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RE-ACTIVATION OF A SMALL HYDROPOWER (SHP) PLANT: OYAN SHP STATION, NIGERIA

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ABSTRACT

Electricity production in small hydropower (SHP) plants can be increased without the need for the construction of new SHP scheme, but by upgrading and optimizing different aspects of existing plant's operations. An assessment of the electromechanical equipment that suites the existing heads, discharge or flow rates and other electromechanical parameters at the Oyan SHP plant, using Retscreen Clean Energy Project Analysis Software and hydraulic turbine specific speed equation ($N_s = (N\sqrt{P_t})/H^{1.25}$) to evaluate plant performances was carried out in this work. Two cases involving upgrading of the electromechanical equipment to yield 10 and 12 MW of installed capacities respectively were considered, while at the same time maintaining the existing structures such as the weir, powerhouse and penstocks. The two cases were analysed and compared with a reference case (the existing installed capacity generation of 9 MW). Findings in terms of the financial and economic analysis for optimum installation and operation, favoured the 10 MW installation. Energy gain by installing the 10 MW is 33.37% relative to the reference case while the 12 MW is 5% compared with the reference. The simple payback for the 10 and 12 MW capacities is 11 and 13 months respectively. Hence, upgrade and optimization to 10 MW is found to be a more profitable option than the 12 MW capacity.

Keywords: Nigeria, re-activation, repowering, small hydropower plant, oyan dam.

INTRODUCTION

Background

The small and medium water flows represent an important power generation option that presents intrinsic advantages in eliminating the eventual social and environmental effects caused by large hydropower plants. Until 1973 during the worldwide energy crisis, the development of small hydropower schemes (micro, mini and small) was not considered economically viable because economies of scale was found to clearly favour the development of large hydro and thermal power plants (ECN, 2004).

Small hydropower (SHP) has been in existence in Nigeria since 1923, 45 years before the commissioning of the country's first large hydropower (Kainji). Today, SHP technology is still at its infancy in spite of the vast potential and the high energy need in the country; however, the situation is different in developed countries where SHP plants find broad adoption in electricity production and other applications (Ohunakin *et al.*, 2011). Nigeria was divided into river basins in 1976 (through the establishment of River Basins Development Authorities), for purposes such as: irrigation, water supply, navigation, hydroelectric power generations, fisheries and recreational facilities; these river basins are accomplished through the construction of small, medium and large dams to impound surface waters thereby making most of the

river basins to be favoured with good heads and capacity for various SHP utilizations (Ohunakin *et al.*, 2011). Summary of SHP potentials in the River Basins are shown in table 1.

Nowadays, new hydroelectric projects (in particular, large hydro plants) are facing great hindrances of initiation, due to existing environmental laws that resulted from the aggressive impacts of such projects on the environment (impacts such as (i) the commencement or acceleration of erosion process at the reservoir banks, (ii) a change in the water quality of the reservoir by organic decomposition which also favours the emission of greenhouse gases (GHGs), (iii) a reduction of the water oxygen concentration thus destroying most aquatic species and generating harmful compounds to human health (Maldonado *et al.*, 2004). SHP on the other hand does not suffer any of these disadvantages associated with large hydro. However, the high initial cost of constructing new SHP plant may call for the need to re-power and upgrade existing SHP facilities, so as to increase the electrical power output, with negligible or no negative impacts. In ESHA (2005), the prospect of reinstating aged/obsolete SHP plants and upgrading existing/underutilized ones, is estimated at an annual electricity production of approximately 4,500 GWh. Provided plants to be re-powered are already installed for more than 30 years, most of the impending impacts would have been absorbed

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by the boundary and nature would have re-adapted to the power plant environment; the emission of greenhouse gases will be practically null and there will be no need to compulsorily remove the riverside populations. A major task may be to find efficient alternatives (projects) to obtain profitable electrical energy supply in a manner that will meet any future demand, without necessarily having to distort nature through the expansion of power reservoirs (Maldonado *et al.*, 2004). Acceptable projects under this guise, are those directed towards the increase of machine efficiency and reduction of water head losses (i.e. upgrading of the whole yield of transformation). The effect will lead to an increase of the plant capacity and production, under the same discharge conditions. These projects turn the hydro capacity increase to the advantage of the producer through the sale of more energy, and to the environment through growth of renewable energy production without negative impact (SHERPA, 2006). The aim of present work is to find the optimal power output that can be obtained, through the rehabilitation and upgrade of the existing SHP scheme of the Oyan dam, Ogun State, Nigeria.

