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Studies on Small Hydro-Power Potentials of Itapaji Dam in Ekiti State, Nigeria.

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***Abstract**: Lack of constant electricity supply with the use of convectional mode are major causes of poverty in many rural areas in Nigeria. An overview of small hydro power potentials in Nigeria to mitigate against the problem of constant electricity supply in rural areas is discussed with surveyed states and expected total generation. A study on the potentials of Itapaji dam in Ekiti state, Nigeria for small hydro power generation is presented. The maximum annual discharge of the dam was calculated as 23.24 cubic metre/sec, with an average nominal flow discharge of 8.33cubic metre/sec, and an average minimal flow of 1.78 cubic metre/sec, while the estimated hydro power potential of the dam is about 1.30MW, being generated with an average annual mean discharge of 8.33m^3/sec with a reservoir capacity balance of 1.922 x 109m^3/year. The components required for small hydro power scheme was discussed for familiarization as well as an assessment of the environmental impact for overall viability. Electricity generation from this hydro scheme can easily be extended to surrounding communities along the present gridline without any major engineering effort, as well as a reduction in green-house gas emission in terms of avoided fossil fuels backed generating schemes.*

***Keywords:** Discharge, flow rate, potential, small hydro, power generation*

I. Introduction

Electrical energy is an integral component of the overall development of any nation. About sixty – five percent (65%) of the Nigerian rural populace do not have access to electricity and the shortages of electric energy production especially in small rural areas hinder the development of rural livelihood[1]. Also, small hydropower scheme is one of the potential renewable energy technologies that is suitable and can be very vital for rural electrification in Nigeria owing to the fact that majority of rural environments are blessed with rivers, streams and run-off waters that have the capacities to generate hydroelectric energy. Furthermore, the average energy consumption patterns for rural communities are small compare to the total energy consumption in Nigeria. The results from the analysis showed that theoretical electrical power ranging from 5.13 kW to 5,000 kW which is enough to cater for average rural community loads is realizable in Nigeria if the identified small hydropower sites are developed [2,3].

Hydropower is a renewable source of power. The exploitable hydropower potential in Nigeria is conservatively estimated to be about 10,000MW (Francis, 2011). Only about 19% is currently been tapped or developed. The hydropower potential in Nigeria accounts for about 29% of the total electrical supply [3,4]. The energy sector distribution in Nigeria is shown in Table 1.

Table 1: Energy Sector Distribution in Nigeria [4].

Petroleum	60%
Natural gas	9%
Hydropower	29%
Coal	2%
Total	100%

There are two general options for supplying electricity to the rural or remote communities. These include the grid connection and the off-grid methods [4,5]. Since the electricity supply from the National grid is insufficient, it is imperative for adoption of the off-grid alternative. Hence, the renewable and sustainable electrical energy plays a prominent and leading role in this respect. Small hydropower scheme is one of the potential renewable energy technologies that is suitable and can be very vital for rural electrification in Nigeria owing to the fact that majority of rural environments are blessed with rivers, streams and run-off waters that have the capacities to generate hydroelectric energy[6,7]. With this, the establishment of small and medium cottage industries, farm produce storages and information communication technology (ICT) schemes are realizable

Small hydrois the development of hydroelectric power on a scale serving a small community or industrial plant. The definition of a small hydro project varies but a generating capacity of up to 10 megawatts (MW) is generally accepted as the upper limit of what can be termed small hydro.Small hydro can be further subdivided into mini hydro, usually defined as less than 1,000 kW, and micro hydro which is less than 100 kW [8]. Micro hydro is usually the application of hydroelectric power sized for smaller communities, single families or small enterprise. Small hydro plants may be connected to conventional electrical distribution networks as a source of low-cost renewable energy. Alternatively, small hydro projects may be built in isolated areas that would be uneconomic to serve from a network, or in areas where there is no national electrical distribution network [3,8]. Since small hydro projects usually have minimal reservoirs and civil construction work, they are seen as having a relatively low environmental impact compared to large hydro. This decreased environmental impact depends strongly on the balance between stream flow and power production. One tool that helps evaluate this issue is the Flow Duration Curve or FDC [8]. The FDC is a Pareto curve of astream's daily flow rate versus frequency. Reductions of diversion help the river's ecosystem, but reduce the hydro system's Return on Investment (ROI). The hydro system designer and site developer usually strike a balance to maintain both the health of the stream and the economics. Plants with reservoir, i.e. small storage and small pumped-storage hydropower plants, can contribute to distributed energy storage and decentralized peak and balancing electricity. Such plants can be built tointegrate at the regional level intermittent renewable energy sources[8,9,10].

