A Small Hydo Power Plant at Tsanga River (Nyanga) to Feed into a Grid

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Abstract - **A small hydro power station was designed at Tsanga River in Nyanga. Nyanga is one of rural communities in Zimbabwe that heavily depends on wood for fuel. This development intends to curb the cutting down of trees as more electricity will be available from the grid. Site data was mainly collected from responsible authorities and was used in the designing of Civil works and Electro-mechanical equipment (turbine and generator). The total cost of the project is US$1 339 000. The Net Present Value of the project after a 15year period would be US$1 694 583. This project is within the financial viability limit of the Zimbabwe Electricity Regulatory Authority that is to implement it therefore is a success.**

The implementation of this project will assist the environment greatly by saving the trees and supplying people with a more environmentally friendly source of power.

I. INTRODUCTION

In rural Zimbabwe, 80-90 per cent of people are heavily dependent on wood fuel. Rural populations light their homes with kerosene and carry out essential food processing tasks such as milling grain, using diesel powered systems. Access to electricity is estimated nationally at nearly 40 per cent, but access to electricity in the rural areas of the country is about 19 per cent, due to very high costs of extending the national electricity grids. [11]

As in most parts of the world, rural areas not connected to grid electricity that have perennial rivers have an option of micro and small hydro power plants for providing electricity. [3] This has the advantage of being a renewable source of energy that is available throughout the year and deforestation is reduced. The once beautiful scenery of Nyanga is slowly being turned to a desolate land by the rampant cutting down of trees therefore development of such a scheme could potentially reduce pressure on the environment as deforestation is reduced, thus improving the lives of the nearby residents. Table 1 provides examples of implemented micro hydropower schemes in Zimbabwe.

Table1: Micro hydropower schemes in Zimbabwe(2013 © UNIDO and ICSHP)

NAME	CAPACITY(kW)	HEAD (m)	FLOW (l/sec)
Chipendeke	25	41.00	100
Dazi	20	121.00	30
Nyafaru	20	25.18	150

Table 2 gives an overview of small hydropower projects prioritized by the Zimbabwe Government for future development.

Table 2:Priority small hydropower projects in Zimbabwe Ministry of Energy and Power Development

DISTRICT	SITE	TYPE OF PLANT	CAPACITY(MW)
Mwenezi	Manyuchi	Dam	1.4
Masvingo	Mutirikwi	Dam	5.0
Mutasa	Osborne	Dam	3.0
Bikita	Siya	Dam	0.9
Mutasa	Duru	Run-of-river	2.3
Nyanga	Tsanga	Run-of-river	3.3

It is against this background that a small hydro power plant was designed at Tsanga River. The electricity produced will be fed into the national grid.

SITE BACKGROUND

There are no two micro-hydro sites that are identical, however, all of them require specific common components of different dimensions to convey the stream water to the power generation units and back into the stream. The Tsanga Hydropower plant is a run-off river of Gairezi river. It is a scheme with a gross head of 117m and a total plant capacity of 564kW at the step-up transformer. The average annual production is estimated to be about 8.8GWh. The project utilises a head over about 1km of the Tsanga River, approximately 5.5km upstream of the conjunction with Gairezi River in Nyanga

Block, Nyanga RDC, with intake weir located about 500m upstream top of main waterfall at elevation 1281 and Head water level at 1285.
The Tsanga Power Station will be directly connected to the 11kV line extended about 2.5km from where the line is ending now, at a warehouse at Gairezi Ranch, close to the power plant access road. Alternatively, it is to be connected to a 33kV line which will also be extended with about 15km.

HYDROPOWER SCHEME

The objective of a hydropower scheme is to convert the potential energy of a mass of water flowing in a stream with a certain fall to the turbine (head), into electric energy at the lower end of the scheme, where a powerhouse is located. [3] Schemes may be classified according to the head:-

- High head; 100m and above
- Medium head; 30-100m
- Low head; 2-30m [5]

These values are used when categorising sites and are therefore not fixed.
Schemes can also be defined as:-

- Run-off-river schemes
- Dammed schemes
- Schemes integrated on a canal or in a water supply pipe

In hydropower generation two main factors are required: Q = Flow rate [m^3/s] and h = Gross head [m]. Figure 1 shows major components of a small hydropower plant highlighting the head. [2]

The power output is proportional to the head and the flow. To determine the actual power output from the Micro Hydropower System the following equation that includes the system efficiency factor, η_{total} is used: [1]

$$P_{actual} = \rho_{water} \times Q \times g \times h_{gross} \times \eta_{total}$$

where P_{actual} is the actual power produced (kW)
ρ_{water} is the density of water (kg/m^3)
Q is the flow in the penstock pipe (m^3/s)
g is the acceleration due to gravity ($9.81 m/s^2$)
h_{gross} is the total vertical drop from intake to turbine (m)