Brief Description of an SHP

The SHP schemes are categorized into: (i) civil works and (ii) electromechanical equipment as shown in figure 1 (Singal *et al.*, 2010). The civil works consist of intake, penstock (an intake structure or an enclosed pipe that delivers water to hydro turbines), power house building (a facility for the generation of electric power), and tail race channel (part of a hydropower facility that carries water away from a turbine) (Singal *et al.*, 2010; Penstock, 2014; Tailrace, 2014). The electromechanical components are turbines with governing system, generator with excitation system, electrical and mechanical auxiliary, and transformer and switchyard equipment (Singal *et al.*, 2010).

MATERIALS AND METHODS

Methodology

Oyan dam is earth filled on the Oyan river, 15 km North-West of Abeokuta on geographical coordinate 7°15'30"N and 3°15'20"E (Fig. 2). The dam and power plant parameters are shown in table 2. The Oyan hydropower plant was completed in 1982 and commissioned in 1983, but has not been put into operation till date. The power plant has a turbo-generator efficiency of 85%, alternator power factor of 80%, with three turbines of 3 MW each to yield 9 MW of total installed capacity and an annual firm energy production of 63.32 GWh. The possibility to re-activate the plant to increase its energy generation capacity was done using Retscreen International Clean/Renewable Energy Project Analysis Software.

SHP Turbine Selection

The hydraulic turbine plays an important role in an SHP station; the selection, type and specification of other equipment in the SHP station are dependent on the turbine (Singal *et al.*, 2010). Furthermore in Singal *et al.* (2010), turbine selection is governed by head, discharge, capacity, speed, part load efficiency, number of units, and cavitation characteristics. Kaplan hydraulic turbine is selected for the power output of the scheme in this work, because it is directly related to low or medium head of the scheme; the relatively high specific speed of a Kaplan turbine also result in favourable economy of scale (i.e. smaller size of turbine and generator and hence reduction in installation and transportation cost) for SHP plants. The specific speed equation needed to improve the operating conditions of the turbine is expressed as:

$$N_s = (N\sqrt{P_t})/H^{1.25} \quad (1)$$

where N_s is the specific speed, N is the rotational speed of turbine (rev/min), P_t rated power output of the turbine (kW) and H is the rated net head (m). In addition, efficiency is maximum at the rated load as cavitation factor becomes higher, thus improving the plant's performance. Data related to the SHP generation is given in table 3.

ECONOMICS ANALYSIS

Generation Cost

Generation cost at different load factors for different type of turbines and generators is based on annual cost and annual energy generation. Annual cost for generation of electric energy includes operation and maintenance (O&M), insurance cost, depreciation of civil works and equipment, interest on the capital invested and replacement cost (Singal *et al.*, 2008). Annual cost has been taken as 16% of the project cost. With the volatile cost of energy today, efficient use of energy in existing plants is as important as planning energy choices in new facilities. Energy performance and fuel selection for revamps and new plant designs will have a major impact on operating costs, capital costs and operating security (Jacob Consultancy, 2012).

Operating and maintenance cost (O & M)

According to Ohunakin and Akinnawonu (2012), manufacturers in recent years are attempting to lower costs arising from operation and maintenance (O&M) significantly, by developing new turbine designs that require fewer regular service visits and less turbine downtime. The O&M costs constitute a sizable share of the total annual costs of the turbine (Ohunakin and Akinnawonu, 2012). It consists of different cost components including land rent, insurance, regular maintenance, repair, spare parts and consumables, own

electricity consumption, administration etc. Information about actual values of O&M costs was not found and believed to vary depending on the particular location of the project. However, a value of 1.5% of the total project cost was adopted in this work in line with India's electricity sector (1998), since Nigeria and India have similarity of business and project terrain.

Depreciation

Equipment get depreciated over the life of the project. Based on the life of the project (hydropower plant) considered as 35 years, an annual rate of depreciation of 4% was adopted.

Interest

Interest rates between 10 to 12% are being charged by financial institutions for projects that exist within the small hydropower range. An interest rate of 11% has been taken for the analysis.

Benefit-Cost Ratio

The benefit-cost ratio (BCR) has been used to evaluate the economic viability of the project. The BCR is the ratio of the present value of future cash flows (benefits) to the present value of the original and subsequent cash out flows (Singal *et al.*, 2008) it is often used to assess the value of a municipal project in relation to its cost (Sepulveda *et al.*, 1984). Accordingly, benefits-cost ratio is worked out as follows:

$$\text{BCR} = \frac{\text{present value of benefits}}{\text{present value of expenditure}} \quad (2)$$

Present Value of Benefits

In order to get consistent values for both benefit and cost, the present value (PV) criterion has been adopted. Under the procedure, the present value at the time of first expenditure of the future stream of benefits was calculated by fixing the discount rate. The PV of the scheme has been evaluated by using the expression given in Equation 3 in Raghuvanshi (1995):

$$\text{PV} = \sum_{i=1}^n \left[\frac{\text{CF}_i}{(1+d)^i} \right] \quad (3)$$

where **PV** is the present value, **CF** is the cash flow, **n** is the last year of cash flow, **i** is the **ith** year starting with the initial investment and **d** is the discount rate. The life of the plant has been taken as 35 years and it was considered that after 25 years, major replacement of equipment and renovation of works may be required; power may not be generated during renovation of the units and other associated works. Hence, present value of benefits was computed for 25 years of the plant's operation (Singal *et al.*, 2008).