Small hydro is often developed using existing dams or through development of new dams whose primary purpose is river and lake water-level control, or irrigation. Occasionally old, abandoned hydro sites may be purchased and re-developed, sometimes salvaging substantial parts of the installation such as penstocks and turbines, or sometimes just re-using the water rights associated with an abandoned site. Either of these cost saving advantages can make the ROI for a small hydro site well worth the use of existing site infrastructure & water rights.The hydropower potentials of small rivers and swift flowing streams in Nigeria has been estimated to be about 736MW of electrical energy. This is a very large quantum of energy, if fully tapped, to propel changes and development rural populace [3,4,7].

The basic principle of hydropower systems is that if water can be piped from a certain level to a lower level, then the resulting water pressure can be used to perform work. If the water pressure is allowed to move a mechanical component, then that movement involves the conversion of water energy into mechanical energy. Hydro turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, a grain mill or some other useful device [9,10]. The system requires a sizeable flow of water and a proper change in elevation, called the effective head, which should be obtained without having to build elaborate and expensive structures. Figure 2 shows the main components of a “run-offriver” micro hydro power scheme.

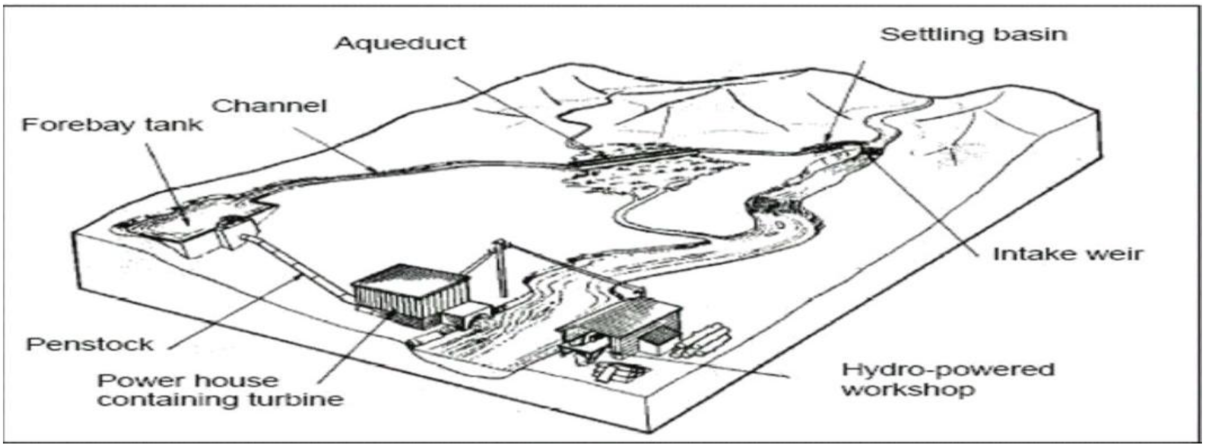


Figure 1: Layout and components of a typical micro hydropower installation [9].