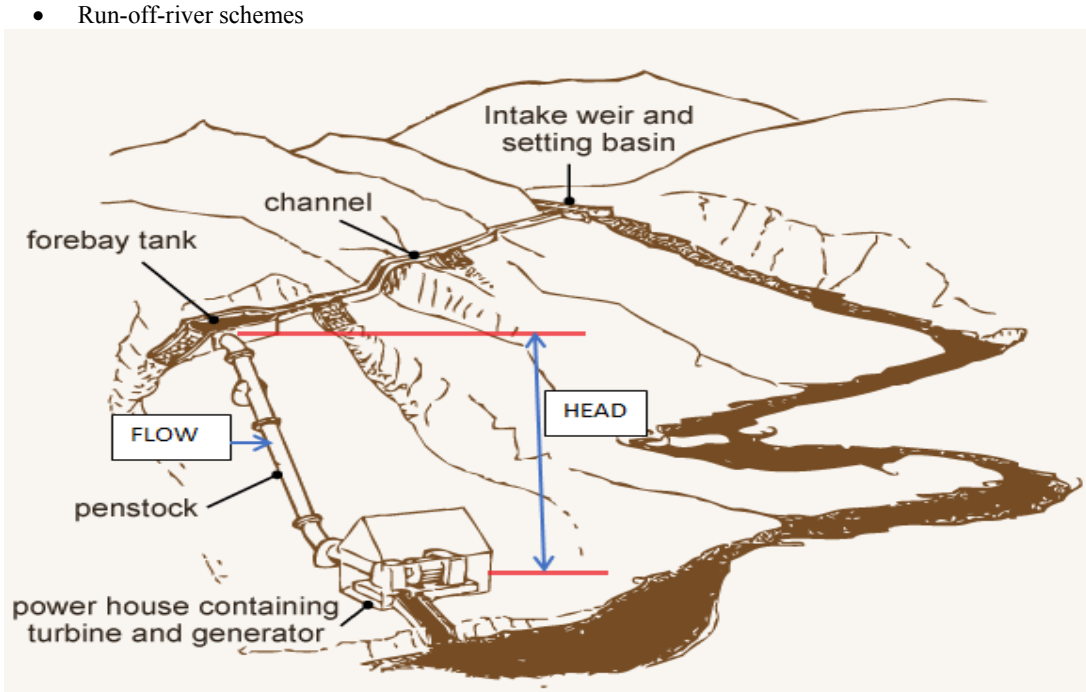


Figure 1: Major components of a small hydropower plant

$$\eta_{total} = \eta_{canal} \times \eta_{penstock} \times \eta_{manifold} \times \eta_{turbine} \times \eta_{drive} \times \eta_{generator}$$

The rest of the paper is structured thus: The next section presents the research methodology. Section III provides the focus areas and the critical success factors for ECM. Section IV proposes an improved ECM framework based on the identified critical success factors. Conclusions and further research directions are presented in Section V.

II. RESEARCH METHODOLOGY

DATA COLLECTION

The following data was collected Zimbabwe National Water Authority (ZINWA), Ministry of Energy and Rural Electrification Agency (REA):

a) Monthly Runoff values for Tsanga River (Gauge Station F6)

These values are a monthly average, covering a period of 55years from 1957 to 2012. They were collected from ZINWA.

b) Daily mean discharges in cubic metres / second for Tsanga River (Gauge Station F6)

This was also collected from ZINWA

c) Site literature review

This was provided by Rural Electrification Agency and also the Ministry of Energy.

DATA ANALYSIS

Data collected is multiplied by a factor of 4.65 since it corresponds to a catchment area of about 17km^2, whilst the proposed site has a catchment area of about 79km^2.

a) Hydrograph

From the daily mean discharge values a hydrograph is produced as follows:

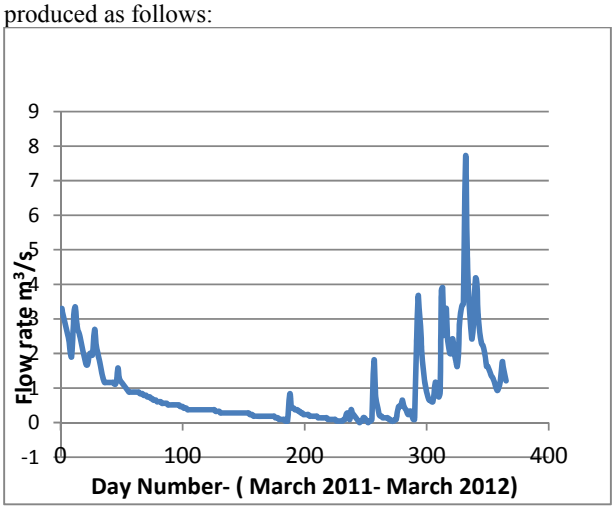


Figure 1: hydrograph

b) Flow duration curve

The flow duration curve is shown in Figure 3:

