Engineering Design Document

Comunidad Nueva Alianza
Micro Hydro Electric Design

Produced By:

Xelateco

Endorsed By:

Appropriate Infrastructure Development Group (AIDG)

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Abstract

This paper details the rehabilitation of a micro-hydro electric system in Comunidad Nueva Alianza, El Palmar, Quetzaltenango, Guatemala. This task was undertaken by the organization of workers in the community, Sindicato de Trabajadores Independiente de la Finca Alianza (STIAP), in response to a need for electrification in the community. The community had a historic hydro electric system with a large concrete civil works, mild steel penstock, and pelton turbine that had been built in the 1930's and decommissioned in the 1970's. In the past 30 years, much of the civil works had become unusable and the electromechanical and transmission systems had been stripped of their components.

The United Nations Development Program (UNDP) small grants program sent an investigator to explore the technical feasibility of recommissioning the historic system. A study was performed and the subsequent grant application led to an award to the community of $19,994 towards the recommissioning of the system. After a prolonged search for potential contractors STIAP contracted the new enterprise Xelateco to perform the system design and installation. With the financial and engineering support of its incubator the U.S. nonprofit, Appropriate Infrastructure Development Group (AIDG), Xelateco began work on the project November 21, 2005 with an original projected commissioning date of June 21, 2006. An extension was permitted on February 24, 2006 until August 31, 2006.

The enclosed document details the design of the micro hydro electric system produced by Xelateco. This document includes information on the civil works, hydrology, penstock, turbine, generators, emergency deflectors, ballast speed governing, transmission, safety, operations and maintenance, and installation. Certain materials of larger size were resized to fit in the document format. Originals are available for viewing at the Xelateco office M-F 8:30-5:00, 1° Ave A 6-53 Quetzaltenango, Quetzaltenango, Guatemala.

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1 General

The Appropriate Infrastructure Development Group (AIDG) is committed to assisting Xelateco with the planning, design, and construction of a micro hydro electric system for the Comunidad Nueva Alianza. The micro hydro electric system will serve 40 community households as well as the community's agro-industrial machinery. This report specifies the components and attributes associated with the design of the micro hydro electric system.

2 Planning Area

This section gives information of the Communidad Nueva Alianza's land area, population and environmental conditions.

2.1 Location

The Comunidad Nueva Alianza is located in the El Palmar municipality roughly 40 kilometers south west of the Quetzaltenango municipality in the country of Guatemala.

Figure 1: Maps Representing both of the Municipality of Quetzaltenango, Guatemala and the Municipality of El Palmar, Guatemala (Guatemala 2006)

2.2 Population

The municipality of El Palmar contains an estimated population of 19,000. Nueva Alianza contains 40 households consisting of roughly 200 community members.

2.3 Climate

The average temperature of the Comunidad Nueva Alianza is roughly 25 degrees Celsius with an annual precipitation of 150 to 350 centimeters per year (Spillman et. al. 2000). Nueva Alianza is located at roughly 900 meters above sea level in comparison to the municipality of Quetzaltenango at 2257 meters above sea level (Gonzalez 2006).

3 Project Background

This project consists of the design and installation of a 16 kW hydroelectric system for a community of 40 families in the Comunidad Nueva Alianza, located near El Palmar, Guatemala. Funding for the project stems primarily from the United Nations Development Programs (UNDP) small grants program. The contractor for the project is Xelateco, an incubated business by the US-based NGO known as the Appropriate Infrastructure Development Group (AIDG).

The Comunidad Nueva Alianza is a self-organized agricultural plantation community determined to liberate itself from the patron of the plantation. After the fall in world prices of coffee and macadamia in 2001, the Patron failed to pay the community for 18 months (Klefbom 2002). The workers demanded their wages and, after a complicated series of negotiations involving banks, Panamanian financiers, and government programs, the community of workers were able to obtain legal title of the plantation. Renaming themselves the Comunidad Nueva Alianza (the Community of the New Alliance), the 40 families formally organized themselves as a cooperative on October 7th, 2002.

The community committed itself to principals of sustainable development and diversified its organic, ecological products beyond coffee and macadamia to include milk, avocado, bottled spring water, and ecotourism. As a community lacking a connection to the Guatemalan national electric grid, Comunidad Nueva Alianza generates electricity through the use of diesel generators. Electricity is needed for the processing of agricultural products and illumination throughout the households. However, when the former Patron left, he took with him electrical generators and transmission lines from a defunct hydroelectric system built over fifty years ago.

Due to the issues of cost and of noise and air pollution, the board of directors of the Comunidad Nueva Alianza sought funding from the UNDP small grants program at the end of 2004 to rehabilitate the hydroelectric system. The UN sent a capable engineer from Spain, lvaro Fernndez-Baldor Martnez, in January 2005, to conduct a detailed feasibility study for the micro hydro electric system. The UN awarded the community $19,994 in the spring of 2005 to build the system.

With funding and plans in place, Sindicato de Trabajadores Independiente de la Finca Alianza (STIAP) sought a contractor to design and install the system. However, by September 1, 2005, STIAP had not found a contractor that could provide for the communitys needs within the funding limit. The community received a deadline of November 23, 2005 set by the UNDP to find a contractor.

At this time, AIDG, was conducting an outreach project at the STIAP by funding the installation of a biodigester system with its newly incubated manufacturing enterprise, Xelateco. This business, launched in August 2005, is focused on the development of renewable energy and clean-water technologies. The AIDG had been training Xelateco in renewable energy systems, including micro hydro electric systems.

Having requested proposals and received cost estimates that the STIAP could not afford, Xelateco began to work with the community to find an affordable solution that would enable the completion of the project. Contract negotiations began in late September 2005 but were delayed by the arrival of Hurricane Stan in October of 2005. STIAP and Xelateco signed a contract on November 21, 2005. With the engineering and funding assistance of AIDG, Xelateco began work on November 21, 2005.

4 Need For Project

lvaro Fernndez-Baldor Martnez, the UN engineer from Spain, specified that "much work remained and local need was large," after his first few days of visiting the community in January 2005 (Fernndez-Baldor 2005).

Due to a small population (about 200 inhabitants) and inaccessible location, Comunidad Nueva Alianza has received little assistance from the Guatemalan government with the development of the community. In early 2005, the community lacked basic necessities, such as light, potable water, education, and reliable roads. As a cooperation, the community established priorities for projects to be executed. The micro hydro electric project is a main priority to the community.

5 Alternatives Considered

This section provides information of the design criteria, alternatives considered and the justification of the recommended alternative associated with the micro hydro electric design.

5.1 Design Criteria

The base design criteria laid out in the STIAP contract with the UNDP calls for a 10 kW potential hydro electric system to provide power for the agroindustrial processes of STIAP, 40 households, the ecotourism facility and the water purification facility. It calls for the use, where possible, of existing infrastructure (Fernndez-Baldor 2005). The peak demand for all of these loads easily exceeds the 10 kW threshold, even with conservation and control mechanisms in place, at 18.5 kW. The original quotation that created the 10 kW figure assumed unattainable water to wire efficiencies for the quoted flow and head figures. As a result to implement a 10 kW micro hydro electric system, a choice would be made between generating the prescribed 10 kw for less time or for generating less electricity for more time.

The variability of flow rate and power needs throughout the year present an important factor to the design criteria. A diagram produced by lvaro Fernndez-Baldor Martnez illustrates flow rate variability at the Communidad Nueva Alianza (Figure 2). Demand for electricity from agroindustrial proceses is highest during the wet season.

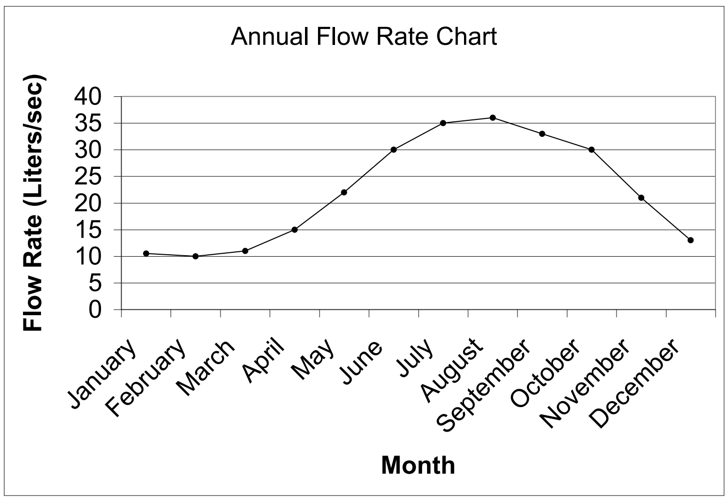

Figure 2: Representation of Annual Flow Rate (Fernndez-Baldor 2005)

Another major factor in the project was the proper leveraging of the historic hydro electric system with its large concrete civil works. This system consisting of a mild steel penstock and pelton turbine had been built in the 1930's and had been decommissioned in the 1970's. In the past 30 years, the system had fallen into disrepair and had been stripped of components. All electromechanical, turbine, transmission and governing equipment no longer existed. The penstock of mild steel encased in cement was broken in multiple places and was rusted through large stretches to the cement support. When the concrete was removed during investigation large sections of the penstock were substantially rusted. The channel from the intake wier to the forebay tank had been broken in multiple areas and needed repair. The goal of the revitalization included utilization of the existing infrastructure.

The well preserved forebay tank provided a good option for solving the annual flow variability issues and is utilized for the micro hydro electric system. The existing penstock in each design is utilized to provide support and protection for a new uPVC penstock.

5.2 Alternatives

For this micro hydro electric rehabilitation, several alternatives were considered. The ultimate decided design provided a system with the highest amount of failover and ease of maintenance. The major augmenting and limiting criteria were the seasonal variability of the flow rate and the utilization of the historic micro hydro electric infrastructure.

5.2.1 Alternative 1 - Single 10 kW Pelton, electronic speed control through ballast, single continuous duty generator 60Hz, 3 phase 10 kW Marathon Electric generator, importerd Pelton, Siemens balast

This alternative, presented to the community by Hidro Energia S.A. would have permitted only 2 hours a day of electricity during the dry season and would have failed to take advantage of additional potential during the winter. In case of failure, use of imported parts could lead to significant periods of no electricity generation from the micro hydro electric system. Failure of a single component could prevent the community from having electricity from the micro hydro electric system for a period of up to several months while imports would be acquired.

5.2.2 Alternative 2 - Banki turbine to 10 kW, Stamford electric alternator adjustable to 6 kW, electronic balast governing

Banki turbines offer an ability to vary power output with flow rate by restricting the amount of water hitting the turbine. Even with flow adjustment Banki turbines produce less power with higher flow than pelton turbines. Local production of a Banki turbine would have been possible through Xelateco ensuring a local supplier for long term maintenance. The adjustment of the generator between the two plate ratings presented an unacceptable risk for generator failure of the communitys only generator due to maintenance error. Failure of a generator componant could prevent the community from having electricity again for a prolonged period. Banki turbines work most efficiently with large, stable flow rates and little variability (Gonzalez 2006).

5.2.3 Alternative 3 - Dual 8 kW continuous duty generator, 60 Hz, 3 phase Voltmaster generator, dual Pelton, tank expansion and electronic speed control through ballast

This alternative provided higher power output, flexible generation based upon flow availabilty, ease of operation, ease of maintenance, and redundancy (i.e. increased redundancy means downtime for parts failure in generator related cases could be reduced from months to hours). It provided a robust option for the community with a high degree of failover. Using the same electric control (AVR) system, ballast, generator and Pelton for each 8 kW system provides the opportunity for continued operation in multiple failure scenarios. With the tank expansion and lower power output, it provided expanded power production both in the dry and wet seasons, allowing for 16kW of production in the wet season and 8 kW in the dry season. With the doubled tank storage, electricity generation is provided for 13 hours a day nine months out of the year (Appendix D). Production of the ballast load circuit and turbines by Xelateco and the use of 8 kW Voltmaster generators allowed for use of two generators for less than the price of the single generator in Alternative 1.

5.2.4 Alternative 4 - No Action

This alternative would not address anyone's needs and would jeopardize the health and living standards of the Comunidad Nueva Alianza.

5.3 Recommended Alternative

Alternative 3 provided the best long term solution for the community. The design fell within the core competence of the Xelateco team and is the best possible option for Xelateco to pursue. The reliance on Xelateco produced components would mean that both the materials and the expertise necessary to manufacture the systems would be available to the community in repair situations.

6 Recommended Alternative Description

This section describes all the components associated with the recommended alternative, the environmental review and safety assessment, and operation and maintenance.

6.1 Estimation of Micro Hydro Electric System Flow Rate

Assuming optimal conditions, the desired flow rate for each 8 kW generator can calculated as follows (McKinney 1983),

$$P = \eta \cdot Q \cdot \rho_w \cdot g \cdot H_g$$

Where

$$\begin{aligned} P &= \text{desired/estimated power output (W)} \\ \eta &= \text{estimated system efficiency} \\ Q &= \text{flow rate (m}^3\text{)} \\ \rho_w &= \text{density of water (1000 kg/m}^3\text{)} \\ g &= \text{acceleration due to gravity (9.81 m/s}^2\text{)} \\ H_g &= \text{gross head (m)} \end{aligned}$$

A value of 57 m for the gross head is used for this calculation. Assuming efficiency values of 0.95 for the Penstock, 0.98 for the Manifold, 0.94 for the nozzle, 0.75 for the Runner, 0.80 for the Generator; an overall estimated system efficiency of 0.52 is used for this design (i.e. $\eta = 0.95(0.98)(0.94)(0.75)(0.80) = 0.52$). Rearranging this equation, the desired flow rate can be solved for as follows,

$$\begin{aligned} Q &= \tfrac{P}{\eta \cdot \rho \cdot g \cdot H} \\ &= \tfrac{8000}{0.52(1000)(9.81)(57)} \\ &= 0.027 \text{ m}^3\text{/s} \end{aligned}$$

6.2 Head Loss Assessment

This section describes the formulae used to calculate the head loss and the input variables associated with the penstock and the manifold sections of the micro hydro electric system. Due to the interdependent relationship between flow rate and head loss, as well as the number of intermediate calculations required in the solution of the problem, it is difficult to obtain an accurate head loss by hand calculations. For this reason, a Scilab computer program was developed (Appendix E).