The source of water is a steam or sometimes an irrigation canal. Small amounts of water can also be diverted from larger flows such as rivers. The most important considerations are that the source of water is reliable and not needed by someone else [12].Run of the river schemes require no water storage; the water is instead diverted by the intake weir into small settling basin where the suspended sediment can settle. A grid to prevent the flow of large objects such as logs, which may damage the turbines, usually protects the intake. The diverted water is drawn via a channel into the fore bay tank. The channel is usually a concrete or steel pipe along the side of a valley to maintain its elevation. The fore bay tank holds sufficient water to ensure that the penstock is always fully submerged to prevent suction of air to the turbine. It also acts as water reservoir during lean season. The water flows from the fore bay tank down a closed pipe called the penstock.

The penstock is often made of high density materials and exposes the water to pressure; hence the water comes out of the nozzle at the end of the penstock as a high pressure jet. The power in the jet, called hydropower (a.k.a. hydraulic power), is transmitted to a turbine wheel, which changes it into mechanical power. The turbine wheel has blades or buckets, which cause it to rotate when they are struck by the water jet due to momentum transfer. Hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, a grain mill or some other useful device. The water returns back to the same stream via the tailrace in the powerhouse [12,13].

Table 2: Classification of Hydropower [9]

TYPE	**CAPACITY**
Larger hydro	> 100MW
Medium hydro	10-100MW
Small hydro	1-10MW
Mini hydro	100kW-1MW
Micro hydro	5-100Kw
Pico hydro	<5kW
kW (kilowatt) = 1000watts, MW (megawatt) = 1000000 watts	

1.1 Small Hydropower Overview and Potential in Nigeria

In recent studies, hydropower potential sites are distributed in 12 States and in the river basin. However, SHP potential sites exist in virtually all parts of Nigeria. There are over 278 unexploited sites with total potentials of 734.3 MW. So far about eight (8) small hydropower stations with aggregate capacity of 37.0 MW has been installed in Nigeria by private companies and the government as shown in Table 3. Some around Jos Plateau, where there is 2MW Station at Kwall fall on N'Gell river (river Kaduna) and 8MW station at Kurra fall, which was developed by a private company (NESCO) more than 75 years ago.

Table 3: Existing Small Hydro Schemes in Nigeria [13]

S/N	RIVER	STATE	INSTALLED CAPACITY (MW)
1	Bagel (I) (II)	Plateau	1.0 2.0
2	Kurra	Plateau	8.0
3	Lere(I) (II)	Plateau	4.0 4.0
4	Bakalor (I)	Sokoto	3.0
5	*Tiga	Kano	6.0
6	*Oyan	Ogun	9.0

There is varying information on the potential of small hydropower in Nigeria. According to UNIDO Regional Centre on Small Hydropower, the gross small hydropower potential (for plants up to 10MW) is 720MW, the technically feasible potential is 605 MW and the economically feasible potential is 498.4 MW. A study from 2006 identified 278 yet undeveloped sites for small hydropower production with a total of 734.2MW (with a capacity of up to 30 MW) (UNDP Nigeria, 2012). Table 4 below summarize the identified small hydro power potentials in Nigeria.

