International Journal of
Science and Engineering Investigations vol. 4, issue 42, July 2015
ISSN: 2251-8843

Evaluation of Operational Efficiency of Shiroro Hydro-Electric Plant in Nigeria

S.L. Gbadamosi[1], Ojo O. Adedayo[2], Nnaa L.[3]
[1,2,3]Department of Electrical Electronic and Computer Engineering, College of Engineering, Afe Babalola University, P.M.B. 5454, Km 8.5, Afe Babalola Way, Ado-Ekiti, Ekiti State, Nigeria
([1]gbadamosiadeolu@gmail.com, [2]adedayojoy@gmail.com, [3]lawrencenna@outlook.com)

Abstract- Electricity generation of any nation serves as an engine that drives an economy of such nation. Sufficient power supply is very crucial for industrial development and economic growth of any nation. Recent studies show that most of the hydro-electric generating stations in Nigeria are operating below their installed capacity which is as a result of non-overhauling of turbines installed at the hydro power plants. This study is aimed at providing an operational efficiency analysis of Shiroro hydro-electric power plant for the reviewed period (2004-2014).The model equations were formulated based on some performance parameters used in power plant analysis. The considered criteria were plant availability factor, capacity factor and the overall efficiency of the plant. Also a Graphical User Interface (GUI) was developed for evaluating plant data on annually basis depending on the interest of the users and comparing the overall efficiencies of the plant graphically. The study reveals that 50.1% to 88.3% MW of the installed capacity was available in the period. The percentage of shortfall of energy generated in the period ranged from 23.5% to 47.3% as against the acceptable value of 5–10%. The capacity factor of the plant is between 23.5% and 50.7% as against international best practice of 80%. The average availability of the plant for the period was about 75% as against industry best practice of 95%, while the overall efficiency of the plant ranges from 27.1% to 80.4%. Measures to improve the performance indices of the plant have been suggested such as training of operation and maintenance (O & M) personnel regularly, improvement in O& M practices, proper spare parts inventory and improvement in general housekeeping of the plant.

Keywords- *Shiroro Hydro-electric Plant, Overall Efficiency, GUI*

I. Introduction

Electricity generation in the world has been on the increase over the last few decades especially in the developing nations where hydropower remains the major source of electricity generation. In Nigeria for example, the history of electricity dates back to 1896 when electricity was first produced in Lagos, fifteen years after its introduction in England [2]. The total capacity of the generators used then was 60 kW. The problem of electric power generation begins in the 1980s, ever since, this poor electric power generation has hindered industrial development and contributed immensely to the poor economic state of Nigeria. Improving power generation in Nigeria has been a top priority of successive Nigerian government since 1999 to the extent that in 2007 Umaru Yar Adua, the late Nigerian President declared a state of emergency in the power sector of Nigeria [14]. Despite all these rhetoric, generation of sufficient electric power to drive the economy is far from being a reality. Apart from insufficient number of power generation plants, existing ones are facing declining output due to ageing, neglect and ineffective maintenance. The hydroelectric power generation plant at Shiroro in Niger State, Nigeria, which started operation in 1990 is no exception to this, and has been facing declining output due to same reasons mentioned above [14].

Shiroro hydroelectric power station is situated in the Shiroro Gorge on the Kaduna River, approximately 60km from Minna, capital of Niger State, in close proximity to Abuja, Nigeria's federal capital. The station was commissioned in June, 1990 by the then Head of State-General Ibrahim Badamosi Babangida [10]. This made Shiroro project the 3rd hydroelectric power station and the 6th generation stations in Nigeria. All the 5 existing generation stations have installed capacity of 4,390MW and were operating below 1700MW[10].