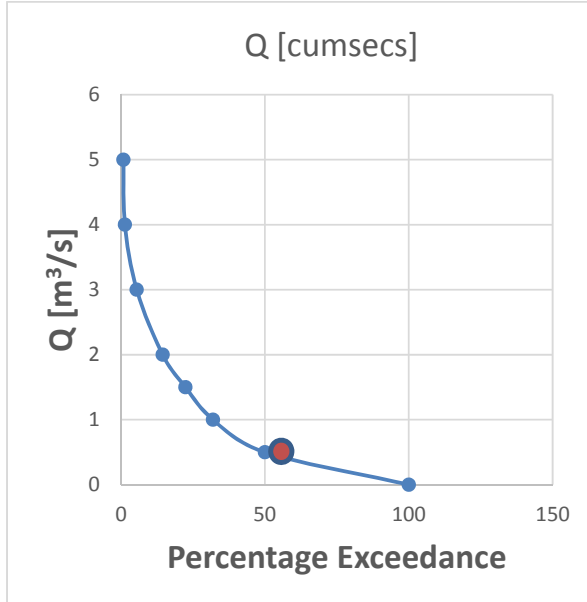


Figure 3: Flow duration curve

THE DESIGN

Figure 4 shows the aerial view of the proposed small hydro power station.

a) Civil Works

Gravity weir

The weir is located about 500m upstream 117m high waterfall. The weir is made of masonry and has the following properties:

- Broad Crested with crest which is 30m long.
- 3.8m high
- Live volume of 15000-20000m^3
- Sluice gate (1m wide by 1m wide)
- Embankment wing walls connecting the weir, 1.5m below existing terrain, made of masonry

$Q_{flood} = b.C_e.C_d.H^{3/2}.\sqrt{(2.g)}$

For broad crested weir, C_d=0.42

$C_e = 1 - \frac{2\sin\theta}{9(1+\varepsilon_\theta{}^4)}$

And

$\varepsilon_\theta = \frac{H-w}{L_\theta}$ *Equation 1*

Where L_θ is width of notch = 0.5m

θ is slope of river which is 0.2%

According to Engineer T.B Mitchell, in Zimbabwe, the Maximum Probable Flood MPF, is given by the following equation:

$$\log_e(MPF+1) = 1.175[\log_e(A+1)]^{0.755} + 3.133$$

A is the catchment area in km^2 which is = 79km^2

MPF is the maximum probable flood with a return period of 1 in 10 000 years. This formula can be adjusted

for MPF with shorter return periods**Table 1: Factors for conversion of MPF to Flood of given return period**

Now for a return period of 10 years:

$\boldsymbol{Q_{flood}}$**= 95.02m³/s**

Now inserting Q_{flood}= 95.02m³/s in **equation 13**, flood rise then becomes, **H=1.5m**

Trash rack

This is used to minimise amount of debris and sediments carried by flowing water **(ESHA, 2004).** These are placed right before the intake, to prevent the debris and sediments from entering the canal. Approach velocity of a trash rack is always designed to be between 0.6m/s and 1.5m/s. Since the turbine to be used in this design is Francis, therefore the spacing between bars is 50mm.

Figure 4: Aerial view of the proposed scheme

<u>Properties and design</u>

Approach velocity, v_0 = 0.75m/s

Spacing, b = 50mm

Angle of inclination of the bars, δ = 60°

Angle of flow, α = 0.11°

Length of bars, L = 2.33m

Width = 1.5m

Shape factor for bars,β_g= 1.0 **(ESHA, 2004)**

Trash rack coefficient for rack with manual cleaning, 1.5 < c < 2

$$\Delta H = \zeta_g . \frac{{v_0}^2}{2.g}$$

Where,

$$\zeta_g = \beta_g . \varepsilon . c . (\sin \delta) . k$$

and

$$\varepsilon = \frac{7}{3}\left(\frac{a}{b} - 1\right)^{4/3}$$

Intake

The intake will be a lateral conveyance one since it supplies water to the canal and not directly to the turbine. It is to be positioned on the outer river bend where river slope, J is 0.17%. This type of intake is suitable since it applies to a range of 0.001% < J < 10%.