6.2.1 Application of Head Loss Computer Program

Table 1: Minor Loss Coefficients for Various Pipe Accessories (Thake 2000)

	Value (m)
D_2/D_1=0.80 (Sudden Contraction)	0.18
D_2/D_1=0.50 (Sudden Contraction)	0.37
D_2/D_1=0.20 (Sudden Contraction)	0.49
Fully Open Gate Valve	0.39
3/4 Open Gate Valve	0.1.1
1/2 Open Gate Valve	4.8
1/4 Open Gate Valve	27
90° Smooth Bend (Bend radius/D = 4)	0.16 - 0.18
90° Smooth Bend (Bend radius/D = 2)	0.19 - 0.25
90° Smooth Bend (Bend radius/D = 1)	0.35 - 0.40
45° Bend	0.2
45° Wye (Line Flow)	0.3
45° Wye (Branch Flow)	0.5

Table 2: Roughness Factor of Pipe Materials (Thake 2000)

	Value (m)
PVC	1×10^{-5}
Galvanized Iron	1.5×10^{-4}

As a necessary part of the solution procedure, the flow rate, number of nozzles, nozzle diameter, jet velocity, and pitch circle diameter (PCD) will be calculated in addition to the head loss of the optimum pipe configuration. Assuming that head loss will be calculated at the center point of the turbine (i.e. the average height of the nozzle exits), the following formulae will be solved iteratively to a epsilon value, ϵ, equal to 0.0001. The gross head is equal to the static head at the nozzle exit plus the velocity head at the nozzle entrance as follows,

$$H_g = H_s + \frac{V_e^2}{2 \cdot g}$$

Where

$$\begin{aligned} H_g &= \text{gross head (m)} \\ H_s &= \text{static head (m)} \\ V_e &= \text{velocity at nozzle entrance} \\ g &= \text{acceleration due to gravity (9.81 m/s}^2\text{)} \end{aligned}$$

Total head loss is due to the sum of the major losses plus the sum of the minor losses in the piping system and expressed as,

$$H_l = \sum h_l + \sum h_m$$

Where

$$\begin{aligned} H_l &= \text{total head loss (m)} \\ h_l &= \text{major head loss (m)} \\ h_m &= \text{minor head loss (m)} \end{aligned}$$

The head loss in the penstock contains only major losses while the manifold incorporates both major and minor losses. Major losses are due to friction between the fluid and the pipe wall and can be expressed as,

$$h_l = f \cdot \frac{L}{d} \cdot \frac{V^2}{2 \cdot g}$$

Where

$$\begin{aligned} L &= \text{length of pipe (m)} \\ d &= \text{measured inside pipe diameter (m)} \\ f &= \text{friction factor} \\ V &= \text{velocity of fluid through pipe (m/s)} \\ g &= \text{acceleration due to gravity (9.81 m/s}^2\text{)} \end{aligned}$$

The friction factor is determined from a Moody form of the Colebrook-White equation (Walski et. al. 2003),

$$f = \frac{0.25}{\log\left(\frac{e}{3.7 \cdot d} + \frac{5.74}{Re^{0.9}}\right)^2}$$

$$Re = \frac{\rho_w \cdot V \cdot d}{\mu}$$

Where

$$\begin{aligned} f &= \text{friction factor} \\ e &= \text{pipe roughness factor (m)} \\ d &= \text{measured inside pipe diameter (m)} \\ Re &= \text{Reynold's number} \\ \rho_w &= \text{density of water (1000 kg/m}^3\text{)} \\ d &= \text{measured inside pipe diameter (m)} \\ V &= \text{velocity of fluid through pipe (m/s)} \\ \mu &= \text{absolute viscosity of water } (1 \times 10^{-3}\text{Pa-s}) \end{aligned}$$

The minor losses throughout the manifold can be calculated with the following formula (Thake 2000),

$$h_m = n \cdot K_L \cdot \frac{V^2}{2 \cdot g}$$

Where

$$\begin{aligned} h_m &= \text{minor head loss (m)} \\ n &= \text{number of assessories} \\ K_L &= \text{minor loss coefficient} \\ V &= \text{velocity of fluid through pipe (m/s)} \\ g &= \text{acceleration due to gravity (9.81 m/s}^2\text{)} \end{aligned}$$

The net head at the nozzle exits can be expressed by the following formula (Walski et. al. 2003),

$$H_n = H_g - H_l$$

Where

$$\begin{aligned} H_n &= \text{net head (m)} \\ H_g &= \text{gross head (m)} \\ H_l &= \text{total head loss (m)} \end{aligned}$$

The jet velocity is derived from Bernoullis Equation. The jet is assumed to be at atmospheric pressure, and the water in the holding tank is assumed to be at steady state. Using these assumptions, the formula for jet velocity is derived as follows,

$$V_j = C_D \cdot \sqrt{2 \cdot g \cdot H_n}$$

Where

$$\begin{aligned} V_j &= \text{jet velocity (m/s)} \\ C_D &= \text{discharge coefficient} \\ g &= \text{acceleration due to gravity (9.81 m/s}^2\text{)} \\ H_n &= \text{net head (m)} \end{aligned}$$

To account for friction losses within the nozzle we include a discharge coefficient which is derived from experimental data for the desired nozzle shape (i.e. 14 degree taper). Note that the discharge coefficient is 0.96 for a 14 degree tapered nozzle. The pitch circle diameter (PCD) is determined by solving a system of two equations relating the angular velocity of the turbine to the velocity of the jet and to the desired number of rpms of the turbine. The derived formula can be expressed as (Thake 2000),

$$PCD = \frac{60 \cdot x \cdot V_j}{\pi \cdot N}$$

Where

$$\begin{aligned} PCD &= \text{pitch circle diameter (m)} \\ x &= \text{ratio of runner velocity to jet velocity} \\ V_j &= \text{jet velocity (m/s)} \\ N &= \text{rotational velocity of runner (rpm)} \end{aligned}$$

Nozzle diameter is related to pitch circle diameter through an optimal ratio and has been determined experimentally for a two nozzle system with approximately 1800 rpm and 50 m of head to be,

$$d_n = 0.14 \cdot PCD$$

Where

$$\begin{aligned} d_n &= \text{nozzle diameter (m)} \\ PCD &= \text{pitch circle diameter (m)} \end{aligned}$$

The flow rate through the nozzle is equal to the jet velocity multiplied by the exit area of the nozzle and expressed as,

$$Q = V_j \cdot A_n$$

Where

$$\begin{aligned} Q &= \text{flow rate through nozzle (m}^3\text{/s)} \\ V_j &= \text{jet velocity (m/s)} \\ A_n &= \text{cross-sectional area of nozzle (m}^2\text{)} \end{aligned}$$

The total flow rate is equal to the flow rate through each nozzle multiplied by the number of nozzles,

$$Q_t = Q \cdot n$$

Where

$$\begin{aligned} Q_t &= \text{total flow rate (m}^3\text{/s)} \\ Q &= \text{flow rate through nozzle (m}^3\text{/s)} \\ n &= \text{number of nozzles} \end{aligned}$$

A series of head loss coefficients and pipe roughness factors were used as variables in the Scilab computer program (Table 1 and Table 2).

6.2.2 Head Loss Program Results

Table 3: Results of Scilab Computer Program

	Value
H_g	57.3 m
H_l	4.81 m
H_l (penstock)	0.85 m
H_l (manifold)	3.96 m
H_n	52.5 m
V_j	0.85 m/s
PCD	0.021 m
d_n	0.15 m
Q	0.0214 m^3/s

The results of the head loss program are illustrated in tabular form (Table 3). A calculated desired flow rate was calculated as $Q = 0.0214\text{m}^3/\text{s}$.

6.3 Design Efficiency Assessment

The efficiency of a turbine is generally affected by three factors: hydraulic losses or power losses that occur due to flow irregularity within the bucket; aerodynamic or windage losses, which occur because of resistance in the air to the moving buckets, and mechanical losses, losses in the system used to transmit the power from the turbine to the generator. In this Pelton design, the turbine is mounted directly to the generator, and so there are no mechanical losses in the turbine. Due the complexity of determining turbine efficiency (i.e.

substantial iterations), a Scilab computer program incorporating a bi-sectional numerical method was developed (Appendix E).

6.3.1 Application of Pelton Bucket Hydraulic Efficiency Computer Program

This section discusses the formulae within the Scilab written computer program used to determine an efficiency value. The hydraulic efficiency of the runner is based on the 2nd law of thermodynamics and expressed as follows,

$$\eta_h = \frac{W_b}{W_j}$$

Where

$$\begin{aligned} \eta_h &= \text{hydraulic efficiency} \\ W_b &= \text{work produced by the jet supplied to the bucket (kW)} \\ W_j &= \text{work capacity of the jet (kW)} \end{aligned}$$

The energy in the portion of the jet that will act on a single bucket can be found by multiplying the power of the jet by the time the bucket will be within the stream of the jet and can be expressed as,

$$W_j = P \cdot t$$

$$P = \frac{\dot{m} \cdot V_j^2}{2}$$

$$t = \frac{\delta}{\omega}$$

$$\omega = \frac{x \cdot V_j}{R}$$

Where

$$\begin{aligned} W_j &= \text{jet work (kJ)} \\ P &= \text{jet power (kW)} \\ t &= \text{time (s)} \\ \dot{m} &= \text{mass flow rate of jet (kg/s)} \\ V_j &= \text{jet velocity (m/s)} \\ \delta &= \text{angular distance between buckets (rad)} \\ \omega &= \text{radial velocity of runner (rad/s)} \\ x &= \text{ratio of runner velocity to jet velocity} \\ R &= \text{radius of PCD (m)} \end{aligned}$$

Note that angular distance is $\frac{2\cdot\pi}{n}$, where, n, is the number of buckets. The computer program determines the optimal number of buckets. This is found by iteration through the range enclosed by n_{min} and n_{max}, where n_{min} is the minimum number of buckets required for all the water from the jet to impact with a bucket and n_{max} is the maximum number of buckets that will fit on the runner (Appendix E). The work done on the bucket is equal to the power output from the bucket integrated over the time it is in contact with the jet. The formula derived from this definition is as follows,

$$W_b = \dot{m}\cdot V_j\cdot R(1+\zeta\cos(\gamma))\left[\Theta_B + \Theta_A + x(x-2)(\tan(\Theta_B) + tan(\Theta_A)) + \frac{x^2}{3}\left(\tan^3(\Theta_B) + \tan^3(\Theta_A)\right)\right]$$

$$\Theta_A = \arccos\left(\frac{R}{R_s}\right)$$

$$\Theta_B = x\cdot\tan(\Theta_A) - \Theta_A + \delta + x\cdot\tan(\Theta_B)$$

Where

W_b	=	work produced by the jet supplied to the bucket (kW)
$\dot{m}$	=	mass flow rate of jet (kg/s)
V_j	=	jet velocity (m/s)
R	=	radius of PCD (m)
ζ	=	surface efficiency of the bucket
γ	=	angle of side walls of the bucket (rad)
Θ_A	=	angle where bucket enters jet stream midpoint (rad)
Θ_B	=	angle where bucket leaves jet stream midpoint (rad)
R_s	=	radius of bucket splitter end (m)
δ	=	angular distance between buckets (rad)

Note, a solution of Θ_B can be solved for by utilizing the bi-sectional numerical method. Aerodynamic efficiency can be computed by dividing the power required to move the runner and buckets through the air in the turbine box by the power in the jet. The power required to overcome drag is calculated by multiplying the drag force by the velocity of the bucket. A simplified formula of the aerodynamic efficiency can be expressed as follows,

$$\eta_a = 1 - K_D\cdot\frac{\rho_c}{\rho_w}\cdot\frac{A_f}{A_j}x^3$$

Where

$$\begin{aligned} \eta_a &= \text{aerodynamic efficiency} \\ K_D &= \text{drag coefficient} \\ \rho_c &= \text{density of air (1.23 kg/m}^3\text{)} \\ \rho_w &= \text{density of water (1000 kg/m}^3\text{)} \\ A_f &= \text{peripheral area of bucket (m}^2\text{)} \\ A_j &= \text{cross-sectional area of jet (m}^2\text{)} \\ x &= \text{ratio of runner velocity to jet velocity} \end{aligned}$$

Due to the direct mount of the turbine to the generator, the mechanical efficiency can be assumed a value of 1. Combining the hydraulic efficiency, aerodynamic efficiency, and mechanical efficiency, the total turbine system efficiency of the turbine can be expressed as,

$$\eta_t = \eta_h \cdot \eta_a \cdot \eta_m$$

Where

$$\begin{aligned} \eta_t &= \text{total turbine system efficiency} \\ \eta_h &= \text{hydraulic efficiency} \\ \eta_a &= \text{aerodynamic efficiency} \\ \eta_m &= \text{mechanical efficiency} \end{aligned}$$

6.3.2 Hydraulic Efficiency Program Results

The calculated value of the turbine efficiency, 0.81, which exceeds the value given in Thake as the average efficiency of a micro-hydro Pelton, 0.75. In the following calculation of predicted power output we will continue to use the value given in Thake, to take into account possible minor inaccuracies in the manufacture of the buckets and the nozzles.

6.4 Prediction of Micro Hydro Electric System Power Output

The predicted power output of the system can be solved using the same equation that was used to estimate the system flow rate, substituting the values outlined in the previous sections.

$$P = \eta \cdot Q \cdot \rho_w \cdot g \cdot H_n$$

Using known constants, ρ_w and g, the calculated values of, $Q = 0.021\mathrm{m}^3/\mathrm{s}, \eta_{generator} = 0.88, H_n = 52.5$ m, and a value of 0.75 for $\eta_{turbine}$, the predicted power output can be calculated as 7.138 kW.

6.5 Aqueduct Component Description

This section describes the usage of water storage and the Penstock design.

6.5.1 Water Storage Tank

The Comunidad Finca Nueva Alianza project will utilize an existing 200,000 liter tank to collect water for the turbine. However, this tank will not store enough water to provide the community with sufficient electricity, specifically during the dry season. When one generator is running, there is not sufficient water to produce electricity all day long until there is a flow rate into the tank of 23 l/s. In the dry season, when the flow rate drops as low as 9 l/s, only 6 hours and 10 minutes of electricity is available, in two 3 hour and 5 minute cycles. The problem is more severe when both generators are needed (i.e. the system does not reach 3 hours of generating time until there is a flow rate of 17 l/s).

Although both generators will not be operating simultaneously except at the time of year when coffee is processed, and the input flow rate is relatively high, the existing tank will not provide enough electricity at peak time periods for any productive work to take place. At the peak flow rate of 40 l/s, 7 hours and 56 minutes of electricity will be produced. However, this is produced in two 3 hour and 28 minute cycles. The 2 hour break required between the cycles for tank refill would substantially impede any work attempts.

A solution to this problem is to construct another 200,000 liter tank upstream of the existing tank, giving an overall water storage capacity of 400,000 liters. With a 400,000 liter capacity, running one generator, the hydro-electric system will provide power all day starting at a flow rate of 20 l/s. At the low flow rate of 9 l/s the generating capacity is increased, though only slightly, from 6 hours and 10 minutes to 7 hours and 40 minutes. Though, quantitatively, this increase may not be extremely significant, the qualitative, practical aspect of the generated electricity is improved greatly. With the new tank, almost all of the available generating time, 6 hours and 10 minutes, will be produced in one cycle. This provides much greater flexibility in the range of options available to the users.

The difference in tank capacity also provides a significant difference in generating capacity when two generators are being used. At the peak flow rate, the first generating cycle will last 7 hours and 56 minutes, which is enough time for a significant amount of work to be done. There will also be over 4 hours of useful energy available in the evening. At the lowest flow rate during the coffee processing season, 20 l/s, 6 hours and 32 minutes of generating time is available, in two 3 hour and 16 minute cycles. At that flow rate with one tank, only 3 hours and 16 minutes of generating time is available, in two 1 hour and 8 minute cycles.

It has become obvious upon analysis of available flow rate and generating time that, for the community to obtain useful energy from the hydro-electric system (i.e. sufficient electricity at necessary times), that the construction of a second 200,000 liter tank is required. For further details of the relationship between flow rate, tank capacity, and generating times, see the following tables (Appendix D).