Present Value of Expenditure

Duration of construction is taken as 2 years. In many situations, it is found that such plants were even installed in less than 2 years in recent past projects. The installation cost was divided as 77% in the first year and 23% in the second year (Forouzbakhsh, 2007). Present value of expenditure has been worked out by taking installation cost in 2 years followed by annual cost in the subsequent 25 years in the same way the present value of benefits was computed (Singal *et al.*, 2008).

Discount Rate

Discount rate signifies the time value of money and is the cost of the capital investment. The source of capital is the equity and the loan (debt); equity and loan ratio has been taken in 30:70 proportion based on the guidelines for financing by leading financial institutions (Singal *et al.*, 2008). A discount rate of 15% is adopted in this work.

Inflation

The inflation, based on consumer price index for the years 1995 to 2007 varies from 3.3 to 8% in Nigeria. The average inflation during this period comes out to be around 5%, which has been taken as inflation on benefits from sale of electrical energy and the O&M cost.

Energy generation output

The amount of energy produced by a hydro power plant depends on: (i) the design capacity of the plant compared to the flow and head available in the stream and (ii) the variations in the load (Gupta, 2008). The annual energy output generated for a constant power (assuming some degree of load management) is expressed in Equation (3) as:

$$\text{E (annual)} = \text{P (design)} \times 8760 \text{ kWh} \quad (3)$$

where E (annual) is the annual energy output in kWh, P (design) is the firm power (kW) while the number of hours in a year is given as 8760.

Since it is not possible for load to be constant, the design capacity of the plant (**P (design)**) would probably be greater than the maximum load in order to accommodate the possibility of future load increase. Furthermore, with occasional maintenance activities, shut down of the plant is also inevitable. Hence, the actual annual energy output will be less than that given in Equation (3). This calls for the inclusion of a plant or capacity factor (**PF**) in the expression, thus giving rise to Equation (4) as expressed:

$$\text{E (annual)} = \text{P (design)} \times \text{PF} \times 8760 \text{ kWh} \quad (4)$$

Model Simulation

Due to the time stepping of the Retscreen software (Fig. 3 shows the flowchart), the model developed is based on the following: (i) annual hydrological statistics (ii) annual production (which includes renewable energy delivered

and the excess renewable energy available) of the installed capacities to be considered and (iii) financial parameters like capital investment, annual cost, operating and maintenance (O&M) cost, production (generation) cost, energy savings income etc. Table 4 gives the basic data adopted for the simulation, considering the new capacities of 10 and 12MW.

RESULTS AND DISCUSSION

The output of production simulation is shown in Table 5. It can be observed from the result of the simulation shown in table 5, that the potential annual mean production at Oyan SHP plant ranges from 63.32 to 88.9 GWh for the installed capacities of 9 and 12 MW respectively. The results also showed an increase in power output for the 10 and 12 MW installed capacities. The increase in installed power from 9 to the 10 and 12 MW installed power is 16.67 and 15%, respectively. The 10 MW plant yielded 33.77% more energy production from the 9MW originally installed power than the 12MW. The plant capacity factor (0.92 of 8700 hours at full power) is quite high thus indicating that the installed capacity will be rather oriented towards the production of base load or energy.

Hydrological and load analysis

Oyan River possesses a steady stream flow whose annual inflow from the catchment area to the reservoir as modelled by the Retscreen Software, gave 56 m³/s firm flow, occurring at 90 to 100% time of the river. This is shown in the flow duration curve in figure 4. The expected load duration for the 10 and 12MW installed capacities with an average load factor of 0.6 are as indicated in figures 5 and 6.

