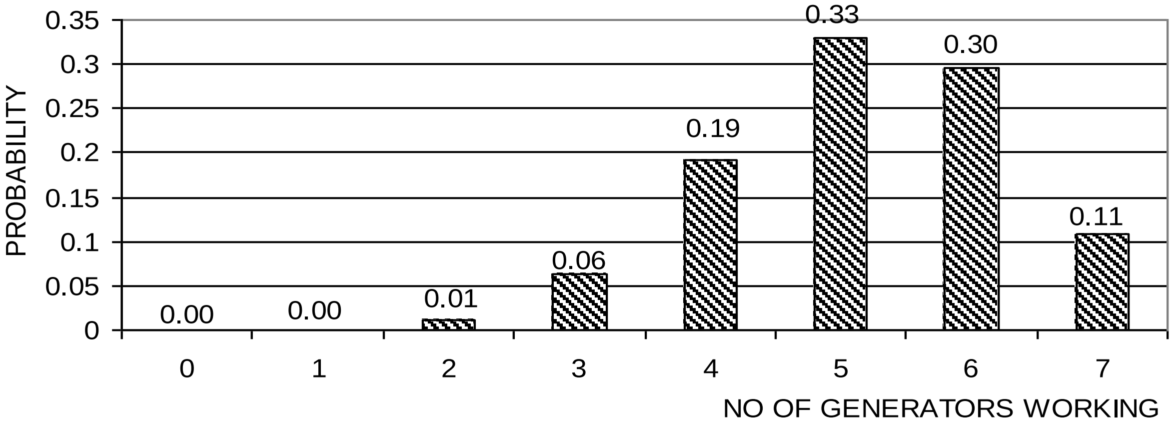

Figure 9: State Probability of Generators at the Kainji Power Station

Information about the conditions of each plant was extracted from daily reports filed with the National Control Center at Osogbo, Osun State. Since these reports were only available from 2006 till 2008 at the time of the work, only this period could be considered. A model of plant reliability was constructed using condition analysis and a 128 state Markov process (Endrenyi, 1978). The availabilities for various plants are shown in Figure 9. The result suggests that 60% of the time 5 or 6 machines are available which is why the station is still able to provide some power although this is a far cry from what is expected from usually very reliable hydro power plants.

As a final step towards the assessment of the condition of the plants in the station, the time between failures and the down times of each plant were determined. The result of the study showing the average time between failures (MTBF) and the mean time to repair (MTTR) are as shown in Table 1.

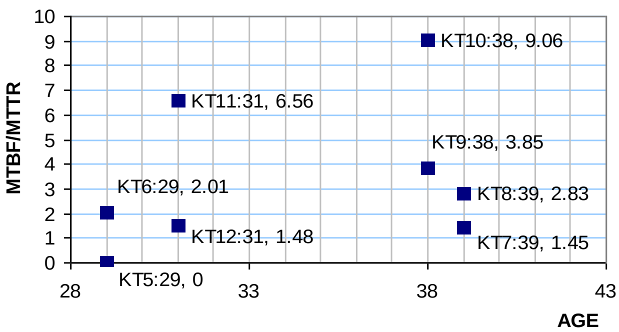

Figure 10: MTBF/MTTR VS AGE

Assessing the behavior of the plants can be facilitated by studying the ratio of MTBF and MTTR as also displayed in Table 1 and in Figure 10. The ratio ranges between 1.48 and 9.6. This implies that the base line of the plant performance is dismal. At the lower end it appears as if for every three days of operations 2 days of repairs must follow while at the higher end every 10 days of operation requires a down time of one day. This is a very unsatisfactory state of affairs as far as reliability and the vaunted superb performance of the hydro plants are concerned. There is a definite need to re-habilitate the plants in the meantime to restore the ratio to over 50. This study can be used as a guide for assessing the viability of a plant especially when closer analysis of performance is to be carried out.

CONCLUSION

The hydro power plant at Kainji on the river Niger in Nigeria has an installed capacity of 760MW. One plant, a Francis turbo-alternator, has been damaged since the mid 1980’s after less than a decade of service. The Kainji Lake seems to be recovering from the debilitating effects of the draught although a new threat is developing in the form of upstream dams on the river located in other transit countries. Their impact will still need to be evaluated but there is a good chance that the potential for power generation of the dam will be reduced. Nonetheless, this may be offset by enhanced maintenance and other measures. Presently the equipment at the station can only function as a poor generating source because of the very low MTBF to MTTR. The best unit has a ratio of slightly less than 10 while the worst one has a measly 1.48. This is most unsatisfactory and has to be addressed before significant improvement in performance can be expected from the station.

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APPENDIX

	UP TimeKT6	DN T KT6	UP Time KT7	DN T KT7	UP Time KT8	DN T KT8	UP TimeK T9	DN T KT9	UP TimeK T10	DN T KT10	UP Time KT11	DN T KT11	UP TimeK T12	DN T KT12
Sum =	732	364	649	447	810	286	870	226	987	109	951	145	654	442
Number =	11	10	11	11	13	13	16	15	13	12	15	14	20	19
Mean(hr) =	1597	873.6	1416	975.3	1495	528	1305	361.6	1822	218	1522	248.6	784.8	558.3
λ (/yr) =	5.485		6.186		5.858		6.713		4.807		5.757		11.16	
μ(/yr) =	10.03		8.982		16.59		24.23		40.18		35.24		15.69	
TOTAL=		1096		1096		1096		1096		1096		1096		1096
UP TIME/DN TIME=		2.011		1.452		2.832		3.85		9.055		6.559		1.48
year of installation		1978		1968		1968		1969		1969		1976		1976