New Tank Design

Safety is the primary concern in construction of the new tank. The channel and existing tank are located on a precipitous hillside, with fairly loose soil conditions. The heavy rain that the region receives at times further lowers the integrity of the soil. For these reasons the amount of excavation done in construction of the new tank should be kept to a minimum. The tank must also be designed so that all of its storage capacity is available to the existing downstream tank, and from there available to the turbines. That is, the bottom of the new tank cannot be lower than the entrance the existing tank or any portion of the channel between the tanks. In order to fulfill these conditions the tank will take on a relatively narrow and shallow form, with most of its storage capacity coming from the designed length.

6.5.2 Penstock

The penstock is the piping that brings the water from the tank to the point where it begins to be directed to the two turbines. The routing of this penstock is determined by the layout of the existing infrastructure from the previous hydro-electric scheme. Penstock material is high pressure uPVC, chosen for its availability, affordability, and low friction loss characteristics. Calculations that verify that uPVC will withstand the maximum possible pressure in the penstock were performed and the results follow this discussion. The disadvantage of uPVC is that it is a relatively fragile material. uPVC is susceptible to mechanical damage from falling rocks or trees, and to chemical damage from UV radiation. If the piping is

Table 4: uPVC Penstock Properties used for Design

	Value	Units
Pressure Rating	1.724	MPa
Thickness (measured)	0.009	m
Inside Diameter (measured)	0.150	m
Penstock Length	117.7	m
Young's Modulus (Harvey et. al. 2005)	2.8×10^9	N/m^2
Tensile Strength (Harvey et. al. 2005)	28×10^6	N/m^2
Roughness factor (Harvey et. al. 2005)	0.01 (normal)	mm

weakened in any way, due to the high pressure in the penstock in any surge event, failure is a definite possibility. To prevent this, the uPVC piping will be founded in concrete along its entire length. At the bottom of the penstock, before the entrance to the machine house, a purge valve will be installed. This valve will allow the penstock to be emptied for turbine maintenance.

An air intake tube will be located at the top of the penstock. Whenever the sluice gate is closed, this intake will prevent a vacuum from forming (caused by the emptying of water at the bottome of the penstock). A vacuum event could result in damage to the penstock.

A six inch Y in the penstock will lead to a six-three inch reducer, followed by three inch PVC piping reaching to an altitude three feet higher than that of the top of the storage tank. The top of the tube will be covered with metal mesh, to prevent entry of any foreign objects while allowing the free passage of air.

The penstock will need to be anchored to prevent any downward or sideways movement. The anchors will consist in flanges cemented to the outside of the pipe every thirty meters, and then cast into the concrete that will cover the penstock. This procedure follows guidelines given for Harvey for installations with a capacity of less than 20 kW and 60 m of head.

The thickness of the penstock is chosen by determining the potential water hammer effect. A water hammer effect is surge pressure that occurs when the nozzles in the turbine become plugged and the flow in the Penstock is suddenly stopped. The surge pressure can be calculated by using the following formulae (Thake 2000),

$$h_{surge} = \frac{V_{wave} \cdot \triangle V}{g}$$

$$V_{wave} = \sqrt{\frac{1}{\rho_w \left(\frac{1}{K} + \frac{d}{E \cdot t}\right)}}$$

Where

$$\begin{aligned}
h_{surge} &= \text{surge head (m)} \\
V_{wave} &= \text{pressure wave velocity - speed of sound within the penstock (m/s)} \\
\triangle V &= \text{change in velocity of flow in penstock (m/s)} \\
g &= \text{acceleration due to gravity (9.81 m/s}^2\text{)} \\
\rho_w &= \text{density of water (1000 kg/m}^3\text{)} \\
K &= \text{bulk modulus of water (2.1 } \times 10^9 \text{ N/m}^2\text{)} \\
d &= \text{measured inside pipe diameter (m)} \\
E &= \text{Young's Modulus for uPVC (2.8 } \times 10^9 \text{ N/m}^2\text{)} \\
t &= \text{ thickness of penstock (m)}
\end{aligned}$$

Using the measured uPVC tube diameter of 0.150 m and thickness of 0.009 m, the pressure wave velocity can be calculated as follows,

$$\begin{aligned}
V_{wave} &= \sqrt{\frac{1}{1000\left(\frac{1}{2.1\times 10^9} + \frac{0.150}{2.8\times 10^9 (0.009)}\right)}} \\
&= 394.4 \text{ m/s}
\end{aligned}$$

For multijet Pelton turbines, an approximation for $\triangle V$ using a factor of safety is given in the following formulae (Thake 2000),

$$\triangle V = \frac{V}{n_{jet}}$$

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

where

$$\begin{aligned}
V &= \text{initial velocity in the pipe (m/s)} \\
n_{jet} &= \text{number of jets on the penstock} \\
Q &= \text{flow rate (m}^3\text{/s)} \\
A &= \text{area of flow (m}^2\text{)}
\end{aligned}$$

With a maximum flow rate of 0.042 m^3/s, the initial velocity in the pipe can be calculated as,

$$\begin{aligned}
V &= \frac{0.042}{\pi (0.075)^2} \\
&= 2.38 \text{ m/s}
\end{aligned}$$

The initial velocity can then be used to calculate the change in velocity in the penstock as follows,

$$\begin{aligned} \triangle V &= \tfrac{2.38}{4} \\ &= 0.594 \text{ m/s} \end{aligned}$$

Using both the value calculated for the initial velocity and pressure wave velocity, the surge head can be calculated

$$\begin{aligned} h_{surge} &= \tfrac{0.594(394.4)}{9.81} \\ &= 23.9 \text{ m} \end{aligned}$$

A formula for the factor of safety can be expressed as (Harvey, 2005),

$$S.F. = \frac{t_{eff} \cdot S}{5 \cdot h_{total} \cdot 10^3 \cdot d}$$

where

$$\begin{aligned} S.F. &= \text{factor of safety} \\ t_{eff} &= \text{effective thickness of pipe (m)} \\ S &= \text{tensile strength (N/m}^2\text{)} \\ d &= \text{measured inside pipe diameter (m)} \\ h_{total} &= h_{surge} + h_{gross} \text{ (m)} \end{aligned}$$

Harvey suggests using factor of safety value of 2.5. Using the values for the uPVC Penstock (Table 4) and 57.3 m for the gross head, h_{gross}, the h_{total} = 23.9m + 57.3m= 81.2m and a calculation for the safety factor is as follows,

$$\begin{aligned} S.F. &= \tfrac{0.009(28\times10^6)}{5(81.2)(10^3)(0.150)} \\ &= 4.14 \end{aligned}$$

Therefore, the 6 in uPVC penstock pipe material is sufficient to mitigate the water hammer effect in this micro hydro electric design according to Harvey's suggestions (Harvey et. al. 2005).

6.6 Power House Component Description

This section describes all the components of the power house. This includes every component associated with the Peltric set and the drainage canal. This project will make use of the existing machine house from the previous generating plant. The house contains various concrete structures in differing states of repair; some of these will be removed to make room for new platforms for the generator/turbine units. For details, see the installation manual or Appendix B.

6.6.1 Peltric Set

This section of the peltric set includes a description of the generator, manifold, nozzles, deflectors, Pelton wheel - buckets and runner, and the turbine platform and housing.

Generator

The Voltmaster EC8-3 was chosen as the generator for the Comunidad Nueva Alianza hydroelectric system. The EC8-3 meets six important selection criteria:

1) The EC8-3 has bi-directional rotational capacity. This provides flexibility in the layout of the turbine house. This flexibility is especially desirable for this project, in which a previously built building with existing concrete structures will be adapted for the new equipment.
2) The EC8-3 is also equipped with an automatic voltage regulator, which provides ease of control of the electrical output of the generator.
3) The EC8-3 produces 3-phase alternating current. As discussed in the electrical distribution section of this document, 3-phase electricity drops voltage much less than single phase in distribution, reducing the number of step-up transformers required which reduces the cost and complexity of the electrical distribution system.
4) The EC8-3 has a rated power output of 8 kW. This was decided upon as the optimum power output for a single turbine, providing a balance between conserving water in the stream, specifically during the dry season, and producing enough electricity for the project to be useful to the community.
5) The EC8-3, when the voltage regulator is connected with the parallel star circuit configuration, presents the ability of producing electricity with both a 120 V and a 240 V potential difference. With both these voltage capacities, a wide range of electrical equipment is available for use in the community.
6) As compared to an induction motor, the EC8-3 also allows the coffee processing machinery to be used safely and reliably. Induction motors do not operate well as generators when they are connected to electrical motors with a large start-up power requirement. The projected motor use for the coffee processing will possess a start-up power requirement of 6

kW before dropping to 4 kW during regular use. This power use requirement exceeds what an induction motor would be able to reliably supply.

Table 5: Voltmaster EC8-3 Generator Specifications

	Value	Units
Rated power capacity	8	kW
Rated current capacity	24	amps
Rated potential difference	240	volts
Number of phases	3	-
Frequency	60	hertz
Optimal rotational velocity	1800	rpm
Power factor	1.0	-
Maximum ambient temperature	40	Celsius

Manifold

As the penstock enters the lower room of the machine house, the single pipe must split into two pipes to reach the two peltric sets. There are no accessories available for this size and pressure rating, and so the splitter must be custom made. For ease of manufacturing, and to ensure that the splitter will withstand the high pressure at this point in the penstock, the splitter will be made of galvanized iron tubing, with a pressure rating of 500 psi. The tubing between the splitter and the turbines will be unsupported. Lengths of up to five meters of small diameter iron piping can run unsupported without risk of damage (Thake 2000). This manifold will be manufactured at Xelateco.

Nozzle

The nozzles focus and direct the flow of water so that it impacts the Pelton spoons at the PCD. The diameter of the nozzles is designed to provide a jet of water of the correct diameter at this point. A 14 degree straight taper nozzle was chosen for this design. According to Thake, this nozzle design is thought to have the best discharge coefficient for Pelton applications (Thake 2000). The following formulae are used to calculate the nozzle diameter and nozzle length used for this design (Thake 2000).

$$d_n = \sqrt{\frac{4 \cdot Q}{V_n \cdot n_n \cdot \pi}}$$

$$V_n = C_D \cdot \sqrt{2 \cdot g \cdot H}$$

$$L_n = \frac{d_c - d_n}{\tan(\theta)}$$

Where

$$\begin{aligned}
d_n &= \text{exit nozzle diameter (m)} \\
Q &= \text{flow rate through turbine (m}^3\text{/s)} \\
n_n &= \text{number of nozzles} \\
V_n &= \text{velocity through nozzle - adjustable (m/s)} \\
C_D &= \text{ discharge coefficient} \\
g &= \text{acceleration due to gravity (9.81 m/s}^2\text{)} \\
H &= \text{head at turbine (m)} \\
L_n &= \text{nozzle length (mm)} \\
d_e &= \text{entrance nozzle diameter (mm)} \\
\theta &= \text{taper angle of nozzle (degrees)}
\end{aligned}$$

Using a flow rate of 0.021m^3/s, 2 nozzles, a discharge coefficient of 0.96 and a net head of 52.5m, the velocity through the nozzle and the nozzle diameter is determined as,

$$\begin{aligned}
V_n &= 0.96\sqrt{2(9.81)(52.5)} \\
&= 30.8 \text{ m/s} \\
d_n &= \sqrt{\tfrac{4(0.021)}{30.8(2)(\pi)}} \\
&= 0.021 \text{ m}
\end{aligned}$$

With a 50.8mm entrance nozzle entrance, 21.0mm calculated exit nozzle diameter and a 14° taper angle of nozzle, the nozzle length can be calculated as,

$$\begin{aligned}
L_n &= \tfrac{50.8-21.0}{\tan(14)} \\
&= 119.8 \text{ mm}
\end{aligned}$$

The placement criteria of these nozzles is as follows,

1) The nozzle exits have to be located as close to the Pelton wheel as possible to prevent the jet from diverging beyond the diameter designed for in the spoon calculations.
2) The distance between the nozzle and the spoons should be 5% of the pitch circle diameter, plus an extra 3mm clearance to account for the emergency deflectors (Equation 1).

$$X_s \geq 0.05 \cdot D_B + T_D \tag{1}$$

Where

$$\begin{aligned} X_s &= \text{minimum safe distance between nozzle and Pelton wheel (mm)} \\ D_B &= \text{outside bucket diameter (mm)} \\ T_D &= \text{thickness of deflectors (mm)} \end{aligned}$$

3) The distance between the center point of the nozzle exit and the pitch circle diameter, measured at a tangent to the pitch circle, should be between 50% and 60% of the pitch circle diameter (Equation 2). The actual distance required, taking into account the minimum clearance between the nozzle and the buckets, will be determined with the help of computer aided design (CAD) software (Equation 2).

$$X_n = 0.625 \cdot PCD \tag{2}$$

Where

$$\begin{aligned} X_n &= \text{distance from nozzle to bucket (100mm - CAD)} \\ PCD &= \text{pitch circle diameter (mm)} \end{aligned}$$

The required distance determined is bigger than the specified maximum distance of 60% of the PCD, due to inconsistencies in the manufacture of the spoons and the need to have a minimum distance of safety between the nozzle and the Pelton wheel.

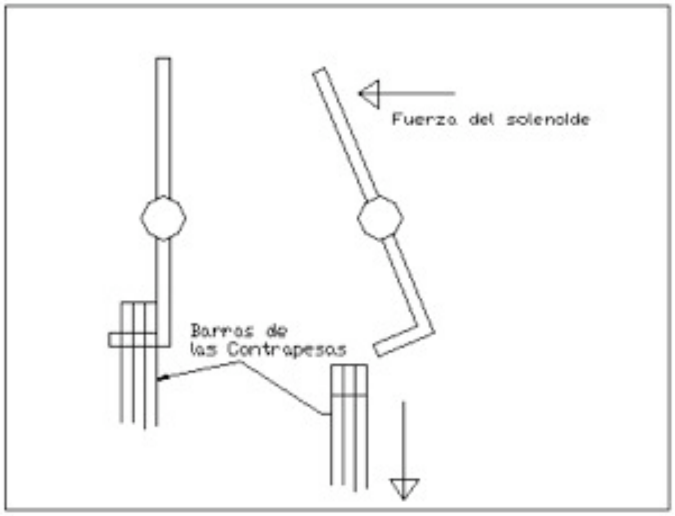

Figure 3: Representation of Deflector Mechanism (Thake 2000)

Deflectors

The generators utilized in this power scheme have a rated operating velocity of 1800 rpm. They can operate efficiently within a 10% +/- range, between 1620 and 1980 rpm. At higher speeds, beginning once a value of 1.5x the rated velocity is reached (i.e. 2700 rpm, the overspeed velocity), damage can occur to the generator assuming this speed is sustained for more than 3-4 minutes. The runaway speed of Pelton turbines, the speed at which turbine efficiency drops to zero and acceleration becomes impossible, is 190%-200% of designed values (Portegijs 2000), in this specific case, 3400-3600 rpm, much higher than the velocity in which damage occurs to the generator. As such, an emergency deflector system must be installed to protect the generators in case of load circuit failure (in which case, for lack of resistance, the force input from the turbine will quickly accelerate the generator past its overspeed velocity). Emergency deflectors can be operated by hydraulic, pneumatic, or mechanical systems. Because of the relative simplicity and low cost of mechanical systems, that is the option that will be chosen for this project.