Canal

This will be an open canal, made of concrete. It has the following properties:

- length of 460m
- gradient of 0.2%
- dimensions of 1.5m wide by 1.5m deep

Manning equation is applied, which is:

$$Q = \frac{A.R^{2/3}.S^{1/2}}{n}$$

And,

$$Q = \frac{A^{5/3}.S^{1/2}}{n.P^{2/3}}$$

Where A is cross-sectional area in m²

S is the hydraulic gradient of the channel

R is the hydraulic radius in m

n is the Manning's coefficient.

P is the wetted perimeter given in m

Table 2: Hydraulic parameters for common canal cross-sections

Artificially lined channels	Manning's coefficient, n
Brass	0.011
Smooth steel	0.012
Painted steel	0.014
Riveted steel	0.015
Cast iron	0.013
Well-finished concrete	0.012
Unfinished concrete	0.014
Planed wood	0.012
Clay tile	0.014
brickwork	0.015
asphalt	0.016
Corrugated metal	0.022
Rubble masonry	0.025

For the purposes of this design, the material for the canal is finished concrete since it is cheaper to construct as compared to the other materials and the materials for the construction are available locally.

For selection of the optimum profile for different channels, the data shown in Figure 5 from **(ESHA, 2004)** is used.

Channel section	Area A	Wetted perimeter P	Hydraulic radius R	Top width T	Water depth d
Trapezoid: half hexagon	1.73 y^2	3.46 y	0.500 y	2.31 y	0.750y
Rectangle : half square	2 y^2	4 y	0.500 y	2 y	y
Triangle: half square	y^2	2.83 y	0.354 y	2 y	0.500y
Semicircle	0.5πy2	π y	0.500 y	2 y	0.250πy

Figure 2: Optimum profile for different channel sections- Courtesy of "Guide on How to Develop a Small Hydropower Plant" ESHA 2004

Considering same cross-sectional area A and slope S, the channel with a larger hydraulic radius R, delivers a larger discharge. The section with the least wetted perimeter is the most hydraulically efficient.

The triangle half square channel is much more efficient hydraulically, but due to complexity when it comes to construction, a trapezoidal half hexagon is to be considered.

b = 0.5m

y = 1.5m

For the purposes of this design, $A = y(b + zy)$

Where z is side slope = 0.5

A= 1.875m^2

Wetted perimeter: $P = b + 2y(1 + z2)0.5$

$P = 3.854$m

Hydraulic radius: $R = {}^{A}/_{P}$

R = 0.486m

Top width: $T = b + 2zy$

$T = 2m$

S = 0.002

Hydraulic depth: $D = {}^{A}/_{T}$

$D = 0.937m$

Now given that the material in consideration is finished concrete, n = 0.012

$$Q = \frac{1.875^{5/3} * 0.002^{1/2}}{0.012 * 3.854^{2/3}}$$

$$\boldsymbol{Q = 4.322 m^3/s}$$

Now velocity through the cross section is given by,

$$V = \frac{Q}{A}$$

$$V = \frac{4.322}{1.875}$$

V = 2.3m/s

Penstock

For the penstock design, the most cost effective material is fibre glass, but due to local conditions, steel is more favourable. One property to be considered when selecting material for the penstock is the roughness. This is shown in the table below as adapted from **(ESHA, 2004)**

Table 3: Roughness height "k", for various commercial pipes- Courtesy of "Guide on How to Develop a Small Hydropower Plant" ESHA 2004

Pipe material	k (mm)
polyethylene	0.003
Fibre glass with epoxy	0.003
New seamless commercial steel	0.025
Light rust seamless commercial steel	0.250
Galvanised seamless commercial steel	0.150
Welded steel	0.600
Enamel coated cast iron	0.120
Asbestos cement	0.025
Wood stave	0.600
Concrete (steel forms, with smooth joints)	0.180

Now for diameter of penstock, the computations are all done in excel.

The formulas that are used in the spreadsheet are as follows:

The first approximation of velocity,

$$v_0 = \sqrt{(2gz)}$$

Maximum head losses (1/3 of gross head) are given by:

$$h_L = \left(\frac{fL}{D} + C_a\right)\frac{v^2}{2g}$$

Velocity used in iterations, v:

$$v = \left(\frac{2gh_L}{\frac{fL}{D} + C_a}\right)^{1/2}$$

Since the flows are in the turbulent range,

$$f = \frac{1.325}{\left[ln\left(0.27\frac{K}{D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$

An alternative method (Manning Method) to calculate the penstock diameter is given as follows:

$$\boldsymbol{D} = \left\lfloor \frac{n^2 Q^2 L}{H} \right\rfloor^{0.1875}$$

Where n is the Manning's coefficient = 0.012

Q is the flow rate in the penstock = 0.5m^3/s

L is the penstock length = 320m

H is the gross head = 117m

Now, $\boldsymbol{D} = \left\lfloor \frac{0.012^2 * 0.5^2 * 320}{117} \right\rfloor^{0.1875} = 0.476m$

Therefore, the pipe of choice is the **smooth weld steel pipe with a diameter of 0.5m**

b) Electro-mechanical equipment

Turbine

From **figure 6**, with a net head of 115m and a flow of 0.5m^3/s, the design falls into the Pelton and Francis turbine range. To distinguish between the two types, the Shape number is brought into picture.