The plant has an installed capacity of 600MW from four generating units rated at 150MW each at a head of 97m. Each unit comprises of a vertical Francis type hydraulic turbine because of its robust and sustainability against high mechanical stress resulting from high heads. The Francis turbine is controlled by an electro hydraulic governor system. The turbine drives a synchronous generator of salient pole construction having a net output of 150MW as shown in Figure 1. Power is generated at a voltage level of 16kV, and the generator steps up the voltage to 330kV for connection to the national grid via a 330kV switchyard. The Shiroro dam as shown in Figure 2 is a concrete face rock fill (CFRD) dam with a crest length of 700m rising 125m above the original river bed. The width of the dam at its toe is over 300m, whilst its crest accommodates a 7.5m wide service road. The reservoir was capable of 7 billion cubic meters of water when constructed. Shiroro hosts Nigeria's SCADA-operated national control centre and the station is also equipped with switchyard facilities that include a technical “step down” function for enhanced distribution into the national grid, an advanced control room and modern training facilities [9]. Each unit of the plant has quick start from cold and load pick-up and can link the national grid in few minutes; hence the vital position of the generating station in handling emergencies resulting from sudden increase in load demand or sudden loss of a machine in another power station which distinguish it from other generating station [9].

In the recent time, studies have shown that most of the hydro-electric generating stations have been operating below their installed capacity as compared to the International Standard Organization (ISO) ratings. According to Mr. Reuben Akinwunmi (CEO) Kainji Hydro Power Plant during delegation of national good governance tour of projects across the country, disclosed that most of the units of turbines installed at the hydro power plants have not been overhauled for some years, and as a result most machines installed at the plant are not functional and also unavailability of water in the dam mostly resulting into shutting down of the stations[9]. With the amount of money invested into power sector by Nigeria government, electric generation crisis in Nigeria should have become a forgotten issue. To rescue this unpleasant situation, a crucial performance evaluation of factors contributing to low energy generation and unreliable supply system is important and necessary.

In this research work, the energy generation history of the turbine units at Shiroro hydro-electric power station was investigated with the view to examining the level of the plant performance parameters, such as overall plant efficiency, plant capacity and capacity factor within the period of 2004 to 2014.

The performance of a power plant by way of its efficiency and other operating factors has definite socio-economic significance both on the company operating the plant as well as the nation at large [6]. However, without adequate and reliable electricity supply, socioeconomic transformation would remain a mirage.

A review of [4] shows that improving the availability of existing units in generating station is as important as improving the reliability expectation of the entire grid network, which would aid the mitigation of harmonics that may affect the generating station. Power plant availability and the causes of unavailability constitute essential performance indicator for assessing services rendered by generating power plants [5]. Therefore, effective maintenance and efficient performance of power generation facilities is highly desirable [11–13].

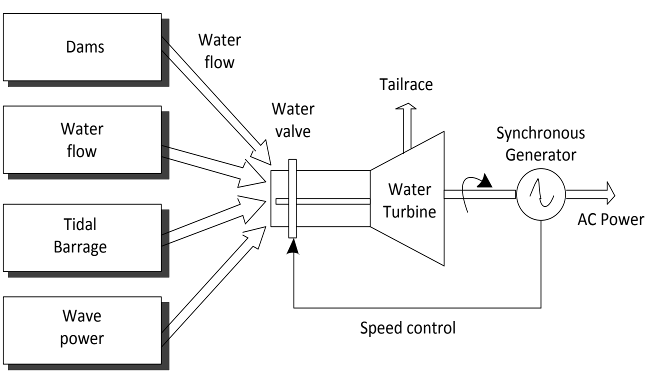

Figure 1. Hydro Electric Generation

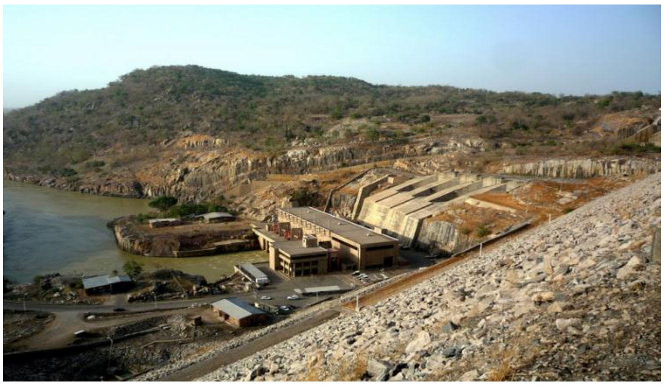

Figure 2. General Overview of Shiroro Hydro-Electric Plant (Google Search)