Economic estimates of re-powering the SHP plant with the consequent upgrade from the initial installed capacity of 9MW to 10MW (Case 1) and 12MW (Case 2) is depicted in table 6. The unit cost for the energy generated which is N10/kWh as given by the Retscreen simulation, is adopted in the computation of the energy generation cost at full load with a capacity factor of 0.92; this may be quite high to operate continuously for 8700 hours to be able to meet the highest production practices (i.e. the installed capacity is oriented towards the production of base load than peak energy). The percentage increase in generation cost from Case 1 to 2 was found to be 14%; this is fairly high and in favour of Case 1 relative to the respective energy output. Since the given average load factor is 60%, increase or decrease in demand of the grid or load centres will affect the load factor either upwardly or downwardly, leading to a decrease or increase in energy generation cost. Furthermore, a drop in plant factor as well as a fall in the firm flow below the rated, will certainly affect energy output. The energy savings income as simulated by Retscreen model resulted in N12/kWh, thus resulting into 5% energy savings from

Case 1 to 2. This was found to be relatively small and also in favour of Case 1. The cumulative cash flow for 35 years of economic life were generated after subjecting the model to effective income tax, depreciation and discount rate and inflation.

The financial estimates, electromechanical equipment and O&M costs of the new projects (Cases 1 and 2) is shown in table 7. The depreciation rate, interest rate, insurance premiums and spare parts are found to be function of capital investment of the entire hydropower project. The cost implication of electromechanical equipment and the financial feasibility of the project as simulated by Retscreen are shown in tables 8 and 9, while table 10 depicts the results of the specific speed of the Reference case and Cases 1 and 2. The difference observed in the specific speeds is associated with variations in the power output. High specific speed can be obtained in Kaplan turbines because of their low heads and large output. Higher specific speed has been proved to give greater runner speed which gives smaller machine size, but characterized with greater cavitation factor. Furthermore, smaller machine dimensions utilize space while greater rotational speed necessitates heavier mechanical designs due to the accompanying centrifugal force and the associated expensive construction materials.

CONCLUSION

In this research work, the following were concluded:

- An alternative to the development of a cost intensive new hydro plant, is to review old/existing hydropower sites via thorough evaluation of their various heads and discharges that can later be employed to upgrade and optimize their electromechanical equipment for more power output.
- This mode of repowering and reactivation was found to provide additional electrical energy in the average range of 10 to 30% and sometimes more of the total installed capacities, at less than one tenth the cost of a new project, with no negative social and environmental impacts as caused by new hydro power installations.
- The 10 MW (16.67% firm power gain of original installed capacity) installation is recommended for this research work because of its favourable economic, financial and technical feasibility.
- The 12MW (33.33% gain of original installed capacity) is also suitable but may be considered as an option which will become more financially and technically viable than 10MW in future, provided the hydrology of the Oyan river dam approach a firm flow of about 65 m³/s, especially with the ongoing trend of global warming effects.

Table 1. Summary of River Basins Small Scale Hydropower Potential.

River Basins	Discharge (m^3/s)	Available Head (m)	Total Theoretical Power (MW)
Sokoto-Rima	7.6 42.5 (27.0)	3.0 25.0 (14.5)	100.4
Hadeija-Jamaare	5.5 36.8 (23.4)	5.0 25.0 (14.5)	149.0
Chad	2.4 35 (14.6)	4.2 25.6 (12.6)	89.0
Niger	12.6 60 (55.0)	6.0 35.0 (30)	650.0
Upper Benue	8.4 106 (67.2)	5.6 120 (45)	985.0
Lower Benue	9.4 68 (47)	3.9 98 (38)	560.0
Cross River	12 86 (56)	5.2 76 (40)	350.0
Anambra-Imo	13 69 (45)	3.5 20 (12)	120.0
Owena	24 78 (56)	5.6 25 (14)	320.0
Ogun-Osun	24 56 (45)	4.5 28 (15)	187.0
Delta	N/A	N/A	N/A

Source: (ECN, 2004)

Table 2. Parameters related to the dam.

Catchment area	9000 km ²
Reservoir area	40 km ²
Embankment length	1100m
Maximum height	32.00m
Embankment top level	67.70 m
Normal water level	63.00m
Maximum water level	65.50m
Average annual flow volume	1770Mcm
Gross storage volume	270Mcm
Length of service spillway	75m
Number of gates of service spillway	4 x 15m x 7m
Crest of service spillway	56.00m
Capacity of service spillway	34.40m ³ /s
Length of auxillary spillway	400m
Crest of auxillary spillway	63.25m
Capacity of auxillary spillway	19.90m ³ /s
Number of outlets	3
Diameter of each outlet	1.8m
Centre line	43.3m
Capacity at low water level	15m ³ /s
Penstock diameter	3.8m
Centre line	41.05m
Installed capacity	3 x 3MW

Table 3. Hydroelectric Power Generation Data (Reference Case).