Shape number

The optimal operating conditions of a turbine is characterized by a dimensionless parameter called the shape number. This is given by

$$K_n = n \frac{\sqrt{\frac{P_o}{\rho}}}{(gH)^{\frac{5}{4}}}$$

Where n is impeller speed in rps = $\frac{1000rpm}{60} = 16.667rps$

P_0 is power output = 564080W

ρ is density of water = 998 kg/m^3

g is acceleration due to gravity =9.81m/s^2

H is net head =115m

Table 4: Properties of water

°C	5	10	15	20	25
ρ (kg/m3)	1000	10000	999	998	997
$\gamma(*10^{-6})$	1.52	1.31	1.14	1.01	0.9

Therefore, for water at20°C,

$$K_n = 16.67 * \frac{\sqrt{\frac{564080}{998}}}{(9.81 * 115)^{5/4}} = 0.061$$

Data in Table 8 is then used to specifically select the final turbine.

Table 5: Turbine selection criteria

Parameter	Pelton	Francis	Kaplan
Shape number	0.015-0.025	0.055-0.37	0.3-0.8
$H_{max}(m)$	1500	370	60
η_{max}	O.85	0.92	0.9

From the table above, K_n of 0.061 falls in the Francis turbine range.

Then for the specific speed of the turbine,

According to (Lugaresi and Massa):

$$n_{QE} = \frac{1.924}{115^{0.512}} = 0.169$$

The value of 0.169 corresponds with the range of the Francis Turbine.

Therefore, **horizontal Francis Turbine** with $\boldsymbol{\eta_{max}}$ **of 0.92.**

But since efficiency of a turbine varies with fraction of flow, doing the calculations in excel spreadsheet, the following curve for the efficiency of this particular turbine is shown in Figure 6.

Now using the equation derived for efficiency in the above curve and introducing two twin turbines, annual energy produced is as follows:

	Using one 564kW turbine	**Using 2 x 282kW turbines**
Annual Energy Output	3044 MWh	3121 MWh

Now to calculate the energy gained annually by using two twin turbines:

$$\frac{3121}{3044} = 1.025$$

Therefore, there is an energy gain of 2.5%.

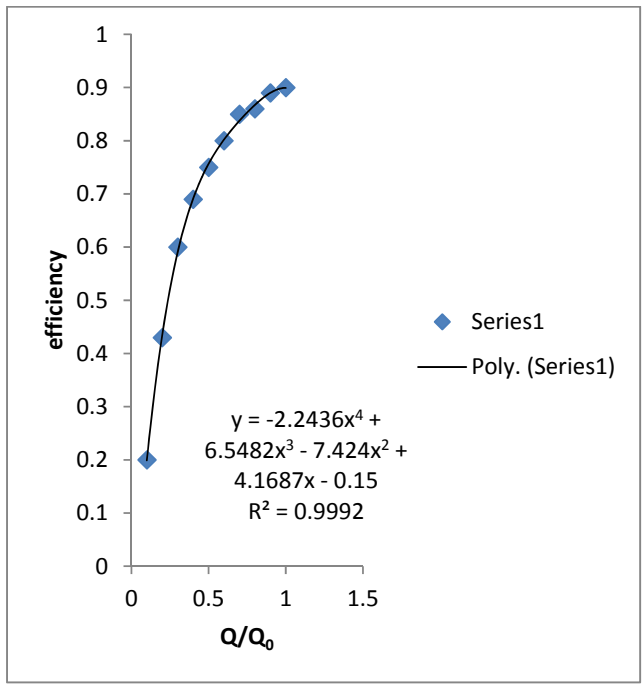


Figure 6: Efficiency curve for Francis Turbine

So for final design specifications, using the arrangement shown in Appendix Section as **A.3**

- 2x Horizontal Francis turbines (both to take 0.25m^3/s each)
- Power rating: 2x282kW
- Synchronous speed is 1000rpm

6.1.2.2 Generator sizing

$N_s = \frac{2f}{N_p}$ *Equation 2*

Where,

N_s is synchronous speed of the generator

f is the frequency

N_p is the number of poles

Turbine kilowatt rating and the requirements for supplying reactive power to transmission network, govern the generator rating.