II. METHODOLOGY

In this study, performance analyses were carried out on each unit of the generating plant. Empirical data of the annual energy generation were obtained from plant inventory records from Shiroro power station's logbook for the period of 2004 to 2014. The following data were obtained from the log book:

- The installed capacity of each generating unit in the plant.
- The annual generated MW of each generating units.

A. *Performance Parameter Indices of the Plant*

In order to the determine plant performance indices, the following parameters were analysis from the data obtained from the plant log book.

- Capacity factor (CF) is the ratio of the average energy output of the plant for a given period of time to the plant capacity. The plant capacity factor can be calculated using equation (1).

$$Capacity\ Factor = \frac{E_G}{R_C * T} x\ 100\% \qquad (1)$$

where E_G is the total energy generated in (MWH); R_C is the rated capacity of the plant in (MW) and T is the running hour of the plant in (H).

- Availability factor of a power plant is the percentage of the time that it is available to provide energy to the grid. The availability of a plant is mostly a factor of its reliability and of the periodic maintenance it requires

$$AvailableFactor = \frac{AP}{I_c} \qquad (2)$$

where AP is the Average MW available and I_c is the Installed capacity of the power plant.

Average MW available is a measure of average usable MW capacity of each station putting external factors into consideration.

B. *Overall Efficiency of the Plant*

The overall efficiency (η) of the hydro-electric power station is defined as the ratio of the electrical power output of the plant to the available hydropower. The equations (3) to (8) were used to evaluate the efficiency and availability of the plant.

The overall efficiency of hydro-power plant

$$(\eta) = \frac{P_o}{P_\psi} \quad (3)$$

where P_o is the electrical power output in kW and P_ψ is the available hydropower in W.

The electrical power output in kW is given as

$$P_o = 9.81qh\ (kW) \quad (4)$$

where q is the rate of flow of water in (m^3/s) and h is the effective head of water in (m).

The available hydropower is the ratio between the potential energy of the water in the reservoir and the time of the falling water, which is given as:

$$P_\psi = \frac{P.E}{t} \quad (5)$$

where P.E is the energy of the water in the reservoir and is proportional to the mass of water and the difference in height between the water impoundment and the water outflow. This height difference is called the head or effective head.

$$P.E = mgh \quad (6)$$

where m is the mass of water and the mass of water is its volume times its density.

$$P.E = volume * \rho gh \quad (7)$$

Therefore,

$$P_\psi = \rho ghq \quad (8)$$

where ρ is the density of water ($\approx 1000\ kg/m^3$), g is the acceleration of gravity ($9.81 m/s^2$), h is the effective head of water in (m) and q is the rate of flow of water in (m^3/s).

C. Development of GUI for Analysis Overall Efficiency and other Performance Parameters.

In order to perform the performance parameter indices and efficiency analysis of the Shiroro hydropower plant, power plant analysis GUI was developed on MATLAB Graphical User Interface Development Environment (GUIDE) platform. The GUI comprises of three sub-panels namely: the input sub-panel, the result sub-panel and the graphical display sub-panel as shown in Figure 3. The input panel is used for obtaining the required data such water head, rate of discharge of water, installed capacity of the plant and running hours of the plant for analyzing the performance parameter and overall efficiency. The GUI employs a block calls an M-file that makes the required calculations and shows graphically the overall efficiencies of reviewed period in the result panel and display panel respectively. The calculated capacity factor and overall efficiency correspond to the GUI graphical display.