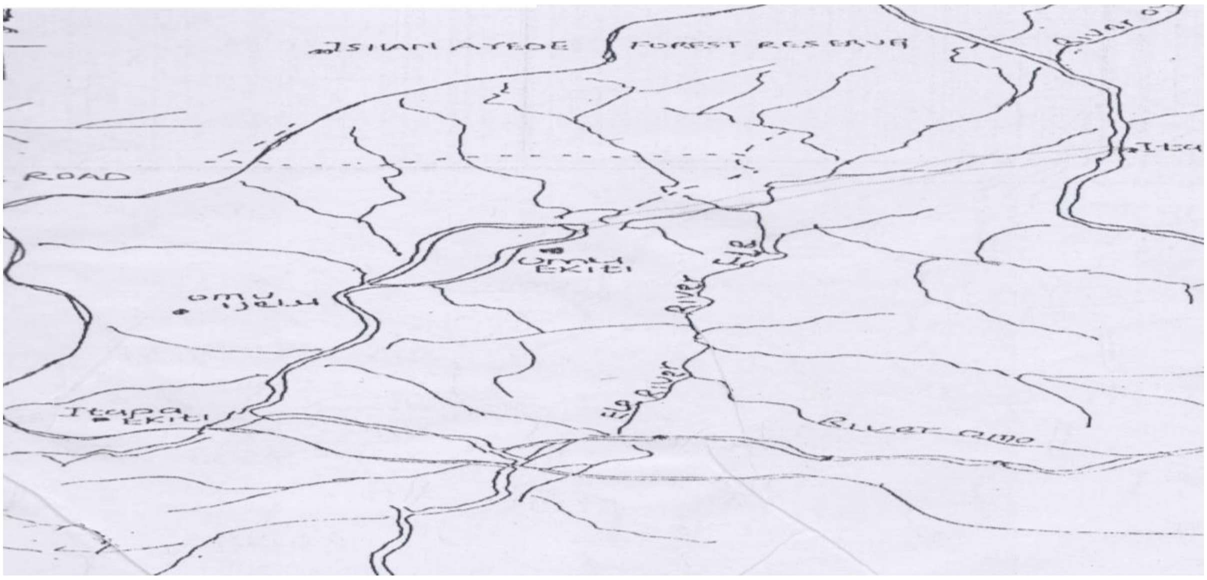
Table 4: Small Hydro Potentials in Surveyed States in Nigeria [12]

S/N	**STATE(PRE 1980)**	**RIVER BASIN**	**SITES**	**TOTAL MW**
1	Sokoto	Sokoto-Rima	22	30.6
2	Katsina	Sokoto-Rima	11	8
3	Niger	Niger	30	117.6
4	Kaduna	Niger	19	59.2
5	Kwara	Niger	12	38.8
6	Kano	Hadejia-Jamaare	28	46.2
7	Borno	Chad	28	20.8
8	Bauchi	Upper Benue	20	46.6
9	Gongol	Upper Benue	38	162.7
10	Plateau	Lower Benue	32	110.4
11	Benue	Lower Benue	19	69.2
12	Rivers	Cross River	18	258.1
TOTAL			277	734.2

1.2 Small Hydropower potential with Itapaji dam development

Ele river in Ekiti State supplies an existing scheme of water supply dam named Itapaji dam which was constructed and commissioned in 1975, with a designed capacity of $5175m^3$/day for the supply of water to 13 towns and villages in 3 local government area. The intake works include rolled earth and concrete dam with a length of 400metre and a height of 24meters, the spillway in concrete with a length of 120metres and an intake sump. The river is located between longitudes 5.25^{o}E to 5.28^{o}E and latitudes 7.55^{o}N to 7.58^{o}N. River Ele, which took its source from the "Undifferentiated Basement Complex" hills around Osin - Ikole, is the major river in this drainage. Sub - basin. It flows northward from source for about 20km to the dam site, 4km northwest of Itapajl. Beyond the dam site, it flows northwestward to join Rivers Omo and Kampe in Kwara State. These two later rivers join the River Niger at a point 5km north-east of Eggan. Rivers Oye and Omo are tributaries of River Ele. While River Omo took its source from the hills around Ikole - Ekiti and flows north westward of Ikole into River Ele, River Oye took its Sources from the hills, 8km north of Itapaji and flows southwardly into River Ele. The area surrounding the river is hilly and about 1500metres above mean sea level. It lies within the northern fringes of the rain forest belt with heavy rainfall pattern year round, and characterized by two major seasons, the rainy season occurring between April and October and dry season between the month of November and March. Total annual rainfall ranges between 1350 – 1400mm while temperature 32^o – 35^o in dry and 21^o-22^o in wet season. River gauging station has existed downstream of the dam since 1982. Another station, upstream of the dam, was recently installed in September, 2003. It is located about 2km from Itapaji on the ltapaji, Itapa Ekiti earth road. The hydrographs derived from the data collected at the gauging station downstream of the dam shows that the dam does not spill any water for a period spanning 4 - 6 months (January - June) annually.