Number of turbine/alternator	3
Turbine type	Vertically doubly regulated full Kaplan turbine
Turbo-generator efficiency	75%

Number of turbine/alternator	3
Turbine type	Vertically doubly regulated full Kaplan turbine
Turbine speed	375rpm
Turbine maximum head	25m
Alternator output power	3.750 kVA
Alternator output voltage	11kV
Alternator output current	196.8A
Alternator power factor	0.8
Alternator frequency	50Hertz
Annual firm energy generated	63.3GWh
Manufacturer	Garbe-Lahmeyer, Germany
Year of manufacture and completion of project	1982

Table 4. Basic data adopted for simulation.

Parameters	10 MW	12MW
Normal operating level (m)	63.00	63.00
Maximum operating level (m)	65.50	65.50
Minimum operating level (m)	55.00	55.00
Gross head (m)	25.00	25.00
Penstock elevation (m)	41.05	41.05
Firm flow (m^3/s)	56.00	56.00
Number of turbines	3.00	3.00
Rated turbine discharge (m^3/s)	18.00	18.00
Turbine efficiency (%)	90.40	90.40
Generator efficiency (%)	95.00	95.00
Power/Capacity factor (%)	92.00	92.00

Table 5. Results of Production Simulation.

Installed power	Change (%)	Firm power	Peak power	Firm annual production (GWh)	Change (%)	Peak annual production (GWh)	Change (%)
9 MW (Original)		9.00MW	9.00 MW	63.32		63.32	
10 MW (New)	+16.67	10.50MW	10.50MW	84.70	+33.77	84.70	+33.77
12 MW (New)	+15.00	11.00MW	12.00MW	88.90	+5.00	96.60	+14.1

Table 6. Economic Analysis of Cases 1 and 2.

Parameters	Values	Quantity	Case 1	Case 2	Change (%)
Unit cost for energy generation	N10/kWh		863,399,400	985,320,000	14.0
Annual energy savings/income	N12/kWh		1,015,760,700	1,066,800,000	5.0
Economic life			35 years	35 years	
Total cumulative cashflow		35 years	46,663,815,900 N/year	53,537,424,750 N/year	14.7
Effective income tax rate			35%	35%	
Depreciation rate			30%	30%	
Discount rate			15%	15%	
Inflation			5%	5%	

Table 7. Financial Analysis of Cases 1 and 2.

Parameters	Unit cost/charges	Quantity	Case 1 (10 MW)	Case 2 (12 MW)
Interest rate	11% / year			
Depreciation time	Year		35 years	35 years
Depreciation rate	4%/year			
Capital costs	N/year/new project		2,319,920,100	2,492,938,500
Turbines/generators, controls	N75000/kW		785,931,300	903,152,550
Equipment installation	10% of electromechanical		78,593,100	90,315,300
Transportation	10% of electromechanical		78,593,100	90,315,300
Feasibility study, Development and others			1,376,802,600	1,409,155,350
Total annual costs (O&M)			45,864,150	47,748,300
Insurance premiums	0.4% of capital costs (N)		9,279,750	9,971,700
Transmission line maintenance			5,625,000	5,625,000
Spare parts	0.5% of capital costs		11,599,650	12,464,700
O&M labour	N5,250,000/year	2	10,500,000	10,500,000
Travel and accomodation	N150,000/trip	6	900,000	900,000
General and administrative	10% of unit cost		3,790,500	3,946,200
Contingencies	10% of unit cost		4,169,400	4,340,700

Table 8. Cost implication of electromechanical equipment.

Parameters	Unit	Case 1	Case 2
Turbo-generator, control	N75,000/kW	N785,931,300	N903,152,550
Equipment installation	10% of turbo-generator, controls	N78,458,100	N90,315,300
Transportation	10% of turbo-generator, controls	N78,458,100	N90,315,300
Total		N942,847,500	N1,083,783,150

Table 9. Financial feasibilities.

Parameters	Unit	Case 1	Case 2
Pre-tax IRR and ROI	%	173.2%	187.5%
After tax IRR and ROI	%	159.6%	171.6%
Simple payback	month	11	11
NPV (N)	year	4,842,311,850	5,616,815,700

Exchange rate: \$1=N150, subject to economic review

Table 10. Specific speed of the homologous turbine performance.