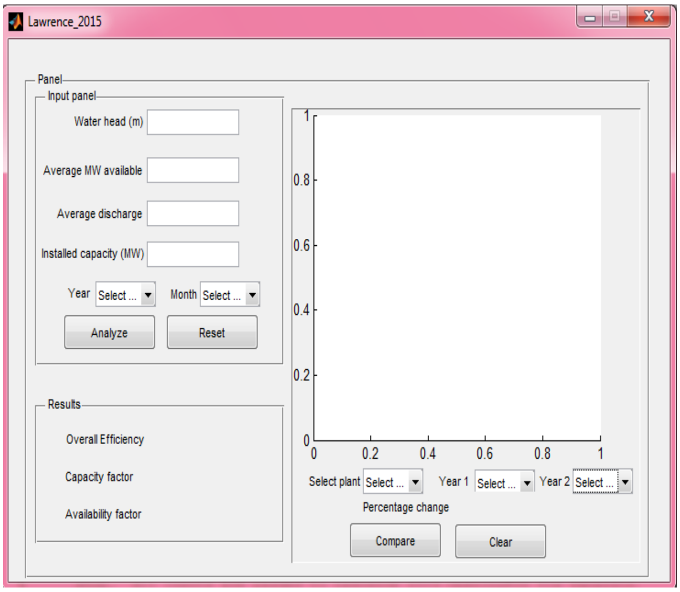

Figure 3. Graphical User Interface Model for Performance Parameters using Matlab

III. RESULTS AND DISCUSSION

Table 1 shows the total installed capacity, average power generated and availability factor of Shiroro hydropower plant for the period of 2004 to 2014.

TABLE I. AVAILABLE FACTOR OF SHIRORO HYDROPOWER PLANT (2004-2014)

YEAR	INSTALLED CAPACITY (MW)	AVERAGE MW AVAILABLE	AVAILABLE FACTOR
2004	600	490.12	0.817
2005	600	480.42	0.801
2006	600	529.9	0.883
2007	600	524.8	0.875
2008	600	488.8	0.815
2009	600	404.6	0.674
2010	600	390.2	0.65
2011	600	392.8	0.655
2012	600	497.5	0.829
2013	600	462.2	0.77
2014	600	300.5	0.501
AVERAGE	600	451.08	0.752

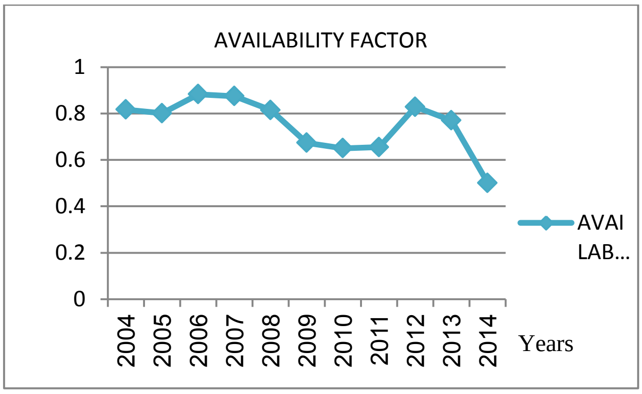

Figure 4. Curve of Annual Availability Factor of Shiroro Hydro-power Plant (2004-2014)

The power plant availability and the causes of unavailability constitute essential performance indicators for assessing services rendered by the generating plant [3]. Therefore, from the data obtained in Table I for the review period (2004-2014), the availability factor ranges from 0.501 to 0.875. Figure 4 shows availability factor of 0.801for 2005 which is slightly lower than 2004 because of the forced outage on generator 411G2 from November to December 2005. The availability factors in 2006 (0.883) and 2007 (0.875) is acceptable for international practice of 0.85, while the availability factor was far below acceptable value for year 2009 (0.675). The MW availability in year 2008 dropped by 7.36% as compared with 2007. This occurs as a result of corrective measures put in place to build up the lake, thereby shutting down the entire power station for some non-consecutive days. In the same way, the overall Shiroro MW availability throughout 2009 dropped by 20.81% when compared with 2008, which occur as a result of the unavailability of two generating units for some months in the later part of the year. The power station experiences the lowest MW availability factor (0.501) in 2014 dropped by 53.7% as compared with 2013 and 76.2% as compared with 2006. It can be deduced from the availability factors reviewed that some generating units were utilized for less than their normal hours of utilization all-round the year and this is due to inadequate routine maintenance and equipment fault development.