Figure 2: Locational diagram of source of river Ele serving Itapaji dam



II. Materials and Methodology of research

A load survey was conducted in the area surrounding the itapaji dam to determine the energy demand of the surrounding communities.

Table 5: Average discharge of Itapaji dam for a year

MONTHS	DISCHARGE(L/S)
JAN	2970
FEB	3200
MAR	3330
APR	2740
MAY	7350
JUN	8450

MONTHS	DISCHARGE(L/S)
JUL	11480
AUG	10400
SEP	23240
OCT	18680
NOV	6340
DEC	1780

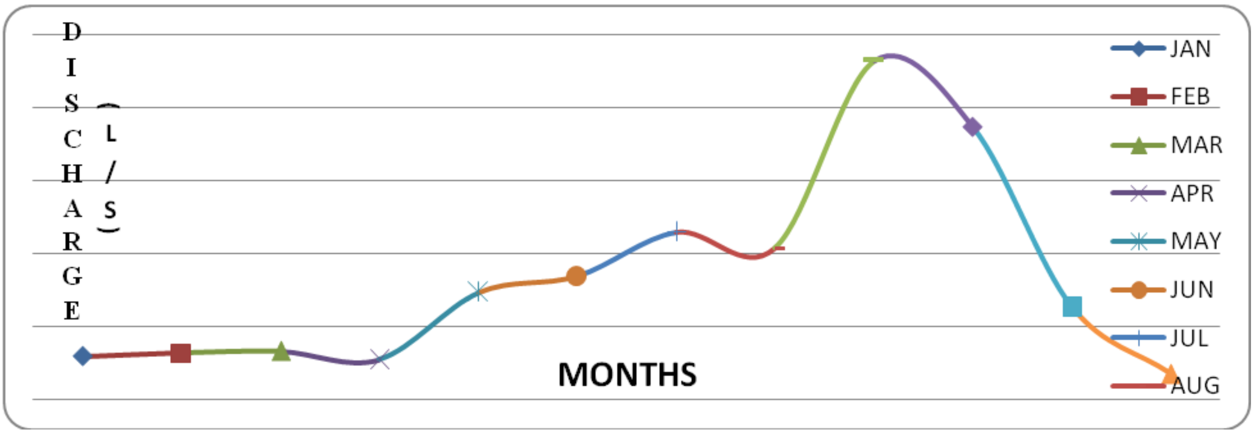


Figure 3: Average Annual Discharge of Itapaji dam.

Table 6: Yearly discharges in m^3/sec

Nos	Year	Maximum	Mean	Minimum
1	2009	3.70	1.34	0.13
2	2010	61.06	13.41	0.13
3	2011	9.51	5.41	0.13
4	2012	15.73	5.97	0.13
5	2013	26.20	15.50	0.13
Average annual Discharge values		23.24	8.33	1.78

Table 7: Yearly discharges in m^3/sec

Nos	Year	Total run-off volume (109m3)
1	2009	0.0235
2	2010	0.1109
3	2011	0.1706
4	2012	0.1386
5	2013	0.2400
Average annual Discharge values		0.1367

III. Results

The amount of power that can be generated from a small hydro-electric power plant is dependent on the net head of the dam, discharge and overall efficiency of the system. The discharge in (m3/s) = width of stream (m) x average stream depth(m) x average velocity in m/s. The average stream depth, the area under consideration can be measured at 5metres intervals and the average stream depth calculated using: Average depth = sum of measured depths/number of readings

And the average velocity is calculated using: Average velocity (m/s) = average distance/ average time taken

Using the Average Discharge Values (in Table 1) and an effective Dam height of 22.5m, the hydropower potentials of Itapaji dam with service from River Ele are as shown below.