The deflectors will be operated by deadweights, supported on the shafts to which the deflectors are attached, mounted outside the turbine housing on the side of the generators. Each deflector has its own deadweight, sized to provide the force necessary to hold the deflector inside the stream of the jet, oversized with a total safety factor of 2. In normal operating conditions, the deadweights are held in an almost completely upright position, with a slight angle to ensure that they will fall in the correct direction. Each deadweight is connected by a flat steel bar to a central point of convergence. At the point of convergence, the two bars are supported, through holes drilled into them, by a lever in the shape of an L. The bars are connected to the deadweights in such a way that they can pivot, allowing it to fall when they are released from the lever that supports them. The lever is activated by a DC solenoid.

The force of in each deflector can be calculated can be calculated with the given formulae (Thake 2000),

$$F = -\rho \cdot Q \cdot \triangle V$$

$$Q = \frac{Q_T}{n}$$

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

where

$$\begin{aligned} \rho &= \text{ density of water (1000 kg/m}^3\text{)} \\ Q &= \text{flow rate through each jet (kg/m}^3\text{)} \\ Q_T &= \text{total flow through (kg/m}^3\text{)} \\ n &= \text{number of jets} \\ \triangle V &= \text{change in velocity at deflector (m/s)} \\ V_j &= \text{velocity of each jet (m/s)} \\ A &= \text{cross-sectional area of nozzle exit (m}^2\text{)} \end{aligned}$$

The flow rate of each jet and the velocity of each jet are calculated using 0.021m^3/s as the total flow rate with 2 nozzles and a cross-sectional area $A = \pi(0.0105)^2 = 3.46 \times 10^{-4}$ m^2 as follows,

$$\begin{aligned} Q &= \tfrac{0.021}{2} \\ &= 0.0105 \text{ m}^3\text{/s} \\ V_j &= \tfrac{0.0105}{3.46 \times 10^{-4}} \\ &= 30.8 \text{ m/s} \end{aligned}$$

The change in velocity at the deflector is calculated as the unknown side of a triangle formed between the velocity vectors V_j and $k \cdot V_j$ (where $k = 0.65$), containing a 65° angle (Thake 2000). Using the law of cosines, a simple evaluation denotes $\triangle V$ equal to -28.8 m/s. The force in each deflector can be evaluated as follows,

$$\begin{aligned} F &= -1000(0.0105)(-28.8) \\ &= 302 \text{ N} \end{aligned}$$

With a safety factor of 1.5, the force applied to the deflector $F_{req} = F(S.F.) = 302(1.5) =$

453N is the force that is used in the design of the micro hydro electric system. The torque acting on the deflector arms can be calculated by useing the following the following formula (Carvill 1993),

$$T = F_{req} \cdot r$$

Where

$$\begin{aligned} T &= \text{torque (N-m)} \\ F_{req} &= \text{force with safety factor (N)} \\ r &= \text{radius of deflector arm (m)} \end{aligned}$$

This design used a radius of the deflector arm as the shortest radius possible taking into consideration the location of the generator. With a radius value of 0.10 m, the torque was calculated as,

$$\begin{aligned} T &= 453(0.10) \\ &= 45.3 \text{ N-m} \end{aligned}$$

The required torque takes into account a friction factor, f, of 1.2 acted upon by the bearings. The required torque calculation can be evaluated as,

$$\begin{aligned} T_{req} &= T \cdot f \\ &= 45.3(1.2) \\ &= 54.4 \text{ Nm} \end{aligned}$$

The deadweight mass of the deflectors is calculated with the following formulae (Carvill 1993),

$$F_D = \frac{T_{req}}{r_D}$$

$$m_D = \frac{F_D}{g}$$

Where

$$\begin{aligned} F_D &= \text{force of deadweight (N)} \\ T_{req} &= \text{required torque (N-m)} \\ r_D &= \text{radius of deadweight arm (m)} \\ m_D &= \text{mass of deadweight} \\ g &= \text{acceleration due to gravity (9.81 m/s}^2\text{)} \end{aligned}$$

This design incorporated a radius of 0.45 m for the deadweight arm to compromise the length of the arm and the necessity to support sufficient weight. The calculations are as follows,

$$\begin{aligned} F_D &= \tfrac{54.4}{0.45} \\ &= 121 \text{ N} \\ m_D &= \tfrac{121}{9.81} \\ &= 12.3 \text{ kg} \end{aligned}$$

Using a safety factor of 1.5, the actual mass of the deadweight used for this design is as shown,

$$\begin{aligned} m_{D\ actual} &= m_D(S.F.) \\ &= 12.3(1.5) \\ &= 18.5 \text{ kg} \end{aligned}$$

The force required to release the deadweights can be calculated by first calculating the torque acting on the lower portion of the solenoid lever. The torque can be calculated by the following formulae (Carvill 1993),

$$T_A = F_A \cdot r_A$$

$$r_A = \frac{c}{\sin{(\alpha)}}$$

$$F_A = n \cdot F_D \cdot \sin \alpha$$

Where

T_A = torque acting on the lower portion of the solenoid lever (N-m)
F_A = force required to remove the lower solenoid lever from the deadweight bars (N)
r_A = radius of lower portion of solenoid lever (m)
c = length of perpendicular lever arm (m)
α = angle of operation of the lever chosen to minimize force required (m)
n = number of deadweights
F_D = force of deadweight (N)

The lever operation angle designed to minimize the force required to release the deadweights was determined as 22.5°. Using lever arm length of 0.019 m for supporting two bars of width 0.0063 m, the lower portion radius of the solenoid lever is calculated as,

$$\begin{aligned} r_A &= \tfrac{0.019}{\sin{(22.5)}} \\ &= 0.0496 \text{ m} \end{aligned}$$

The forces required to remove the solenoid levers from the deadweight bars can be calculated using the force of the deadweight, 182 N, and the number of deadweights, 2, as follows,

$$
\begin{aligned}
F_A &= 2(182)(\sin 22.5) \\
&= 139 \text{ N}
\end{aligned}
$$

These values are then used to calculate a torque value of 6.027 N-m (i.e. $T_A = 0.0496(139) = 6.89$ N-m). A similar equation will be used to determine the force required by the solenoid in relation to the upper portion of the solenoid lever and is expressed as,

$$F_B = \frac{T_B}{r_B}$$

Where

$$
\begin{aligned}
T_B &= \text{torque acting on the upper portion of the solenoid lever (N-m)} \\
F_B &= \text{force required to remove the upper solenoid lever from the deadweight bars (N)} \\
r_B &= \text{radius of upper portion of solenoid lever (m)}
\end{aligned}
$$

Using the same torque value for T_B as was calculated for T_A and a 0.1 m radius for the upper portion of the solenoid lever, the force required to remove the upper portion solenoid lever from the deadweight bars, F_B, is as shown,

$$
\begin{aligned}
F_B &= \tfrac{6.89}{0.1} \\
&= 68.9 \text{ N}
\end{aligned}
$$

Therefore, 68.9 N will be the required operating force of the solenoid.

The operating stroke is equal to the horizontal length of the solenoid lever, 19 mm.

Pelton Wheel - Runner and Buckets

The runner size is determined by the pitch circle diameter, and the shaper is determined by

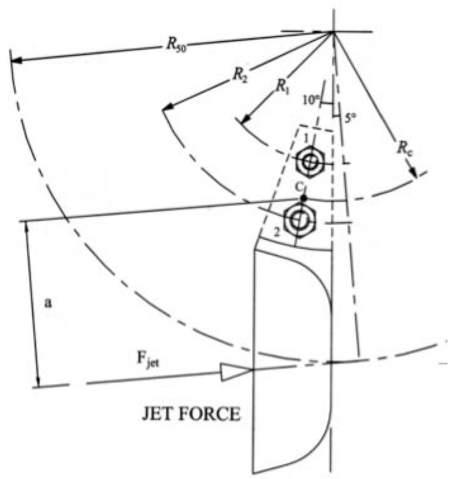

Figure 4: Representation of the Jet Force Applied to Each Individual Cup (Thake 2000)

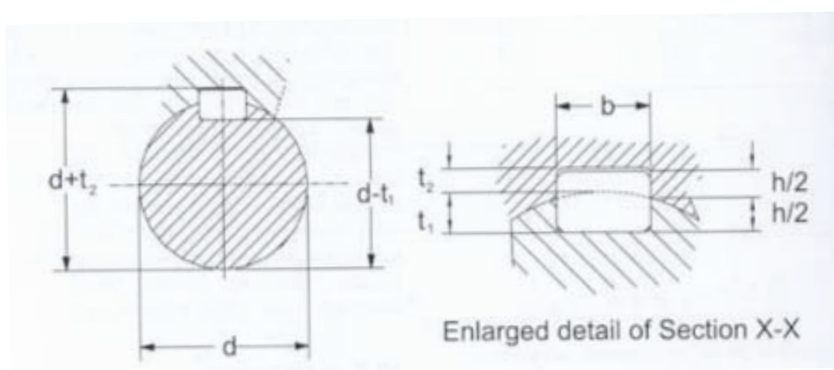

Figure 5: Representation of Runner Shaft Keyway (Thake 2000)

the number of buckets on the runner. The shaft is sized to mount directly on the generator shaft. It is also necessary to seal the hole through which the generator shaft enters the turbine box. This will be accomplished by a flinger seal. The flinger seal is a non-contact seal that has been proven very effective in practice.

For the runner shaft design, the runner shaft keyway will be sized based on generator shaft dimensions and the British standard for parallel and taper metric keyways, BS142345 (Thake 2000). The runner shaft hole will be machined to transition location fit K6, defined

Table 6: Generator Shaft Dimensions

Description	Value
Key Width, w_k	10 mm
Key Height, h_k	3 mm
Allowed Width of Keyway, b	$w_k \pm$ 0.018 mm
Allowed Height of Keyway, t	$h_k + 0.2$ mm
Radius of Mill Cut in Keyway, r_{min}, r_{max}	0.25 - 0.4 mm

as a fit that gives a small clearance that is not easy to assemble or disassemble. This fit is considered suitable for hubs and pulleys on keyed shafts.

With thousands of jet impacts daily, the main source of failure of the Pelton buckets will be fatigue. To analyze fatigue stress on the bucket stems we use the following formula,

$$\sigma_f = \frac{M}{Z}$$

Where

$$\begin{aligned} \sigma_f &= \text{Fatigue stress (MPa)} \\ M &= \text{Bending moment at fatigue point (N-mm)} \\ Z &= \text{Stem section fatigue modulus(mm}^3\text{)} \end{aligned}$$

The bending moment can be analyzed as follows, calculating jet force as force from net head and discounting nozzle losses (Thake 2000),

$$M = F_j \cdot r$$

$$F_j = \rho_w \cdot g \cdot H_g \cdot A_j$$

$$r = 0.195 \cdot PCD$$

Where

$$\begin{aligned}
M &= \text{bending moment at fatigue point (N-mm)}\\
F_j &= \text{force of jet (N)}\\
r &= \text{moment arm of bucket (mm)}\\
\rho_w &= \text{density of water(1000 kg/m}^3\text{)}\\
g &= \text{Acceleration due to gravity (m/s}^2\text{)}\\
H_g &= \text{gross head (m)}\\
A_j &= \text{area of jet (m}^2\text{)}\\
r &= \text{moment arm of bucket (mm)}\\
PCD &= \text{pitch circle diameter (m)}
\end{aligned}$$

The stem section fatigue modulus is calculated as, $Z = 0.00024 \cdot PCD^3 = 819.2\text{mm}^3$. This value can then be used to calculate the fatigue stress as, $\sigma_f = \frac{5665}{819.2} = 6.92$ MPa. Thake states the fatigue design stress for bronze is 20 MPa (Thake 2000). This value includes a factor of safety of 4.5, and is well over our calculated stress of 6.92 Mpa.

For the bucket design, there is a variety of standard Pelton bucket designs used by manufacturers today. Because of the complexity of the flow within the bucket, it has been impossible for one standard design to be developed which is considered most efficient. However, a basic shape has been established, and all the designs that are used follow this basic shape, with small variations. The bucket design used in this project comes from Thake. It has the advantage of being easy to make in manufacturing facilities equipped with simple technology, while at the same time providing a reasonable hydraulic efficiency. The proportions used are further discussed in this section.

The stem portions of each individual bucket are designed to withstand the tensile stresses at overload radial velocity (i.e. runaway) to accommodate centrifugal force. Each individual cup will also need to accommodate fatigue load of constant operation. The tensile stress calculations of the stem portions of each individual cup on the Pelton wheel can be evaluated with the following formulae (Thake 2000),

$$\sigma_t = \frac{F_{runaway}}{A_{stem}} = \frac{m_b \cdot R_g \left(\frac{\pi \cdot N_{runaway}}{30}\right)^2}{A_{stem}}$$

$$m_b = V_b \cdot \rho_{bronze}$$

$$R_g = 0.47 \cdot PCD$$

$$N_{runaway} = 1.8 \cdot N_{optimal}$$

$$A_{stem} = A_{R_2} - A_{bolt}$$

$$V_b = 0.0063 \cdot PCD^3$$

Where

$$\begin{aligned}
\sigma_t &= \text{tensile stress at runaway (Pa)} \\
F_{runaway} &= \text{force at runaway (N)} \\
A_{stem} &= \text{area of stem at center line of bolt - Figure 4 (m}^2\text{)} \\
m_b &= \text{mass of bucket (kg)} \\
R_g &= \text{radius of bucket center of mass to runner center (m)} \\
N_{runaway} &= \text{runaway speed (rpm)} \\
N_{optimal} &= \text{optimal speed - Table 6 (rpm)} \\
A_{R_2} &= \text{cross-sectional area of stem at } R_2 \text{ - Figure 5 (m}^2\text{)} \\
A_{bolt} &= \text{cross-sectional area of bolt at } R_2 \text{ (m}^2\text{)} \\
V_b &= \text{bucket volume outside of stress point (m}^3\text{)} \\
PCD &= \text{pitch circle diameter (m)} \\
\rho_{bronze} &= \text{density of bronze (8700 kg/m}^3\text{)}
\end{aligned}$$

The calculation of the bucket volume with a PCD value of 0.15 m is as follows,

$$\begin{aligned}
V_b &= 0.0063(0.15)^3 \\
&= 21.3 \times 10^{-6} \text{ m}^3
\end{aligned}$$

The mass of the bucket is as follows,

$$\begin{aligned}
m_b &= 21.3 \times 10^{-6}(8700) \\
&= 0.185 \text{ kg}
\end{aligned}$$

The radius of bucket center of mass to runner center can be calculated as,

$$\begin{aligned}
R_g &= 0.44 \cdot 0.16 \\
&= 0.0704 \text{ m}
\end{aligned}$$

The area of the stem at the weakest point can be calculated as,

$$\begin{aligned}
A_{stem} &= (3.66 \times 10^{-4}) - (1.2 \times 10^{-4}) \\
&= 2.46 \times 10^{-4} \text{ m}
\end{aligned}$$

The runaway speed is expressed as,

$$\begin{aligned}
N_{runaway} &= 1.8 \times 1800 \\
&= 3240 \text{ rpm}
\end{aligned}$$

The tensile stress at runaway can then be calculated as,

$$\begin{aligned}\sigma_t &= \frac{0.185(0.0704)\left(\frac{\pi(3240)}{30}\right)^2}{2.46\times10^{-4}} \\ &= 6.09 \text{ MPa}\end{aligned}$$

Using a factor of safety equal to 4, the design criteria of a maximum tensile stress will be 24.4 MPa (i.e. 6.09(4) = 24.4). Material properties of bronze indicate a maximum tensile strength of 60 MPa; hence, the maximum tensile stress calculated with a factor of safety equal to 4 meets the design criteria. The buckets will be held to the runner with bolts made

Table 7: Stainless Steel 304 Material Properties

Description	Value
Tensile Strength	621 MPa
Yield Strength	290 MPa
Modulus of Elasticity - Tension	193 GPa
Modulus of Elasticity - Torsion	78 GPa

of stainless steel 304 (Table 7). This is the most widely used and versatile stainless steel available, highly regarded for its corrosion resistance, weldability, and relative affordability.