Using the "add 60%" rule to provide for sufficient reactive power,

Generator kVA = (max kW load / power factor)* 1.6

a. first Generator kVA = (282/0.8)*1.6= 564
b. second Generator kVA = (282/0.8)*1.6 = 564

So two, 3 phase, brushed, rotating armature synchronous generators with the following specifications will be required.

- Generator: 2x: 564kVA, 282kW, speed 1000rpm
- p.f 0.8 lagging, efficiency~90%, insulation class F
- Over speed protection – 180% continuously
- Excitation- self excitation..

Automatic Voltage Regulator (AVR)

An AVR is required to maintain the AC voltage constant.

Generator Transformer

The step up transformer has the same kVA rating as the generator

Transformer data:

Rated output- 1128kVA

Rated LV voltage = to generator voltage and usually depends on manufacturer's design.

Control and Governing Systems

An electronic load controller system is going to be used. This system is used to adjust the load by controlling the speed of the turbo-generator set. The advantages of the system are:

- Almost maintenance free
- Lower investment cost
- Quick reaction time

III. ECONOMIC EVALUATION

a) COSTING

A micro hydro scheme is a capital intensive project. Investors must have the confidence that the project is viable.

The time value of money

The project is expected to achieve benefits in the future. But the benefits are not worth the same as if they were securely in our hands now. Consequently they are discounted that is,resent value (PV)

The general formula for discounting is:

$$PV = \frac{Future\ value}{(1+m)^n}$$

n= number of years

m=is the discount over the period of years

Payback period

A very common financial indicator is the payback period. This often used in pre-feasibility studies when the finances of a scheme are seen in terms of fixed annual sums which do not vary year by year.

$$Simple\ payback = \frac{total\ capital\ cost}{annual\ revenue - annual\ expenditure}$$

Evaluation of payback period at 12% payback period

Installed capacity=1000*9.81*0.50*115

=564.06Kw

Estimated Annual Output= annual energy produced*$0.14

Where $0.14 is the tariff set by ZERA as cost of 1kWh

= 3121000kWh* $0.14

=$436940

Scheme becomes operative at the end of the second year

First year

- Planning and design
- Management and maintenance
- 60% Civil Works
- 40%Electro-mechanical

Second year

- Civil works(completed)
- Electro-mechanical(completed)
- Installation and distribution

Planning/designing	**40000**
Management and finance	20000
Civil works	750000
Electro mechanical	360000
Installation and distribution	130000
Subtotal	1300000
Unforeseen expenses(3%)	39000
Total investment	1339000

Operation and Maintenance (O&M) cost estimated are 4% of the total Investment= $53560

Investment cost per installed kW would be $\frac{\$1339000}{564.08}$

=$2374/kW

Therefore the net present value obtained **$1 694 583**

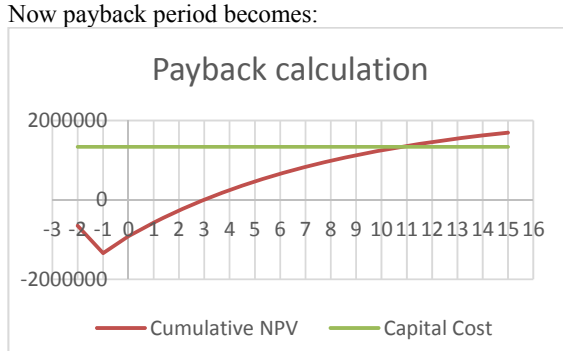
Calculating the payback period

According to the table it falls between year 3 and year 4

$2+\frac{4259}{(4259+268708)}$*12months

=2years 11months after start of operation, the project worth then becomes positive.

Now payback period becomes:



Therefore, the payback period is **11 years** against a lifespan of 30 years

Present Worth Annuity Factor (PWAF)

$$\boldsymbol{PWAF = \frac{1-(1+r)^{-n}}{r}}$$

Where r is the rate of return, n is the lifespan of the project

$$\mathbf{PWAF} = \frac{1-(1+0.1)^{-30}}{0.1} = 9.42$$

$$Annualised\ Cost = \frac{NPV}{PWAF}$$

$$NPV = 1339000 + 53560 * PWAF$$

NPV = $1 843 535

Therefore, Annualised Cost = $\frac{1843535}{9.42}$

= $195704/kWh

Unit Cost of electricity = Annualised Cost/ kWh generated per annum

$$= \frac{195704}{3121000}$$

=US $0.06 **per kWh**

IV. ENVIRONMENTAL ASSESSMENT: ENVIRONMENTAL IMPACT AND MITIGATION

a) Burdens and impacts identification

The impacts of small hydropower schemes are so specific of the location and technology used. A river diversion scheme that is situated in a highly sensitive area is more likely to generate a bigger impact than an integral low-head scheme in a valley. [4] The general process is that, water is diverted from the main river and re-enters the river again at the tailrace after the powerhouse. In this case, entire area of the main river may be bypassed by a large volume of water especially when the plant is operating. According to REA, a maximum of a third of the flow must re-enter the river.