The installed capacity and energy output is calculated using standard equations[4]:

$$P = (Q \times \rho \times H \times g \times \eta)/1000 \qquad (2.2)$$

Where:

P = power or installed capacity in kilowatts

Q =discharge rate in cubic meter per second

ρ = density of water in kg per cubic meter
H = effective head in meters
g = acceleration due to gravity and is 9.81 m/s2
η = efficiency of hydro turbine generator in %
And Annual Output Energy (kWh) = P x hr x CF
Where
P = power or installed capacity in kilowatts
hr = Annual continuous generating duration (8760 hours in a year)
CF = Plant Capacity Factor (typically 95% for run-of-the-river type systems).
Hence, a theoretically good SHP site should have a high head and a high flow rate. It implies that a hilly area with rivers that posses high flow should normally yield high power.

From the hydrological year book published by Benin- Owena River Basin Development Authority. The data obtained on Itapaji dam are the average annual maximum, minimum and mean discharge from Tables 5,6,7 and the data used to calculate expected obtainable power:
Average Annual maximum discharge = 23.24 cubic metre/sec
Average Annual Minimum Discharge= 1.78 cubic metre/sec
Annual Mean Discharge = 8.33 cubic metre/sec
Average Annual Total Run- off volume= 0.1367 x $10^9 m^3$
Gross head = 22.5m
Hydraulic loss = 4% of gross head

Maximum design capacity utilization for water supply = 5175m^3/day
Residual Flow= 4.33m^3/sec
A calculated value of the power should be multiplied by a certain value known as the correction factor. Correction factor values of 0.65 and 0.85 are usually used for streams with rocky bases and non-rocky bases respectively. However, for research purposes, an average value of 0.75 is usually used. The penstock, turbine and generator efficiencies are respectively 0.95, 0.90 and 0.85.
Net Head= Gross Head - Hydraulic Loss
Hydraulic Loss= 4/100 × 22.5= 0.90
Net Head= 22.5- 0.90= 21.6metre
At maximum Discharge, Q= 23.24cubic meter/sec
Power in (kW) =Q × H × E × g
Q = 23.24cubic metre/sec, H= 21.6metre
E= 0.95 × 0.90 × 0.85 = 0.73
g = 9.8 metre/ square sec
Therefore, at maximum discharge of 23.24cubic metre/ sec
From equation 1
Power in (kW) = 23.24 × 21.60 × 0.73 × 9.81= 3591.1935kW
Obtainable power = P (kW) × 0.75k(correction factor)
= 3591.1935 ×0.75= 2693.40kW= 2.69MW
At mean discharge, Q = 8.33cubic metre/ sec
Power in (kW) = 8.33 ×21 .6 × 0. 73 × 9.81= 1287.20kW
Obtainable power = 1287.20 × 0.75= 965.40kW
Obtainable power at mean discharge of 8.33cubic metre/sec is 0.97MW
At minimum discharge, Q = 1.78cubic metre/ sec
Power in (kW) = 1.78 × 21.60 × 0.73 × 9.81= 275.20kW
Obtainable power = 275.20 × 0.75= 206.10kW
Obtainable power at minimum discharge at 1.78cubic metre/sec is 206.10Kw
Average Mean (Norminal Flow) Discharge is = 8.33m^3/sec.
The Total Yearly Run-Off volume of the river at this discharge value is 8.33m^3/sec × 60 sec × 60 min × 24hrs × 365 days = 0.2627 × $10^9 m^3$

Average Total Yearly Run-Off Volume of the river downstream of dam = 0.1367 × 109m^3
Therefore, balance in the Reservoir is the difference of (i) and (ii) i.e 0.126 × 109m^3
Maximum designed capacity utilization for water supply to 13 towns and villages = 5,175m^3/day.