The bolts will be made in the same machine shop as the runner, to ensure an accurate fit. A tight, dowel style fit is necessary to increase the holding load of the bolts; the small diameter bolts used here cannot hold a sufficiently high load solely with friction clamping force. Following is the calculation for allowable bolt stress; where, $R_1 = 27$mm, $R_2 = 40$mm, $D_{bolt} = 5$mm, $A_1 = A_2 = A_{bolt} = 19.64 \times 10^{-6}\text{m}^2$ (Figure 4). Note, the force of the jet acting on the bucket is assumed to be from static head acting on an immobile bucket, which will give a substantially higher force than in reality. Using the afore mentioned formula for the jet force, $F_j = (1000\text{kg/m}^3)(9.81\text{m/s}^2)(58\text{m})(3.46 \times 10^{-4}\text{m}^2) = 194.5$ N. The centroid of the bolt holes will be used to find the moment arm of the force acting on the bucket and can be expressed by,

$$R_c = \frac{A_1 \cdot R_1 + A_2 \cdot R_2}{A_1 + A_2}$$

Where

$$
\begin{aligned}
R_c &= \text{centroid of bolt holes (mm)} \\
A_1 &= \text{area of bolt number 1 (mm}^2\text{)} \\
R_1 &= \text{radius from runner centerline to center of bolt number 1 (mm)} \\
A_2 &= \text{area of bolt number 2 (mm}^2\text{)} \\
R_2 &= \text{radius from runner centerline to center of bolt number 2 (mm)}
\end{aligned}
$$

Since $A_1 = A_2$, the centroid can be calculated as, $R_c = \frac{19.63 \times 10^{-6}(0.027+0.040)}{2(19.63 \times 10^{-6})} = 33.5$ mm. The formula for the direct shear force can be expressed as,

$$S_1 = F_j \left(\frac{A_1}{A_1 + A_2} \right)$$

$$S_2 = F_j \left(\frac{A_2}{A_1 + A_2} \right)$$

Where

$$
\begin{aligned}
S_1 &= \text{direct shear force on bolt number 1(N)} \\
S_2 &= \text{direct shear force on bolt number 2(N)} \\
F_j &= \text{force of jet (N)} \\
A_1 &= \text{area of bolt number 1 (mm}^2\text{)} \\
A_2 &= \text{area of bolt number 2 (mm}^2\text{)}
\end{aligned}
$$

Once again, since $A_1 = A_2, S_1 = S_2$ and can be calculated as, $S_2 = 194.5 \left(\frac{19.63 \times 10^{-6}}{2(19.63 \times 10^{-6})} \right) = 97.25$ N. Since $A_1 = A_2$, the secondary shear formula of bolt number 1 is the same as bolt number 2 in which, T_1, can be expressed as,

$$T_1 = F_j \cdot a \cdot \left(\frac{A_2(R_2 - R_1)}{A_1(R_2 - R_1)^2 + A_2(R_2 - R_1)^2} \right)$$

Where

$$
\begin{aligned}
T_1 &= \text{secondary shear (N)} \\
F_j &= \text{force of jet (N)} \\
A_1 &= \text{area of bolt number 1 (mm}^2\text{)} \\
R_1 &= \text{radius from runner centerline to center of bolt number 1 (mm)} \\
A_2 &= \text{area of bolt number 2 (mm}^2\text{)} \\
R_2 &= \text{radius from runner centerline to center of bolt number 2 (mm)}
\end{aligned}
$$

The shear stress can then be calculated as, $T_1 = 621$ N. The maximum shear force occurs in secondary shear. The bolts need to withstand this force multiplied by an appropriate factor of safety for shear stress. Using a factor of safety equal to 3, $T_{max} = 3(621) = 1.86$ kN. The yield strength of Stainless Steel 304 is 290 MPa (Table 7). To find the force that the bolt can withstand in shear, multiply the yield strength by the area of the bolt as follows,

$$F_{yield} = \sigma_{yield} \cdot A_{x-sec}$$

Where

$$\begin{aligned} F_{yield} &= \text{yield force from shear force (kN)} \\ \sigma_{yield} &= \text{yield strength (MPa)} \\ A_{x-sec} &= \text{area of bolt (MPa)} \end{aligned}$$

This gives a yield force of 5.69 kN for the bolt, which is much larger than the maximum shear force of 1.86 kN.

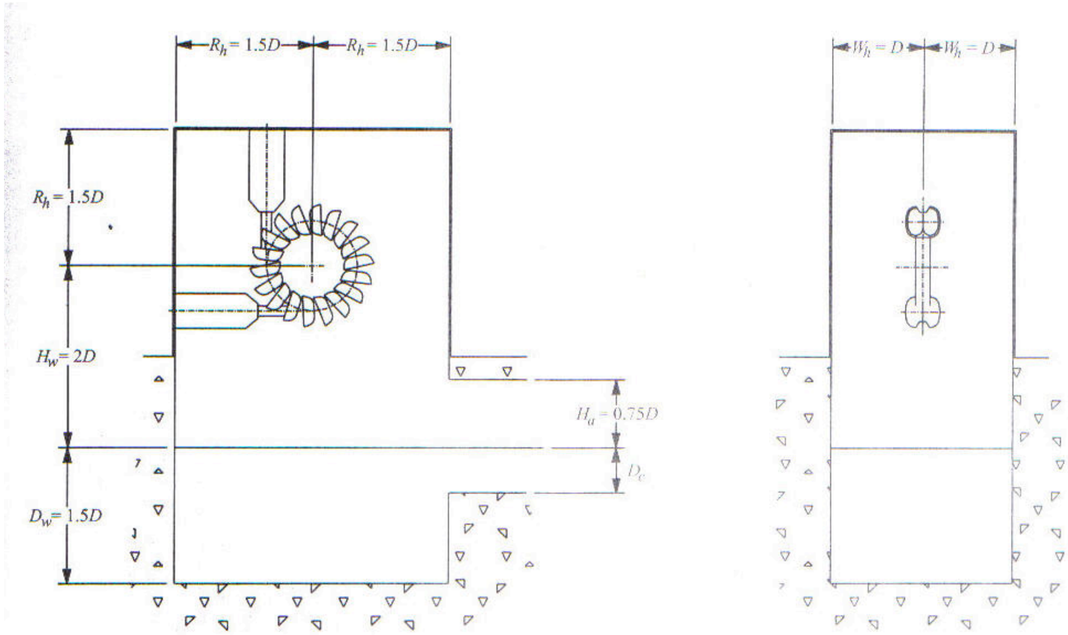

Figure 6: Representation of Suggested Housing Dimensions for a Pelton Turbine (Thake, 2000)

Turbine Platform and Housing

New concrete platforms will be cast into the machine house floor to hold the peltric set in place. These platforms will be reinforced with 3/8 steel bar, as detailed in the construction drawings. Cast into the platforms will be two rows of four anchor bolts each. Once the peltric set has been installed on the platform, the space between the steel and the concrete must be sealed to prevent corrosion damage to the anchor bolts. First the space will be filled with caulk, and then a flexible plastic splash guard will be installed on the steel platform.

The turbine platform design is made with rigid 0.5 in (12.7 mm) steel to support the Pelton turbine housing (Appendix B). The Pelton turbine housing is designed to account for the forces applied by the manifold and bearings (Thake 2000). Thake suggests that horizontal axis micro hydro turbine systems contain side plates that are thicker then the top plates and end plates to reduce vibration and noise from water hitting them (Thake 2000). For a system of a few kilowatts, a 2-3 mm steel plates are suggested; whereas for a system of 50-100 kW, 6-8 mm side plates and 5mm end plates are suggested (Thake 2000). This 16 kW micro hydro electric design uses rigid 0.25 in (6.35 mm) steel for both the side plates and end plates to ensure reduction of both vibration and noise. With the given diameter of 0.15 m, the minimum suggested dimension values of the Pelton turbine housing can be calculated as follows (Figure 6),

$$\begin{aligned}
R_h &= 1.5(D) \\
H_w &= 2(D) \\
D_w &= 1.5(D) \\
H_a &= 0.75(D) \\
W_h &= D
\end{aligned}$$

This particular design contained values of,

$$\begin{aligned}
R_h &= 0.30\text{m} \\
H_w &= 0.49\text{m} \\
D_w &= 0.24\text{m} \\
H_a &= 0.15\text{m} \\
W_h &= 0.15\text{m}
\end{aligned}$$

A minimum value width of 0.15m was used for this design to reduce the hub extension and, hence, bearing strain.

6.6.2 Drainage Component Description

The drainage channel, or tailrace channel, is a concrete channel cast onto the floor of the turbine house that returns the water to the stream. The channel should be designed to carry all of the water from the turbine to the stream without allowing any of it onto the floor of the power house. This means that the slope of the channel must provide a small enough velocity to allow a smooth flowing stream of water. The channel should also have a sufficiently large freeboard (the space between the designed depth of water and the top of the channel) to prevent any splashing that may occur from leaving the channel. The part of the channel immediately below the turbine house will include a settling pit, about twice the depth of the channel, in which the augmented depth will remove energy from the falling water to ensure proper flow in the channel.

The calculations for the drainage channel are as follows (Thake 2000),

$$V = \frac{r^{\frac{2}{3}} \cdot s^{\frac{1}{2}}}{n}$$

$$r = \frac{A}{P}$$

$$P = 2 \cdot C + W$$

$$A = C \cdot W$$

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

Where

V = velocity of water in the channel (m)
s = slope of channel (m/m)
n = roughness factor of channel material (m)
r = ratio of cross-sectional area of water to hydraulic perimeter of channel (m)
P = hydraulic perimeter of channel (m)
A = cross-sectional area of water (m^2)
C = depth of water in channel (m)
W = width of channel (m)
Q = flow rate through turbine (m^3/s)
V = less than V_{max} for a channel of less than 300mm (m^3/s)

Since C is unknown, A will be solved with a flow rate of 0.021 m^3/s and a velocity of 1.0 m/s as shown,

$$\begin{aligned} A &= \tfrac{0.021}{1.0} \\ &= 0.021 \text{ m}^2 \end{aligned}$$

Since $c = \frac{A}{W}$, C can be solved for with a width value of 0.4 m (determined by power house layout),

$$\begin{aligned} C &= \tfrac{0.021}{0.4} \\ &= 0.054 \text{ m} \end{aligned}$$

P and r can then be solved for as follows,

$$\begin{aligned} P &= 2(0.054) + 0.4 \\ &= 0.508 \text{ m} \end{aligned}$$

$$\begin{aligned} r &= \tfrac{0.021}{0.508} \\ &= 0.0413 \text{ m} \end{aligned}$$

Using 0.02 m for the roughness factor of concrete and rearranging the given equation to solve for s is as follows,

$$\begin{aligned} s &= \frac{(V \cdot n)^2}{r^{\frac{4}{3}}} \\ &= \frac{(1.0(0.02))^2}{(0.0413)^{\frac{4}{3}}} \\ &= 0.020 \text{ m/m} \end{aligned}$$

To solve for the depth of the channel, the following formula is used (Thake 2000),

$$d = F + C$$

Where

$$\begin{aligned} d &= \text{depth of channel (m)} \\ F &= \text{Freeboard (m)} \\ C &= \text{depth of water in channel (m)} \end{aligned}$$

Therefore, with a C value of 0.054 m and the Freeboard = 0.4·C, d can be solved for as,

$$\begin{aligned} d &= 1.4(0.054) \\ &= 0.076 \text{ m} \end{aligned}$$

The height of the channel at the turbine platform can be calculated from the following formula (Thake 2000),

$$h = l \cdot s + d$$

$$h_a = h + \triangle h$$

Where

$$\begin{aligned} h &= \text{calculated height of channel (m)} \\ s &= \text{slope of channel (m/m)} \\ l &= \text{length of drainage channel (m)} \\ \triangle h &= \text{change in altitude of the turbine house floor over the length of the channel (m)} \\ h_a &= \text{actual height of channel at turbine platform (m)} \end{aligned}$$

With the given values of, $l = 2.19$ m determined by the power house layout and $h = -0.02$ m measured in the power house, the actual height of the channel is expressed as,

$$\begin{aligned} h &= 2.19(0.020) + 0.076 \\ &= 0.12 \text{ m} \end{aligned}$$

$$\begin{aligned} h_a &= 0.12 + (-0.02) \\ &= 0.10 \text{ m} \end{aligned}$$

This value of the actual height was then used to design the channel (Appendix B).

6.7 Control House Component Description

This section describes the components and attributes of the control house associated with this micro hydro electric design.

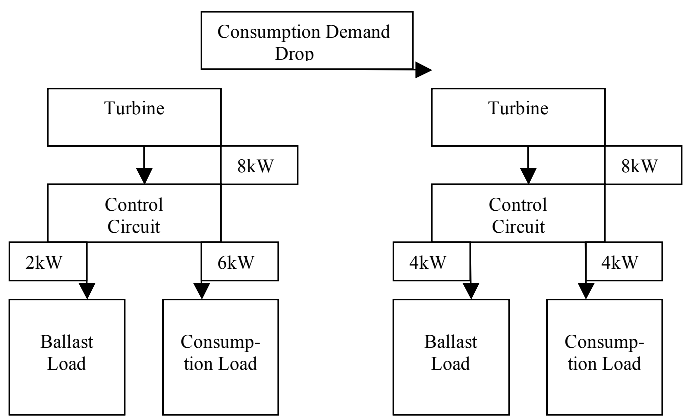

Figure 7: Flow Chart of Load Control

6.7.1 Electric Load Controller (ELC)

There are two basic types of turbine governing systems: load control and flow control. In a load control system, the turbine always operates with the same amount of water and produces the same amount of electricity, but the destination of the electricity is regulated by an electronic control circuit. A ballast load is connected to the generator alongside the intended consumer load. When consumer usage drops, the control circuit directs the electricity to the ballast load, maintaining the resistance in the circuit and keeping the generator from overspeeding. When consumer need rises again, the control circuit redirects electricity to the consumer load, ensuring continuing supply of a sufficient amount of electricity. In a flow control system, the amount of power that the turbine actually produces is regulated, by means of adjustment of the amount of water flowing through the system.

Both systems have advantages and disadvantages. A flow control system always produces exactly the amount of electricity that is needed. In this way energy is conserved, allowing more water to be available when more energy is needed. But flow control is a complex proposition, requiring high pressure hydraulic actuators for the control valves, and a complex controller system that has an extremely exact understanding of the hydraulic functioning of the penstock and manifold under different velocity condition.