Table 9 Effects during operation as stipulated by EMA

Events during construction	**People or resources affected**	**Impact**	**Level of impact**
Vegetation removal	Forestry and wildlife	Alteration of habitat	Medium
Enlargement or extension of Roads	General public	Opportunity and job Creation, alteration of habitat	Medium
Earth Moving	Site geology	Slope stability	Low
Tunnels Excavation	Site hydro-geology	Alteration of circulation groundwater	Low
Embankment Realisation	River life, site hydro-morphology	Alteration of river hydraulic	Medium
Temporary Earth Accumulations	Site geology	Slope stability	Low
Temporary Displacements (People, Roads, Electric Lines)	General public		Negligible
Realisation of Roads and Sheds for the Yard	Wildlife, general public	Visual intrusion, wildlife disturbance	Low
Water Courses Dredging	Aquatic ecosystem	Alteration of habitat	Medium
Temporary Diversion of Rivers	Aquatic ecosystem	Alteration of habitat	High
Use of Excavators, Trucks, Cars for the Personnel,	Wildlife, general public	Noise	High
Human Presence During the Works on Site	Wildlife, general public	Noise	Low

Impacts in the construction phase

a) Water intakes, open canals, penstocks, tailraces

Since Gairezi Ranch is the nearby residential area, the impacts to be caused by this hydropower scheme are well known which are:

- Danger of erosion due to the loss of vegetation through downstream sediment deposition,
- Noise affecting animals,
- Excavation work,
- Turbidity of the water because of the sediments carried.

To minimise these impacts it is strongly recommended that the excavation work should be undertaken in the low water season (dry season) and the disturbed ground should be restored as soon as possible.

To reduce the effects of erosion, it is wise to restore and reinforce the riverbank vegetation that may have been damaged during the construction of the hydraulic structures. The ground is to be repopulated by the abundant Msasa tree which is available in large quantities in the region.

To mitigate the above impacts, traffic operation must be planned carefully in such a way that traffic is minimum and to eliminate unnecessary movements.

Impacts arising from the operation of the scheme

a) Sonic (sound) impacts

The noise level allowed depends on the isolated houses near to the powerhouse or local population. In this case, there are available population is not found near the powerhouse so noise will not cause much disturbance.

Events during operation	People or resources affected	Impact	Level of impact
Renewable Energy Production	General public	Reduction of Pollutants	High
Watercourses	River Life (Aquatic ecosystem)	Modification of habitat	High
Permanent Works in the Riverbed	River life	Modification of habitat	High
Diversion of Watercourses	River life	Modification of habitat	High
Penstocks	Livestock and Wildlife	Visual intrusion	Medium
New Electric Lines	General public,livestock	Visual intrusion	Low
Flow Rate modification	Fish	Modification of habitat	High
Noise from electromechanical equipment	General public	Alteration of life quality	Low
Removal of material from streambed	Aquatic life, General public	Improvement of water quality	high

Table 10: Effects encountered during small hydropower construction- by EMA

The noise usually produced originates from the turbines and from the speed increasers if they are used. Noise inside the powerhouse can be reduced. To reach the acceptable levels of noise it is generally encouraged that all the components - turbines, speed increasers, and asynchronous generator, should be bought in one package from one trusted supplier. An example of a trusted supplier is Siemens.

b) Landscape impact

The Gairezi settlement area is full of beauty scenery and there is a higher probability that people will not easily accept the scheme. The concern is frequently generated in the form of public comments and even of legal challenges to those developers seeking to change a loved and sacred landscape by developing a hydropower plant. The components that make up this hydro scheme which are: the powerhouse, intake, canal, weir, penstock, tailrace and transmission lines have the potential to change the view of the scenery by introducing contrasting forms, lines, colour or textures. So this basically means that the design, appearance and location of any one feature may well determine the level of public acceptance for the entire scheme. Components of the scheme may be screened from the view using landscaping and vegetation. These components can be painted in non-contrasting colours and textures to obtain non-reflecting surfaces. A component is supposed to blend with or complement the characteristic landscape.