For one year, volume of water required is 5,175m^3/day × 365 = 1,888,875m^3/ year = 1.889 × 106m^3 = 0.0019 × 109m^3. Balance in the reservoir, after abstraction of water for potable water supply is the difference between (iii) and (iv), i.e. 0.1241 ×109m^3/ year (= 334,985.97m^3/ day)
The above value is the volume of water that will be available for hydropower development in this scheme since there are no plans for any irrigation scheme within the Ele River sub-basin. Non-availability of large contiguous land space due to the ruggedness of the terrain is a disadvantage for any irrigation scheme to be profitable. A 1.29Mw SHP scheme is proposed. As mentioned earlier, the scheme will consist of the forebay from which the flow of water will be regulated into and through the penstock to the powerhouse. The powerhouse will house the Electro – mechanical equipment for the generation of electricity. Electricity generated will be transmitted to the load centre(s) existing NEPA facilities.

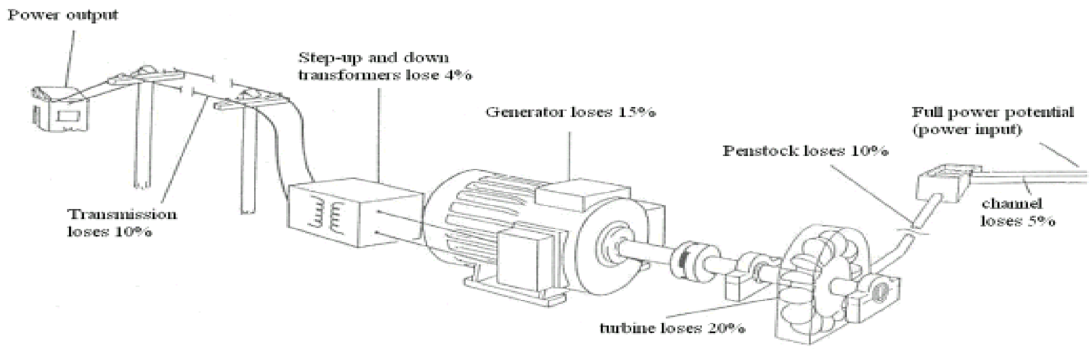


Figure 4: Typical system efficiency of small-hydro power generation [15]

IV. Small Hydro-power development Components

4.1 Penstocks

Penstocks are conduit which carries water to the turbine. They are generally made of reinforced concrete or steal. The friction in the penstocks (as they carry water to the turbine) causes power loss. Therefore, for a low head of 21.6 m, it is very important to use large penstocks to reduce losses. Also certain devises such as automatic butterfly valve, air valve and storage tank should be provided for the protection of penstocks. Automatic butterfly valve shuts off water flow through the penstocks promptly if it ruptures. Air valve maintains the air pressure inside the penstocks equal to the outside atmospheric pressure. When water runs out of penstocks faster than it enters, a vacuum is created which may cause the penstocks to collapse. Under such conditions, air valves open and admit air in the penstock to maintain the inside air pressure to be equal to the atmospheric pressure.
A surge tank is a small reservoir or tank (open at the top) in which water level rises or falls to reduce the pressure swing in the conduit. It is located near the beginning of the conduit. When the turbine is running at a steady load, there is no surge in the flow of water through the conduit (the quantity of water flowing in the conduit is just sufficient to meet the turbine requirement). However, when the load on the turbine decreases, the governor closes the gate of the turbine, reducing water supplied to the turbine. The excess water at the lower end of the conduit rushes back to the surge back and increases its water level. Thus, the conduit is prevented from bursting. On the other hand, when the load on the turbine increases additional water is drawn from the surge tank to meet the increased load requirement. Hence, a surge tank overcomes the abnormal pressure in the conduit when the load on the turbine falls and acts as a reservoir during increases of load on the turbine.

4.2 Trash Rack and Head Gate

Track rack should be installed at the head of penstocks to protect the generator and water passage from debris. Normally, trash racks are set on an incline to increase area thereby increasing the water velocity.
A head gate or valve should be installed below the trash rack to control flow and allow the turbine to be inspected and repaired.