TABLE II. SHOWS THE ANNUAL CAPACITY FACTOR OF THE PLANT, THE TOTAL PLANT CAPACITY AND THE ANNUAL ENERGY GENERATED IN THE POWER PLANT BETWEEN THE PERIODS OF 2004 TO 2014.

YEAR	ENERGY GENERATED (MWH)	TOTAL PLANT CAPACITY (MWH)	CAPACITY FACTOR (%)
2004	2425575	5256000	0.462
2005	2432640	5256000	0.463
2006	1236090	5256000	0.235
2007	2230761	5256000	0.424
2008	1941344	5256000	0.369
2009	2282117	5256000	0.434
2010	2421116	5256000	0.461
2011	2373993	5256000	0.452
2012	2664630	5256000	0.507
2013	2485005	5256000	0.473
2014	2444040	5256000	0.465
AVERAGE	2267028	5256000	0.431

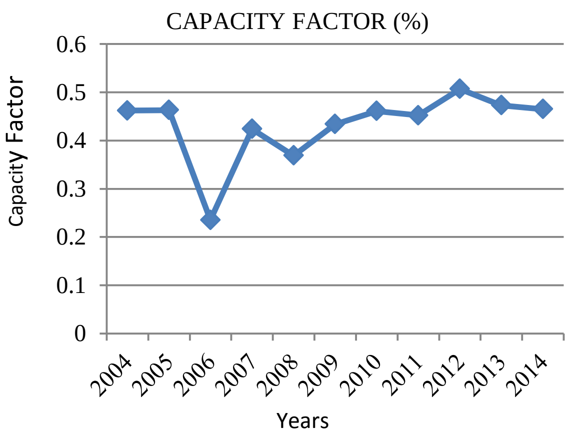

Figure 5. Curve of the Annual Capacity Factor of the Plant (2004-2014)

The plant capacity factor for reviewed period (2004-2014) is presented in Fig. 5. The average capacity factor of the plant is 43.1% with a minimum value of 23.5% in 2006 and a maximum value of 50.7% in 2012 as against standard practice of between 50% and 80%. Thus, the capacity factor determines the characteristic behavior of the generating station. High capacity factor is desirable for a viable economic operation of the plant. The low capacity factor (23.5%) of the plant shows that the average energy generation is low in 2006. This is due to forced outage on one of the generating unit in the later part of year 2006. Generally, low capacity factor signifies excessive plant failure which reveals that the capacity of the generating plant remains unutilized for major part of the year, so the cost would be high [1]. Therefore, high capacity factor is desirable for a viable economic operation of the plant. If scheduled routine maintenance of the plant and the average head water elevation are significantly improved, the frequency of failure and availability of the plant will reduce, high capacity factor will be achieved. Table III shows the average head water elevation, the hydrological summary of Shiroro lakes and the overall efficiency of Shiroro hydropower plant.

TABLE III. THE HYDROLOGICAL SUMMARY, AVERAGE MW AVAILABLE AND OVERALL EFFICIENCY OF THE SHIRORO HYDROPOWER PLANT

YEAR	AVERAGE TOTAL DISCHARGE(CUB. M/SEC)	Effective Head (m)	AVERAGE MW AVAILABLE	OVERALL EFFICIENCY (%)
2004	315	369.65	490.12	42.9
2005	163.65	372.32	529.9	80.4
2006	305.63	375.58	480.42	47
2007	289.06	373.45	524.8	50
2008	248.22	369.05	488.8	54.4
2009	294.67	378.27	404.6	37
2010	309.46	374.88	390.2	34.3
2011	313	371.76	392.8	34.4
2012	339.35	370.92	497.5	40.3
2013	320.37	371.64	462.2	39.6
2014	304.98	370.45	300.5	27.1
AVE	291.22	372.54	451.08	44.31