Parameters	Reference case	Case 1	Case 2
Specific speed (metric units)	759.0	806.5	862.2
Alternator output power (kVA)	9.80	11.40	13.00

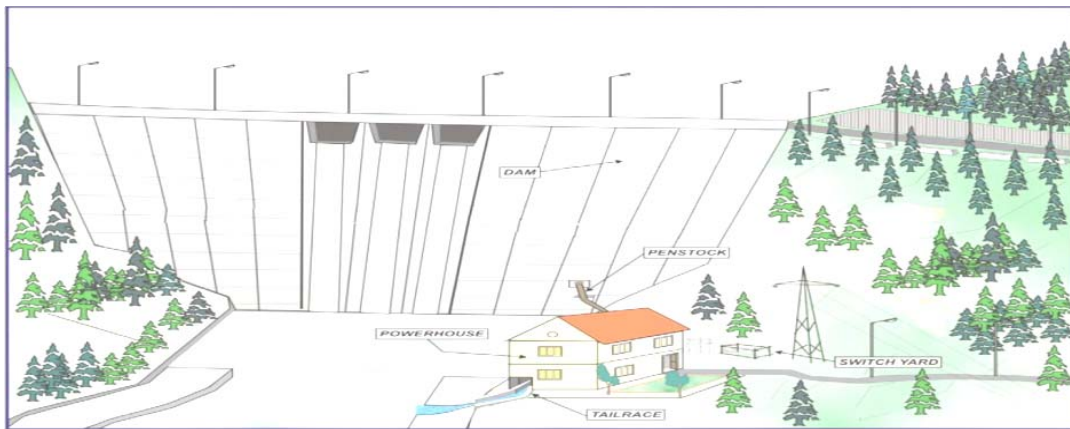


Fig. 1. Schematic of typical SHP scheme (Source: Singal *et al.*, 2010)

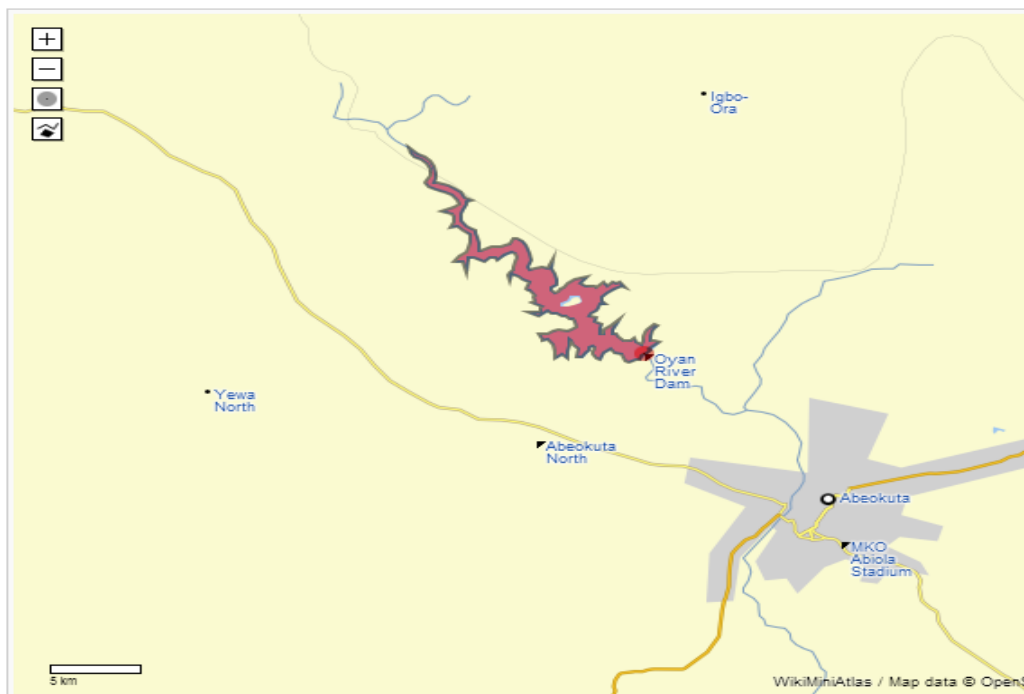


Fig. 2. Geographical view of the Oyan River Dam (Source: http://tools.wmflabs.org/geohack/geohack.php?pagename=Oyan_River_Dam¶ms=7_15_30_N_3_15_20_E_type:landmark)