4.3 Turbine and Generator

Generator coupled to water turbines to convert mechanical energy to electrical energy. Three phase alternating current generator should be used. For head between the range of 3 to 40m, with a flow between the range of 3 to 20m^3/s and power output between the range of 50 to 5000KW, a Kaplan turbine is recommended for Itapaji dam for maximum efficiency.

V. Assessment of environmental impact as a prerequisite to overall viability.

The need for Environmental impact Assessment (EIA) of development projects has grown in response to increasing public awareness of the harmful effects on the environment human well-being and economic development caused by projects that were implemented with minimum concern for long term environmental consequences. Pressure development to alleviate the socio - economic inadequacies of people, especially in the developing nation, often tend to obscure the need forEnvironmental Impact Assessment.Along with consideration for technical and economic merits and the responsiveness of any proposed development to an urgent extent or anticipated social and economic needs, its environmental sustainability and potential impacts should also be assessed at the project planning stage. This is because the cost of retroactive restoration of tile integrity of a degraded environment is much greater than that of preventing the degradation.Today, the global concern for the environment has led to a situation in which the EIA of development activities has been made a statutory requirement by several policy, legislative amid funding bodies including the World Bank, Ministries of Environment, Works and Housing, etc.The construction and operation of the proposed Hydro Power scheme using the already existing Itapaji Dam facilities represent a major development and thus have the potential for significant environmental consequences for bedrock, vegetation, wild life and especially the human populations in the project area.

The scenarios associated with the project development, for instance, involve the use of a variety of equipment and machinery in the construction and operations of the facilities. Each of these will potentially impact different components of the environment. A few of the environmentally significant project activities include civil works such; as site preparations, clearing and grubbing to remove vegetation (trees and shrubs), cut and earth fill, excavation, compaction, actual construction and operational activities for power generation.The magnitude and importance of the potential impacts ofa project depends on the type of operation, method of execution and sensitivity of the ambient environment. Information on the potential impacts of the project and the sensitivity of the environment is necessary to identify potential environmental problems early in the project to enhance the design of appropriate environmental improvements, to guide

VI. Conclusion

Locating a good site for installation of a new plant is one of the main obstacles for small hydroelectric power generation. The site where the small hydropower is installed must have sufficient head and enough water flow rate to produce sufficient amount of energy and the site must also be close to the location where the energy is going to be utilized. Flow rate is very essential for hydropower generation since the head at a proposed site is practically constant while the available flow is highly variable. Having known the water discharge, annual energy output of the proposed site under consideration can be estimated which will serve as an input energy to run hydro turbine of the SHP scheme to generate electricity. Since the entire quantity available at a site is utilized in power production, the study of water demand for hydropower amount to collection of stream flow data and their analysis. Therefore, stream flow is an important parameter in determining the maximum power derivable from any flowing river

VII. Recommendations

Sales to the grid when power is in excess could provide for better load management and more potential for reliable cash flow. This is being recommended because if there are micro hydropower systems that can supply to the grid, they should be allowed to be economically viable to sustain operation and maintenance. Furthermore, the grid consumers receive both a capital subsidy as well as an operational subsidy as the electricity tariffs are well below the actual cost of supply. These will have to be kept in mind when developing a subsidy scheme for the off-grid consumers to ensure some level of equity between the on-grid consumers and the off-grid consumers.

Exploring the potential of SHP scheme as eco-friendly source of energy serves the least cost option for provision of electricity to underdeveloped rural areas compared to the extension of grid. They are affordable if necessary subsidy is provided. Furthermore, the value added benefits of the scheme is as follow: Availability of local labour and materials; thereby, increasing the income of the poor. They help to check rural/urban immigration. They are flexible and can usefully be integrated into almost any kind of development program such as rural development, poverty alleviation program and environment protection program

An awareness and educational program complimented with refresher training has to be provided in order to continuously maintain and upgrade the skills of the stakeholders.

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