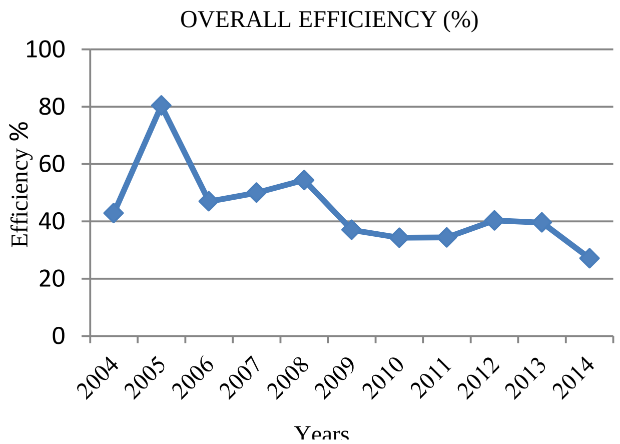

Figure 6. Curve of the Overall Efficiency of the Plant (2004-2014).

Table III presents the energy assessment result of some performance parameters of the Shiroro power plant. The table shows the values of plant overall efficiency. Figure 6 is the plot of the overall plant efficiency for the reviewed period. Figure 6 shows the maximum overall plant efficiency of 80.4% in the year 2005 as compared to the least overall plant efficiency of 27.1% in 2014.

The overall plant efficiency of Shiroro power plant is suitably measured by the proportion of the rate flow of discharge water and the effective head of water which is converted into useful mechanical work. The fluctuations in the annual overall efficiency were as a result of shift in climatic conditions which cause an earlier arrival of peak of the flood, making it impossible to fill the Shiroro lakes. The efficiency in 20014 indicates that 27.1% of the potential energy in water is converted to electricity and 71.9% of the energy is lost. The maximum loss in energy is the combined effect of the low effective water head and low rate flow of discharge water from the lake. The parameter which promptly reflects the available hydropower is the water flow discharge rate, which is inversely proportional to the efficiency. Hence the lower the rate flow of discharge water the better for the operational performance of the generators. Obviously, the rate flow of discharge water and the effective water head affect the plant operation because of unpredictable climatic condition, water spillage due to flood, inadequate maintenance and inefficient operation practices. The figure 6 shows the maximum value for the average generated MW as 529.9MW (88.3%) in year 2005 where the plant has the highest overall efficiency and the least generated MW as 300.5MW (50%) in 2014 where the lowest overall efficiency was experience. It was observed that the higher the generated MW, the more efficient the plant becomes.

The Figures 7, 8 & 9 show the results obtained from the developed graphical user interface for computation of the overall efficiency and performance parameter indices such as capacity factor and availability factor of the plant for the reviewed period.

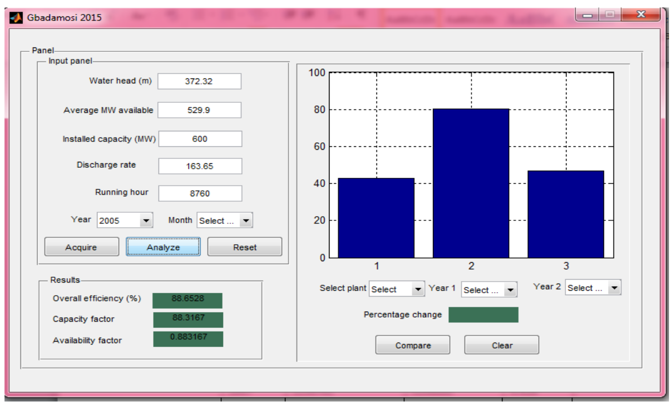

Figure 7. GUI Model Comparing the Plant Overall Efficiencies of 2004, 2005 & 2006

Figure 7 presents both the computed results and graphical chart obtained from the GUI model comparing the overall efficiencies between year 2004, 2005 and 2006. From the chart, the plant has the highest efficiency in year 2005 with a value of 80.4%, followed by 47% for 2006 and 42.9% for year 2004.