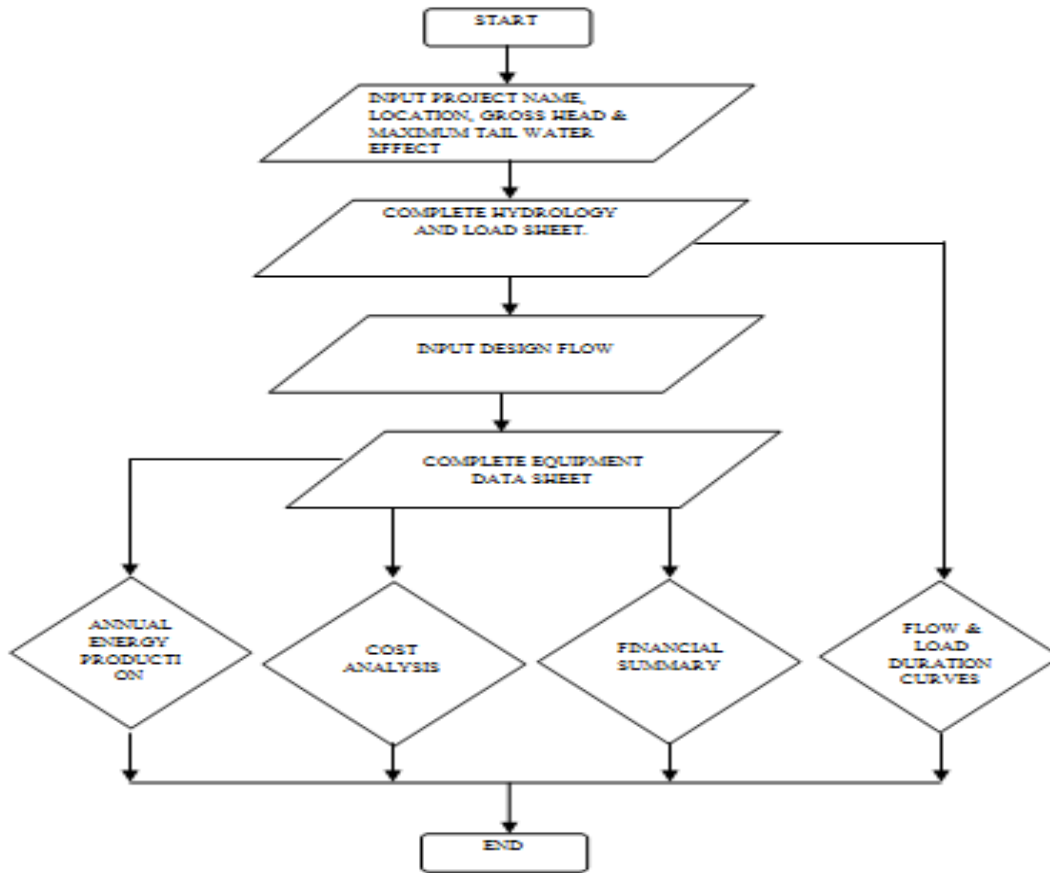


Fig. 3. Retcreen Analysis Flowchart.

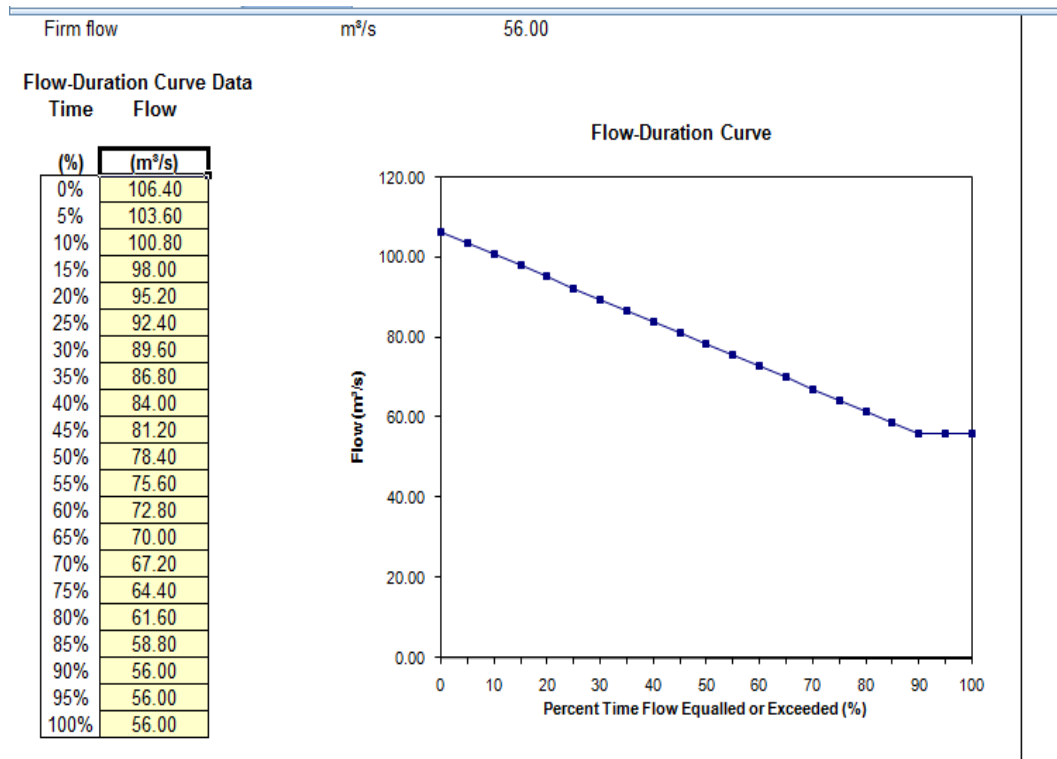


Fig 4. Hydrological Analysis for Oyan Dam.