Turbines with load control systems always produce the same amount of electricity, sufficient to support peak demand, wasting energy when consumer demand is not at its highest point. But load control systems are much cheaper and simpler, requiring only the electronic control circuit and the ballast load system.

For the Finca Nueva Alianza project, a load control system designed by Norwegian engineer Jan Portegijs will be utilized, because of both the economic limitations of the project and the relatively small amounts of electricity involved. In the future, the installation of water pumps to return water from the turbine drain to the storage tank will be considered as a way to utilize at least part of the energy wasted in the control system. However, at this time, these pumps are beyond the economic scope of the project.

Protection Features

The ELC is fitted with three principal circuit protection features. The protection features are meant mainly to protect user appliances against conditions that might destroy certain types of appliances:

1. Overspeed: Against too high a frequency. This is dangerous for motor driven appliances, especially if the driven machinery requires much more power when driven too fast, e.g. fans or centrifugal pumps. It can occur if the ELC or dump loads fail and the turbine speeds up to run-away speed. The emergency deflector system will also protect both the generator and the user circuits in this case.
2. Overvoltage: Against too high generator voltage. This is dangerous for many types of appliances. Normally, this can only happen with a compound type generator when the ELC or dump loads fail. Because of this it is linked to the overspeed protection. An overvoltage situation might also occur if the generator AVR fails.
3. Undervoltage: Against too low voltage. Then electrical motors might be unable to start or might overheat.

For circuit diagrams of the ELC, see Appendix E.

6.7.2 Ballast Load

The ballast load, or dump load, is the electrical load to which the ELC sends the electricity produced by the generator which is not consumed in the user load. The ballast load usually is composed of submersible resistive heaters; a reliable, safe, and compact method of consuming large amounts of electricity. The ballast load can be used to produce hot water for processing and household purposes. However, at this time, in Comunidad Nueva Alianza there is no use which regularly consumes enough hot water to ensure that the heaters do not burn out. For this reason the ballast tanks will be placed in the storage tank. Although the excess electricity will be wasted, placing the ballast loads in the storage tank will ensure that they always have sufficient water flowing around them to remove the heat from the heaters and prevent failure.

6.8 Electrical Distribution Description

This section describes the design's distribution lines, the expected power use, voltage drop, and use of transformers.

6.8.1 Distribution Lines

Attached to the following documents is a plan for the distribution network for the houses within the community. This plan is specifically designed such that the electricity network conforms to the new urban plan. This takes into account the difficulty in creating a distribution network when houses are located at a considerable distance from each other. With the urbanization of the community, the distances between distribution lines is reduced, creating a more economically viable solution.

The measurements have been made in the distribution network to the houses, and the distances fulfill the regulations established by the National Institute of Electricity (INDE). The measurements also conform to the standards set by the electrical manual for the United States Army for low-tension electricity. The measurements also conform to US Army standards for the depth of the posts, and the distances between the posts.

Pole setting depths shall be as follows:

Length of Pole (mm)	Setting in Soil (mm)	Setting in Solid Rock (mm)
6095	1520	910
7600	1675	1065
9120	1675	1065
10640	1825	1215
12160	1825	1215
13680	1975	1370
15200	2130	1370
16720	2280	1520
18240	2440	1520

Length of Pole (feet)	Setting in Soil (feet)	Setting in Solid Rock (feet)
20	5.0	3.0
25	5.5	3.5
30	5.5	3.5
35	6.0	4.0
40	6.0	4.0
45	6.5	4.5
50	7.0	4.5
55	7.5	5.0
60	8.0	5.0

Figure 8: Representation of UFGS regulations followed for Power Pole Depth (UFGS 2006)

1.) The minimum height of the lines that cross streets is 18 feet (5.48 meters)

2.) The minimum distance between insulators (if the wires are stripped) is 12 inches

3.) The maximum between a house and a post is 150 feet (45.73 meters)

4.) The minimum buried depth of a 10-meter post is 1.8 meters (Figure 7

5.) The maximum distance between electricity posts is 50m-55m depending on the topography and geographical issues

6.) ASCR #2 is the minimum cable type for low-tension transmission lines that can support a 95 amp intensity.

In conforming to the safety regulations are established sufficient conductors for system efficiency.

6.8.2 Household Power Use

Assuming the households utilize a 110 V system at 1.5 amps, a calculation of the maximum power of 165 W for each house connected to the network can be verified by Ohm's law ,

$$P = I \cdot V$$

Where

$$\begin{aligned} P &= \text{power (W)} \\ I &= \text{amperage (amps)} \\ V &= \text{voltage (V)} \end{aligned}$$

Table 8: Example of Electricity Consumption

Device	Amount	Capacity (W)	Daily Use (hr)	Consumption (Whr)
Light (Kitchen)	1	20	4.0	80
Light (Comedor)	1	20	4.0	80
Light (Living room)	1	20	1.0	20
Light (Bathroom)	1	20	1.0	20
Light (Bedroom)	2	40	2.0	80
Television	1	95	4.0	1000
Blender	1	125	0.16	20
Radio	1	50	4.3	301

Using 40 houses yields a rough maximum power demand of, $40(165) = 6.6kW$. Due to the relatively low maximum power use constraint, a detection system has been designed for overloads in the house systems. The system trips if the houses consumption exceeds 1.5 amps by use of a fuse. This regulation has been derived from the norms that the engineer Alvaro Fernandez-Baldor Martinez and engineer Erick Gonzalez wrote up for Comunidad Nueva Alianzas system (Fernndez-Baldor 2005). Furthermore, the Comunidad Nueva Alianza Committee of Micro-hydroelectric Maintenance created regulation with these specifications, including rules and respective sanctions to violators of this regulation. Xelateco is properly informing the community members the capacity of the micro hydro electric system. A table of electrical consumption for domestic electrical devices illustrates the options for which devices can be used, and to what extent. To determine the approximate consumption one can apply the following formula,

$$\text{Average consumption}(W - hr) = \text{Average value}(W) \cdot \text{time of consumption in hours}(hr)$$

6.8.3 Voltage Drop

A voltage drop calculation for a three phase system is as follows,

$$V_{drop} = \frac{1.732 \cdot K \cdot A \cdot D}{CM}$$

where

$$\begin{aligned} V_{drop} &= \text{3 phase voltage drop (V)} \\ K &= \text{resistance in ohms} \\ A &= \text{current in amps} \\ D &= \text{distance (m)} \\ CM &= \text{circular mills - wire size} \end{aligned}$$

From the generator to the control house, the design contains a distance of 180 m (590 pies), utilizes 24 amps, and uses a #6 (26,800 CM) copper wire with a resistance of 12.9 ohms. The calculation of the voltage drop is as follows,

$$\begin{aligned} V_{drop} &= \tfrac{1.732(12.9)(24)(590)}{26800} \\ &= 11.81 \text{ V} \end{aligned}$$

Therefore, from the generator to the control house, this design contains a 4.92% voltage drop assuming a 240 voltage system. From the control house to the household loads, the design contains a distance of 1100 m (3520 pies), utilizes 24 amps, and uses a #1/0 (108036 CM) aluminum wire with a resistance of 21.2 ohms. The calculation of the voltage drop is as follows,

$$\begin{aligned} V_{drop} &= \tfrac{1.732(21.2)(24)(3520)}{108036} \\ &= 28.71 \text{ V} \end{aligned}$$

Therefore, from the generator to the control house, this design contains a 11.96% voltage drop assuming a 240 voltage system. In comparison to a single phase voltage distribution system, a 3 phase voltage distribution system saves 1.82 V(0.78%) of voltage drop from the generator to the control house and 4.44 V (1.85%) of voltage drop from the control house to the household loads (Appendix E).

6.8.4 Voltage Stabilization

To stabilize and restore voltage, there will be provided a system of transformers. The transformers support 20 houses each, according to the guidelines provided by INDE.

6.9 Safety Assessment

This section details the safety issues and regulations associated with the micro hydro electric design.

6.9.1 Water Storage Tank

The tanks are a dangerous part of the micro-hydro system, especially for children. When they are full, the danger of drowning is ever-present, and when they are empty, there relatively high walls and hard surface create the danger of serious injury from falls. For this reason a fence with a locked access gate will be installed around both the existing tank and the new tank.

6.9.2 Power Poles

The regulations that were followed can be seen in Appendix D.

6.9.3 Conduit

"The National Electric Code puts forth the following:

1. If more than three current carrying conductors are to be installed inside a conduit you are only supposed to fill up 40% of the space inside the conduit to help prevent build up of heat. The attached chart show that we are within these parameters with eight #6 awg conductors and three #10 conductors in a 2" conduit. The chart is taken from table C.10 of the 2005 NEC. It takes into account the 40% rule and tells you how many conductors you may install in a specific sized conduit and still be under the 40% fill.

2. The NEC (Table 352.30(B) of the 2005 NEC) says a 2” conduit should be supported every 5 feet along its run and within three feet of each junction box. I don’t know if this rule has been complied with.
3. The only other thing I can think of at this point is the possibility of expansion and contraction of the conduit due to ambient temperature fluctuations. According to Table 352.44(A) of the 2005 NEC a 50 degree farenheit change in temperature will cause the conduit to expand 2.03 inches for every 100 feet.

For additional regulations that were followed, please see Appendix D.

6.9.4 Electrical

Safety is a priority for the entire system. Because of this there is implemented a safety plan for the all of the community members. The Committee of Micro-hydroelectric Maintenance has trained a person to be specifically in charge of servicing maintenance and installation.

Training has been provided to community members to implement electrical installations for housing and industrial needs. With the purpose of guaranteeing safety, all the security measures have been taken, using established international for domestic electricity provision code. Instruments regulate overloads by deactivating the system, such as with residential circuit breakers. The committee of Micro-hydroelectric Maintenance has placed the necessary devices to guarantee the safety of all the people who inhabit the Comunidad Nueva Alianza.

6.10 Installation Guidelines

This section covers installation of the electronic load controller (ELC), turbine and generator with onsite startup of the completed system. Installation of other components, including assembly of the Pelton wheel, construction of concrete structures, and installation of tubing and of electrical components, is covered, at time implicitly, in the design section.

6.11 Operation and Maintenance

6.11.1 Operation

6.11.2 Maintenance

Regular maintenance of the micro-hydro system is necessary to ensure that the system operates as designed and to prolong the life of all the components. Not all parts of the system require maintenance, but all of them require at least to be inspected regularly. Following the section describing what is required is a set of detailed charts to be used at each scheduled maintenance.

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8 Appendix

8.1 Appendix A - Official Contract of Micro Hydro Electric Design

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CONTRATO DE PROYECTO

De Fabricación, Servicios, Instalación, de Energías Alternativas entre la Empresa Xela Teco 1ra. Avenida y 7ma. Calle 6-53 y STIAP Sindicato de Trabajadores Independientes Comunidad Nueva Alianza El Palmar

La Empresa XelaTeco, representado por: **Everardo López y López** en calidad de **Gerente Administrativo** y **Javier Jiménez Recinos representante del STIAP** Sindicato de trabajadores de la Comunidad Nueva Alianza celebramos el siguiente contrato de Fabricación, Servicios, Instalación de Mini-hidroeléctrica.

PRIMERA: SERVICIOS Y FABRICACIONES: La Empresa XelaTeco ha implementado un sistema de Energías Renovables con la finalidad de ayudar a las personas y al medio ambiente, a construir y generar la energía limpia y necesaria del cliente que lo este solicitando. La empresa prestará al CLIENTE, **STIAP-Sindicato de Trabajadores Independientes Comunidad Nueva Alianza El Palmar,** el servicio o los servicios que se describen con respecto a la fabricación e instalación de una mini hidroeléctrica en la Comunidad Nueva Alianza el Palmar.

SEGUNDA: PLAZO: El presente contrato tendrá un plazo obligado de **7 Meses** contados a partir de la fecha de suscripción del mismo; dicho plazo podrá ser prorrogado por períodos iguales, salvo que alguna de las partes, por lo menos un mes de anticipación al vencimiento de plazo de cualquiera de sus prorrogas, manifieste a la otra su deseo de dar por terminado el mismo; sin embargo el cliente, está obligado a pagar el monto del resto de los meses que hicieran falta para terminar el periodo de plazo correspondiente.

TERCERA: OBLIGACIONES DE LA EMPRESA: La empresa esta obligada a:

a) Realizar oportunamente todas las instalaciones necesarias para la realización de los servicios y proyectos **siempre y cuando el cliente haya concluido todos los requisitos sugeridos.**
b) Proporcionar los equipos necesarios e infraestructura para brindar al cliente, el servicio contratado por este (solo en caso de que el cliente lo solicite).
c) Dar mantenimiento adecuado a las diferentes estructuras del proyecto en un plazo acordado por ambas partes.
d) Crear un comité para el uso, mantenimiento y operación de la maquinaria de la cual esta constituida la mini hidroeléctrica.
e) Capacitar a las personas de la Comunidad Nueva Alianza sobre el correcto uso de la mini hidroeléctrica así como su mantenimiento y los servicios que se le entregará a la comunidad, consistente en iluminación de las viviendas que existen en la comunidad.
f) Elaborar un manual sobre el uso, operación y mantenimiento de la mini hidroeléctrica (Solo especificando el mantenimiento que se pueda realizar por las personas capacitadas más no la reparación pues al desarmar alguno de los aparatos la garantía se invalidaría).
g) Brindar un juego de herramientas exclusivamente para el mantenimiento de la maquinaria el cual se entregará al comité encargado de la operación y mantenimiento de la mini hidroeléctrica.

CUARTA: DE LA CALIDAD DEL SERVICIO: La empresa garantiza el buen funcionamiento del proyecto, realizando un estricto control de pruebas para garantizar la calidad del mismo de lo contrario no se podrá entregar al cliente el proyecto.

La empresa de XelaTeco se compromete a garantizar el funcionamiento del proyecto, seccionados en las siguientes partes:

a) Turbinas pelton fabricadas por XelaTeco con garantía de 5 años. Así como caja de las turbinas.
b) Generadores que producen no menos de 8 Kw. con garantía de 2 años.
c) Tubería pvc y accesorios con garantía de 5 años. (dependiendo del mantenimiento o uso que se le dé, así será la garantía).
d) Líneas de transmisión y distribución con garantía de 5 años.
e) La garantía solo es sobre defectos del proyecto.

QUINTA: INSTALACION DEL PROYECTO COMUNIDAD NUEVA ALIANZA:
La Empresa se compromete de la instalación de la Mini-hidroeléctrica de las diversas actividades a realizar.

a) Instalación de tubería pvc con sus accesorios y abrazaderas.
b) Instalación de caja de máquinas con sus diferentes accesorios, donde se encuentra la casa de máquinas.
c) Se colocaran dos generadores que producen no menos de 8 Kw. cada uno para el proceso de la agroindustria de Macadamia, café y el de suministrar de energía eléctrica a los habitantes de la comunidad.
d) Se colocarán dos turbinas fabricadas por la empresa XelaTeco adjuntas a los generadores.
e) Asegurar el perímetro del proyecto.
f) Instalación de líneas de transmisión y de distribución.