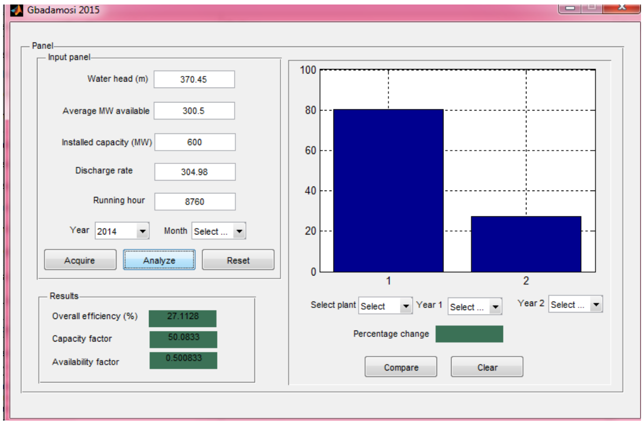

Figure 8. GUI Model Comparing the Highest & Lowest Plant Overall Efficiencies

Figure 8 shows the computed results and the graphical charts comparing the plant highest and lowest overall efficiencies. From the obtained result, in the 2005 the plant experiences the highest efficiency of 80.4% and in 2014 the plant experiences efficiency of 27.1%.

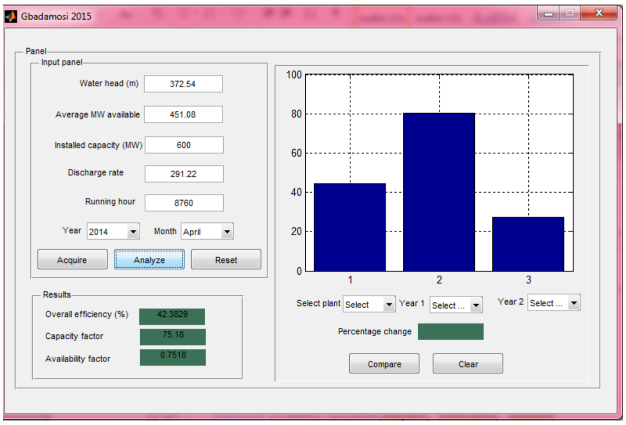

Figure 9. GUI Model Comparing the Average, Highest & Lowest Plant Overall Efficiencies

Figure 9 presents the graphical charts comparing the plant average overall efficiency, the highest efficiency of the plant and plant lowest efficiency.

IV. Conclusion and Recommendation

In this study, performance evaluation has been carried out on Shiroro hydropower plant with emphasis on the operational parameters such as availability factor, capacity factor and overall efficiency of the plant. The calculated availability factor of the plant for the reviewed period ranges from 0.501 to 0.883 with an average availability factor of 0.752. The average capacity factor was 0.431 with minimum value of 0.235 in 2006 and maximum value of 0.463 in 2005 as against the international standard of 50-80%.

The study reveals that 88.3% of the installed capacity was available in 2005 and 50.1% of the installed capacity was available in 2014, signifying 21.7% shortfall of energy generated in 2005 and 49.9% shortfall of energy generated in 2014 as against the standard values of 5-10%. This implies that the plant is unutilized below the rated capacity. The overall efficiencies for the reviewed period varied from 27.1% to 80.4%, with an average value of 44.3%.

This paper has developed an effective method of evaluating the performance of hydropower plants. It is therefore suggested that the Nigeria government and other part of the world adopt this studies for performance evaluation of hydropower plant by determining the parameter indices and overall efficiency for hydropower plant. This will have a very positive effect on the state of Nigeria's economy which has been declining over the years.