Load-Duration Curve Data

Time (%)	Load (kW)
0%	10 547
5%	8 932
10%	8 476
15%	8 145
20%	7 850
25%	7 565
30%	7 280
35%	7 031
40%	6 792
45%	6 507
50%	6 221
55%	5 909
60%	5 632
65%	5 402
70%	5 209
75%	5 034
80%	4 786
85%	4 491
90%	4 095
95%	3 635
100%	3 083

Load-Duration Curve

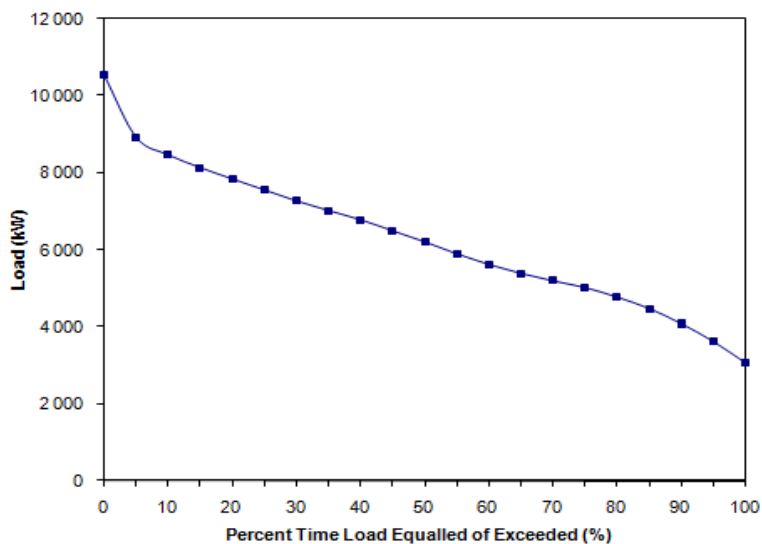


Fig. 5. Load Duration Curve for 10 MW with an Average Load Factor of 60%.

Load-Duration Curve Data

Time (%)	Load (kW)
0%	11 032
5%	9 343
10%	8 866
15%	8 519
20%	8 211
25%	7 913
30%	7 615
35%	7 355
40%	7 104
45%	6 806
50%	6 508
55%	6 180
60%	5 891
65%	5 651
70%	5 449
75%	5 266
80%	5 006
85%	4 698
90%	4 284
95%	3 802
100%	3 225

Load-Duration Curve

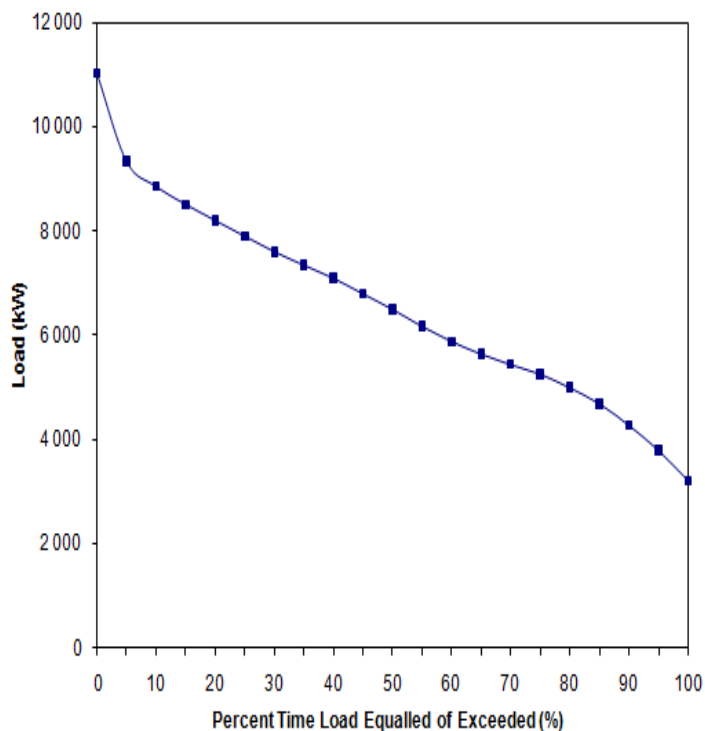


Fig. 6. Load Duration Curve for 12MW with an Average Load Factor of 60%.

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