SEXTA: DERECHOS DE LA EMPRESA: a) Cobrar el pago que como consecuencia de este contrato el cliente esta obligado a pagar. b) Cobrar y percibir el monto del proyecto seccionado en cuatro pagos un primer pago de 25,000 quetzales para seguridad del trabajo; segundo pago de 25,000 quetzales cuando el trabajo comience; tercer pago de 92,979 quetzales cuando XelaTeco adquiera todo el equipo y maquinaria y tubería Y un pago final de 30,500. Siendo este monto total de Q173,479.00 Este monto se utilizará para la adquisición de los materiales, accesorios así como la maquinaria y equipo que se necesita para la realización del proyecto.

SEPTIMA: DERECHOS DEL CLIENTE: El cliente tiene derecho de recibir el proyecto en óptimas condiciones y de funcionamiento; así como el servicio eléctrico con potencia de no menos de 8kw. Para poder satisfacer las necesidades de la comunidad.

OCTAVO: LAS OBLIGACIONES DEL CLIENTE: El cliente se compromete a preparar toda la infraestructura necesaria para la rehabilitación de la mini hidroeléctrica, haciendo este trabajo en las siguientes partes: a) Realización del cimiento para tubería en común acuerdo en fecha estimada por ambas partes. b) Realización de ampliación del tanque de agua de la comunidad en tiempo estimado de no más de 3 meses a partir de la fecha. c) Colocación de los postes de electrificación tanto de líneas de transmisión así como de distribución. Limpieza de los lugares cercanos a la ubicación del proyecto. d) Construcción del nuevo cuarto de maquinas con las especificaciones de la empresa XelaTeco
e) Suministro de alimentación, hospedaje y acceso al sitio del proyecto f) Dar mantenimiento al proyecto.

NOVENO: ACEPTACION DEL CONTRATO: El cliente manifiesta que en los términos y condiciones que la EMPRESA le realice el servicio de instalación y puesta en marcha del proyecto antes mencionado. Ambas partes, en los términos indicados en este contrato y en las calidades en que gestionamos, aceptamos todas y cada una de las cláusulas del presente contrato contenidas en 4 hojas de papel bond tamaño carta, el cual hemos leído y lo ratificamos y aceptamos, firmándolo de entera conformidad.

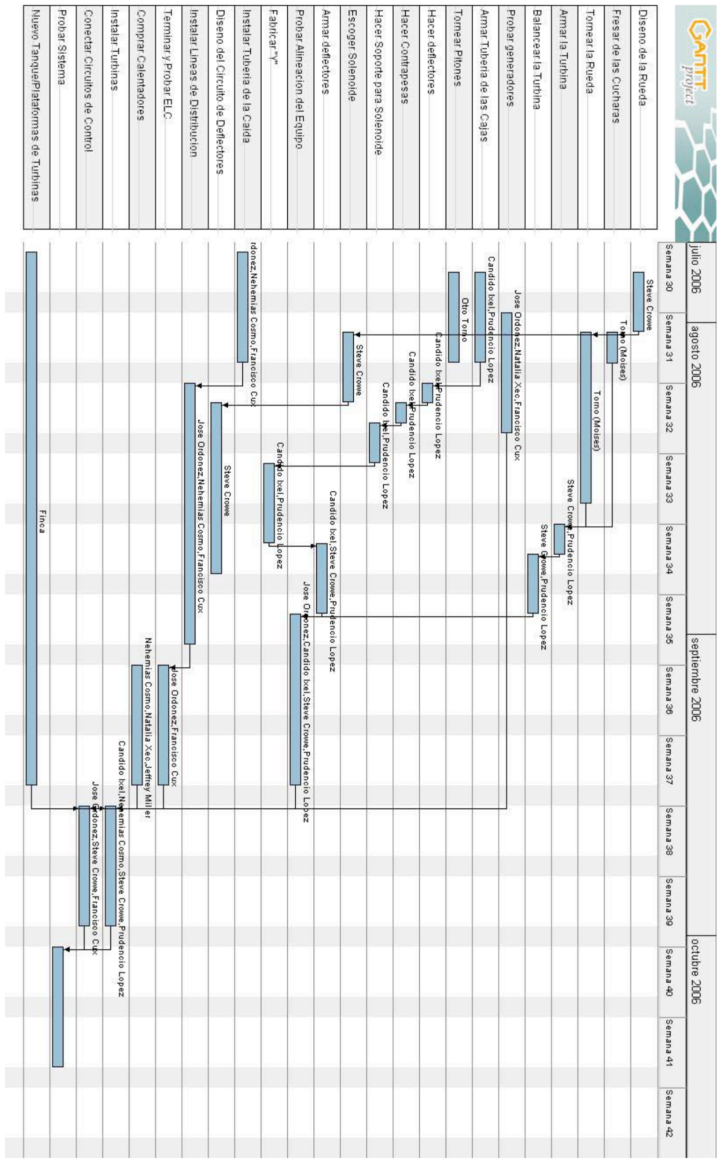
f) ____________________ f) __________________________

El cliente STIAP Por la empresa

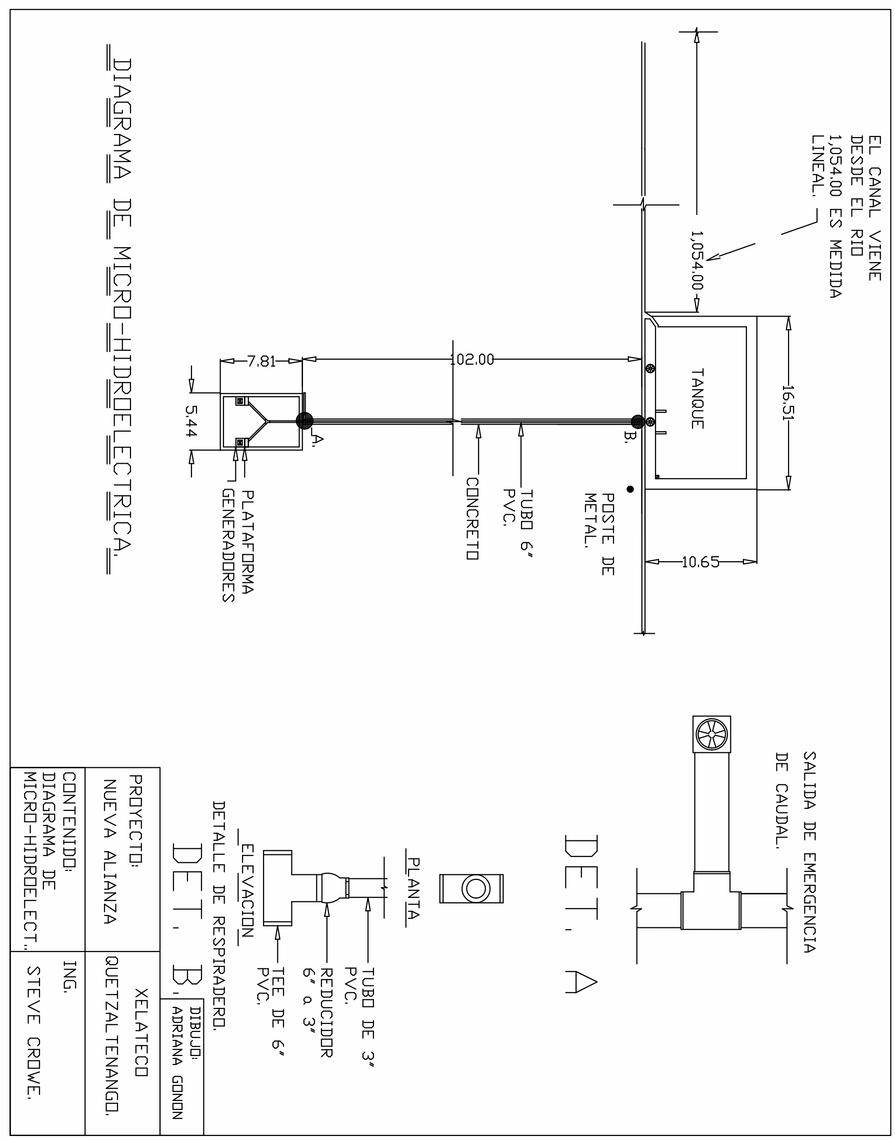
Nombre________________ Nombre_______________________

En la ciudad de Quetzaltenango, Noviembre de 2005.