Furthermore, the analysis and the GUI develops in the research covers only Shiroro plant (hydropower station), it is therefore recommended that future research work in the line of this project can look into other generating stations (thermal station) in Nigeria. Also other performance parameters could be inoculated into the future works to enhance the overall performance of the GUI.

REFERENCES

[1] [1] G.A. Adegboyega and J.O. Famoriji **"**Performance Analysis of Central Gas Turbine Power Station, Edjeba, Delta State, Nigeria," International Journal of Science and Research (IJSR), India Online ISSN: 2319-7064, Volume 2 Issue 3, March 2013.

[2] [2] Y.A. Adeniran. and M.B. Jenyo "Availability Analysis of Shiroro Hydro-electric Power Station," Proceedings of 1999 quarterly lectures of the National Institute of Industrial Engineering, 1999.

[3] [3] Eke M. N "Long Term Energy Performance Analysis of Egbin Power Plant, Nigeria," Nigeria Journal of Technology (NIJOTECH) by Faculty of Engineering, University of Nigeria, Nsukka, ISSN: 1115-8443, 2014.

[4] [4] S.L. Gbadamosi and A.O. Melodi, "Harmonic Distortion from Induction Furnace Loads in a Steel Production Plant," International Institute for Science, Technology and Education, Vol. 3 (10) 2013, U.S.A, pp 8-16, Dec, 2013.

[5] [5] H. Gujba, Y. Mulugetta, and A. Azapagic "Environmental and economic appraisal of power generation capacity expansion plan in Nigeria". Energy Policy 38:5636–52, 2010.

[6] [6] O. Obodeh and F.O. Isaac "Performance Analysis for Sapele Thermal Power Station: Case Study of Nigeria," J. Emerg. Trends Eng. Appl.Sci., 2(1): 166 – 171, 2011.

[7] [7] Observ'ER and Foundation Energies "Worldwide Electricity Production from Renewable Energy Sources'" 2010.

[8] [8] S.O. Oyedepo, R.O. Fagbenle, S.S. Adefila and S.A. Adavbiele "Performance evaluation and economic analysis of a gas turbine power plant in Nigeria," Energy Conversion and Management 79 ,431–440, 2014.

[9] [9] Transmission Company of Nigeria Plc "Opportunities for Investment in Power," Published by Transmission Company of Nigeria Plc, 2009.

[10] [10] Zarma I. H "Hydro Power Resources in Nigeria," 2nd Hydro power for today conference international centre on small hydro power (IC-SHP), Hangzhou, china, 2006.

[11] [11] K. Ghedamsi and D. Aouzellag "Improvement of the performances for wind energy conversions systems," Int J Electr Power Energy System;32(6):936–45, 2010.

[12] [12] Alves de Sousa MP, Filho MR, Alves Nunes MV, da Costa Lopes A “Maintenance and operation of a hydroelectric unit of energy in a power system using virtual reality”. Int J Electr Power Energy System, 32(6):599–606, 2010.

[13] [13] Zhang Y, Wang Z, Zhang J, Ma J. “Fault localization in electrical power systems: a pattern recognition approach,” Int J Electr Power Energy System;33(3):791–8,2011.

[14] [14] C.C. Nwobi-Okoye and A.C Igbonugo “Performance evaluation of hydropower generation system using transfer function modeling,” Published by Elesevier, Electrical Power and Energy systems 43, 245-254, 2012.

Gbadamosi Saheed Lekan received his Bachelor of Technology (B.Tech) degree in Electronics and Electrical Engineering from Ladoke Akintola University of Technology, Ogbomoso, Oyo state Nigeria in 2009. He bagged his Master of Engineering (M.Eng) degree in power system and machine engineering in the department of Electronics and Electrical Engineering from Federal University of Technology, Akure in 2014. He is currently a Lecturer in the department of Electronics and Electrical Engineering, Afe Babalola University Ado- Ekiti.