The layout must be carefully studied and should in-cooperate natural features like rocks, ground and vegetation, to cover the components if no other solution is found, painting it so as to minimise contrast with the background.

In the case of penstock, usually the best answer is to reduce or eliminate the number of expansion joints and concrete anchor blocks; the ground is returned to its original state and the pipe does not form a barrier to the passage of livestock. The powerhouse, intake, penstock tailrace and transmission lines must be carefully constructed into the landscape. Any mitigation strategies should be incorporated in the project, usually without too much extra cost to facilitate permit approval.

c) Trash rack material

This hydropower plant has a trash rack, which removes materials like debris from flowing water in order to stop it from entering the plant waterways and damaging the turbine and reducing hydraulic performance. Annually kilograms of material (bottles ,plastic bags, cansand carcasses, leaves and natural detritus also found in water) are taken out of the water path.

When everything, inclusive of organic matter (leaves, branches and so on) is removed from the main stream, it becomes waste material automatically. In this case it cannot be thrown back into the water but should be disposed properly often at significant costs. It is therefore correct to say that hydropower plants play a major role in cleaning the environment of rivers. This benefit is usually unacknowledged though it clearly represents a positive impact by the small hydropower plants and it must be taken into account. Suitable support measures should be undertaken to reduce the economic burdens on small hydropower plant operators on this matter (for example by allowing different methods of treating organic and non-organic material and reduction in waste disposal fees).

Impacts from transmission lines

a) Visual impact

Transmission lines above ground can have a negative impact on the landscape. The impacts can be reduced by adaption of the line to the landscape or even burying it.

To attain optimal clearance from the ground the transmission lines are to be placed on the top of the hills, constituting a very dominating element of the landscape. The cost can be reduced by reducing the number of bends in the route which then will decrease the number of angle and ordinary pylons

Gairezi area is very mountainous and transmission lines can dominate the landscape and therefore impact negatively the beauty of the scenery. In some schemes, transformers and transmission lines are hidden from public view and the situation much improved, however it is an expensive solution that only can be offered if the plant is profitable enough.

b) Health impact

Since Gairezi is a bit still a bit more remote some people may dislike walking under transmission lines because of perceived health risks in addition also to visual intrusion. During construction phase however there is likely to be an increase of sexually related diseases due to the fact of

increase in experts and contract workers from other places as in the case with most big projects sites.

V. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSION

This research has shown that this small hydro power station can be successfully constructed. The total cost of the project is US$1 339 000. The Net Present Value of the project after a 15year period would be US$1 694 583. This falls within the viable budget of the Zimbabwe Electricity Regulatory Authority - the funder of the project. A broad-crested weir is to be constructed using masonry, as well as the embankment wing halls to strengthen it, made of masonry too. A lateral conveyance intake is then used to divert the required flowing water for power generation into a trapezoidal canal, 460m long. Water in the canal is then deposited into the forebay tank where it is brought to a temporary halt. It then flows into a 320m long penstock, made of smooth weld steel, which leads directly to the turbines. From the forebay tank to the turbines, there is a gross head of 117m and flow in the penstock is $0.5m^3/s$. Using this flow rate and head, a power potential 564kW is produced. Two Francis turbines are used each taking $0.25m^3/s$ and coupled to a generator each. The discharge is then taken back into the river through the tailrace. Electricity to be produced is to be fed into the national grid to curb the deficit of electricity in the community.

The increase in the level of activity in an area by using small local subcontractors and local manpower during the construction phase is greatly welcomed. This generally creates employment for the locals and they benefit also in skill and knowledge.

RECOMMENDATIONS

a) Use of Light Emitting Diode (LED)

A considerable amount of electricity can be saved by utilizing more efficient light bulbs. The following are the types of light bulbs in use in Zimbabwe:

- Compact fluorescent (CFL)
- Incandescent
- Light Emitting Diode(LED)

The traditional incandescent light bulb is only 10% efficient i.e 90% of energy used is heat produced with only 10% being converted to light

If the residents of this country switch to LED type from incandescent bulbs, they have the following advantages:

- Long life
- Energy efficiency
- Environmentally friendliness
- Durability

b) Installing a Bio-Acoustic fish fence(BAFF)

This system is required by EMA regulations and has been developed in the United Kingdom and other European countries. It uses a combination of bubbles and sound waves to form a behavioural screen to guide fish away from intakes this way it allows for the preservation of the aquatic life.

c) Cascaded project

Since the river considered in this project is a perennial one with a number of rapids and waterfalls, another small hydropower plant can be installed along the same river. This shows that the river has greater power potential than utilised in this project.

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BIOGRAPHY

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