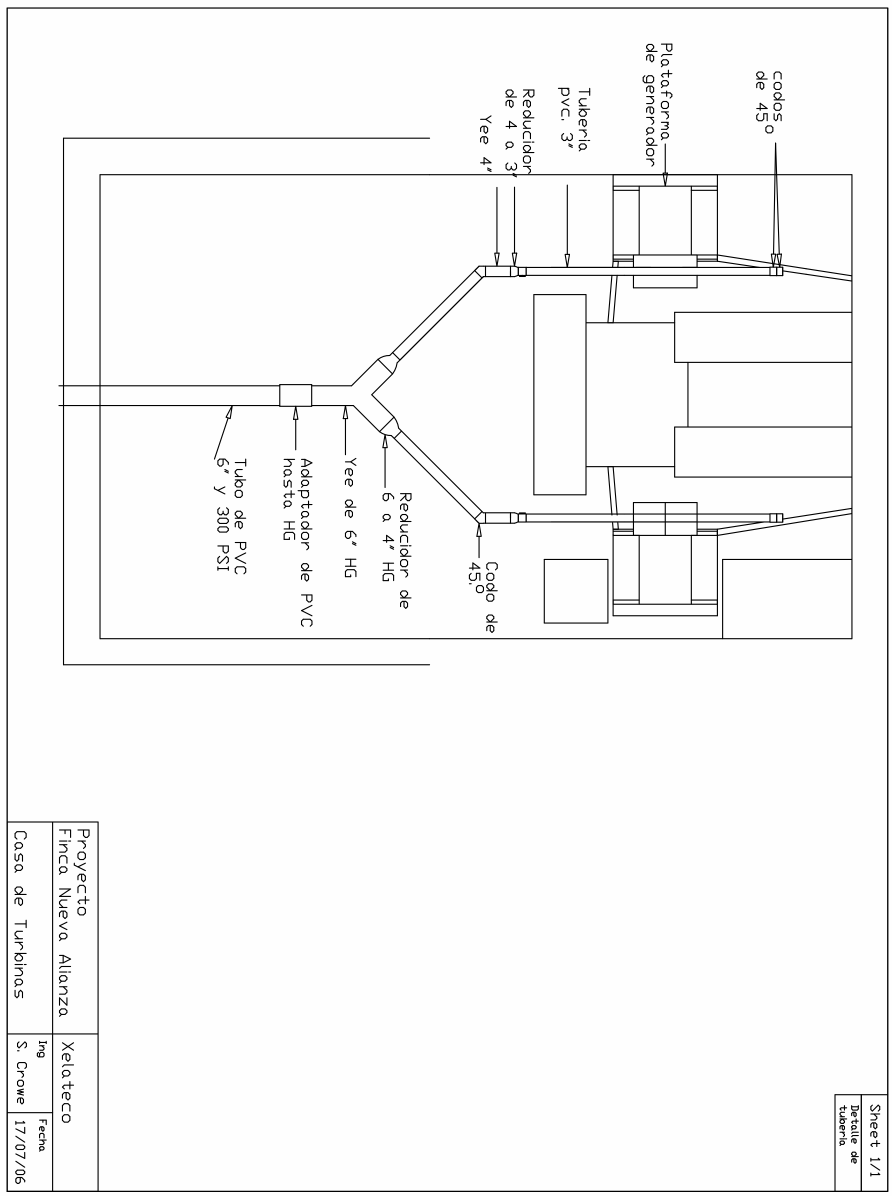
8.2 Appendix B - Gantt Chart

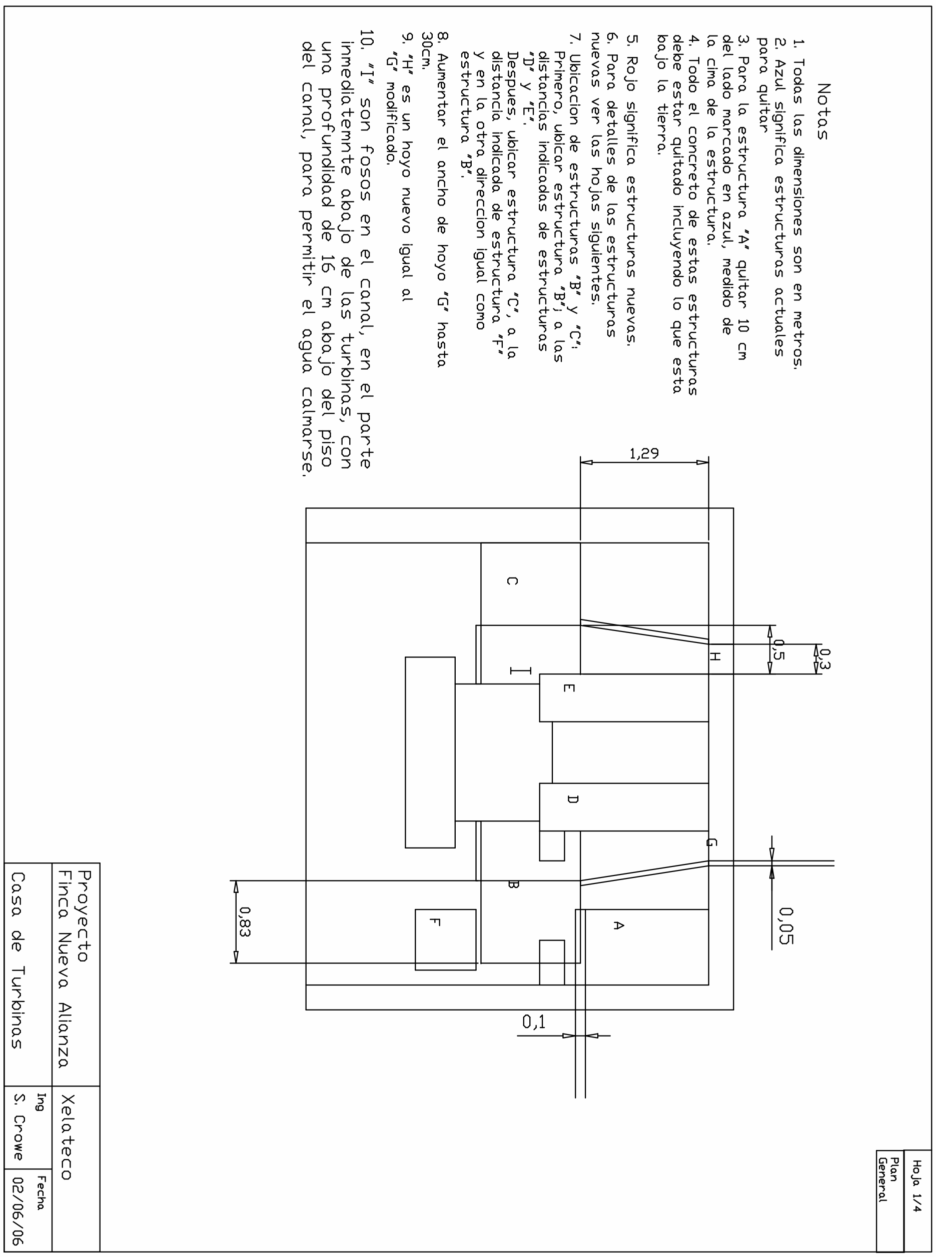


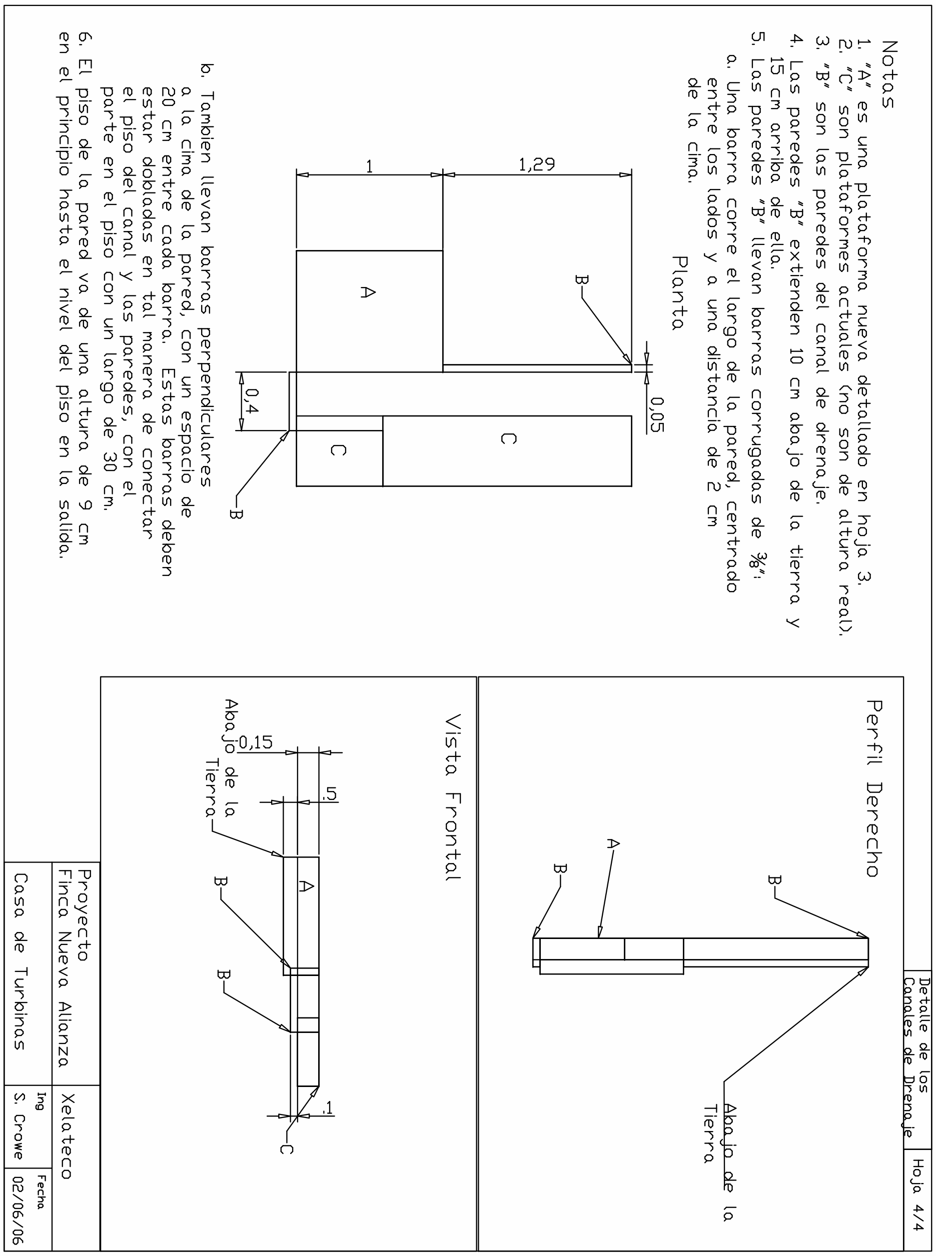
8.3 Appendix C - CAD Drawings - Aqueduct

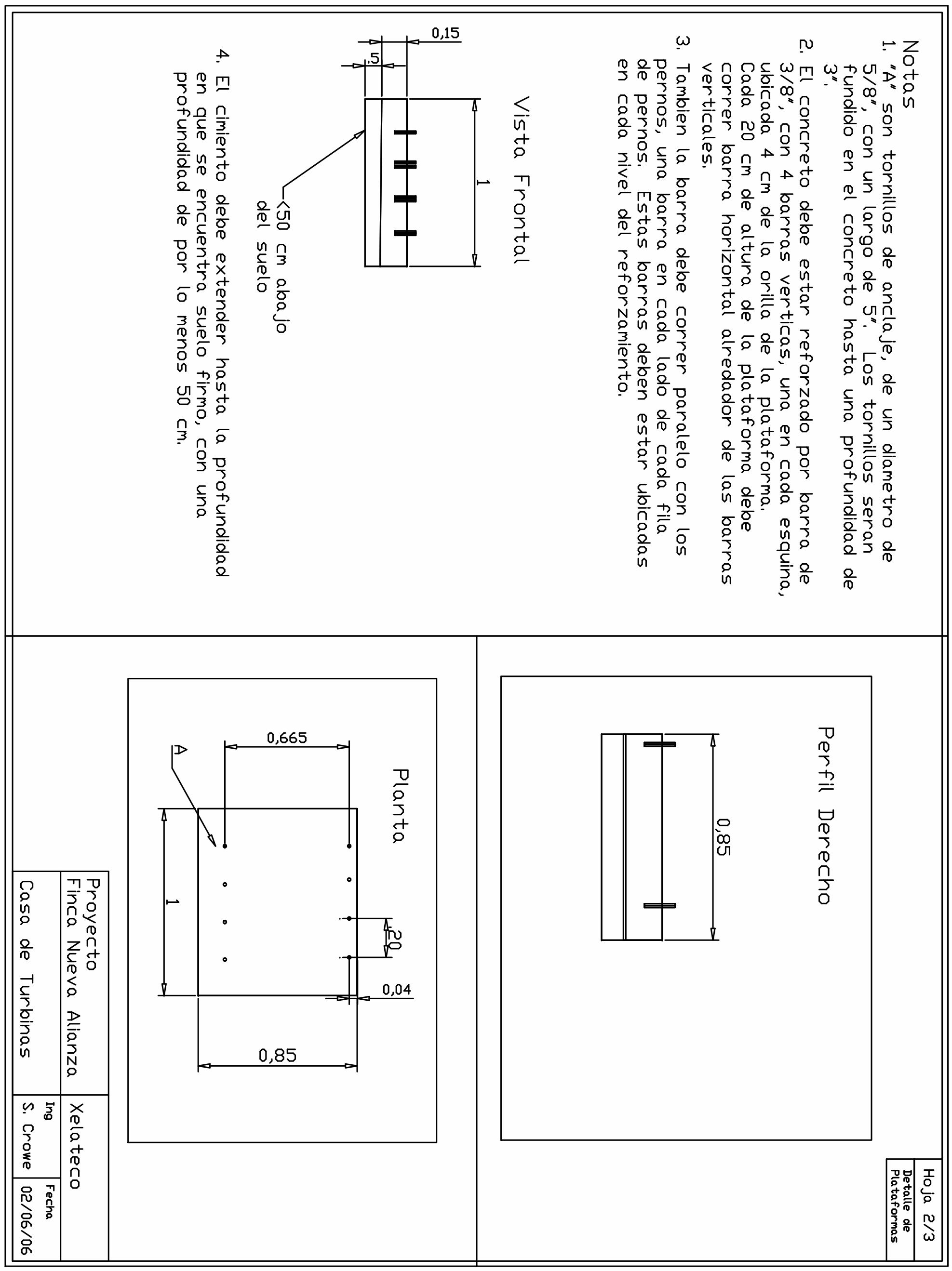


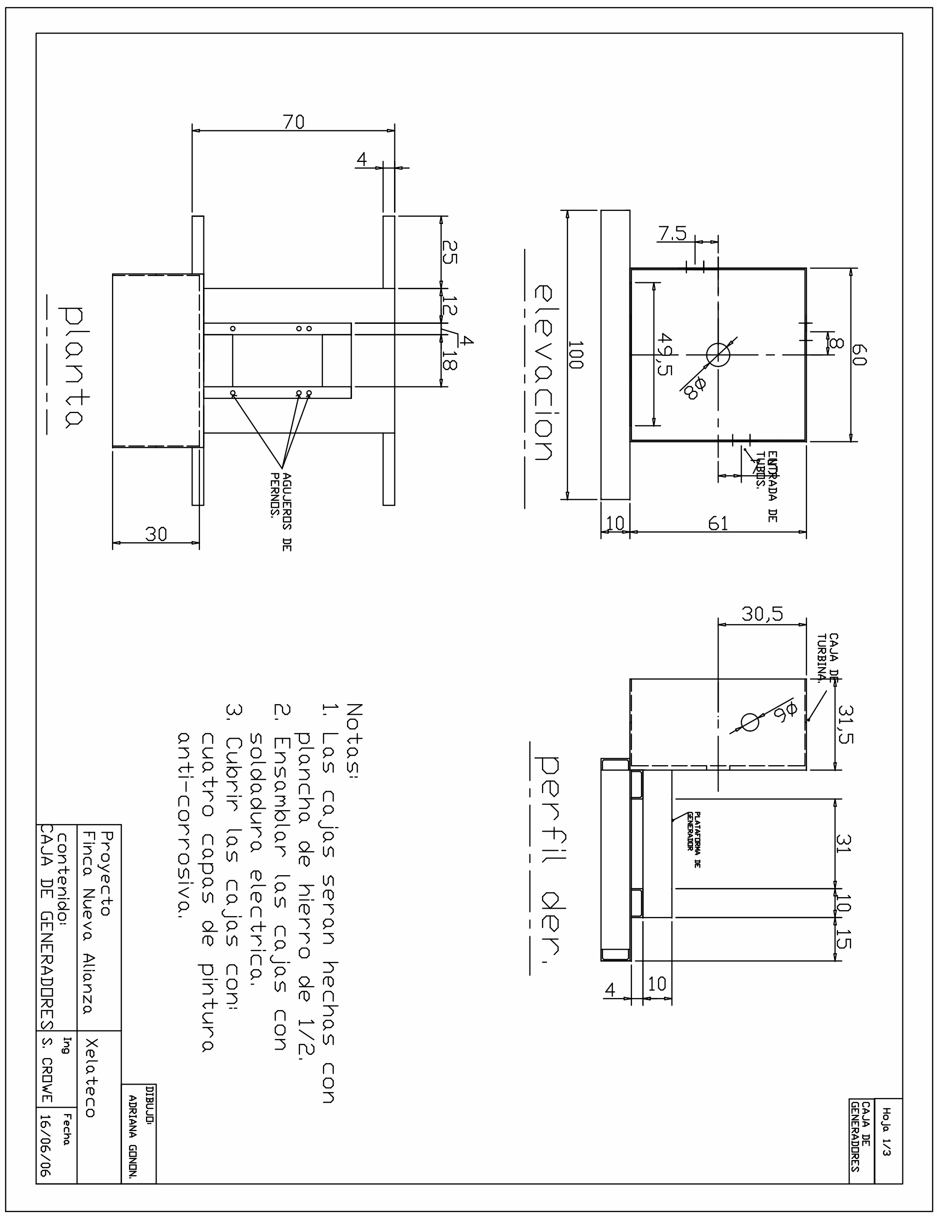
8.4 Appendix C - CAD Drawings - Power House and Components

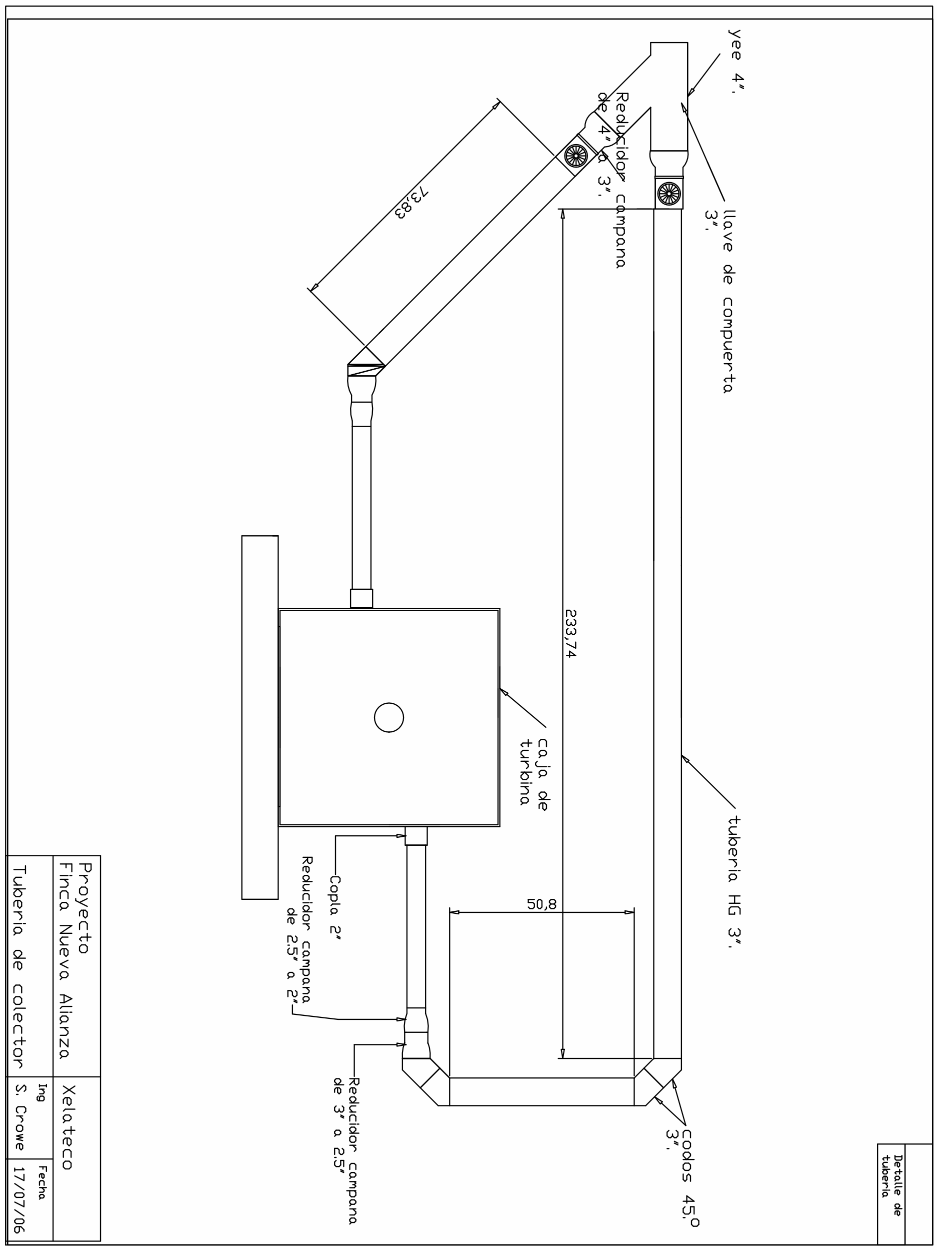


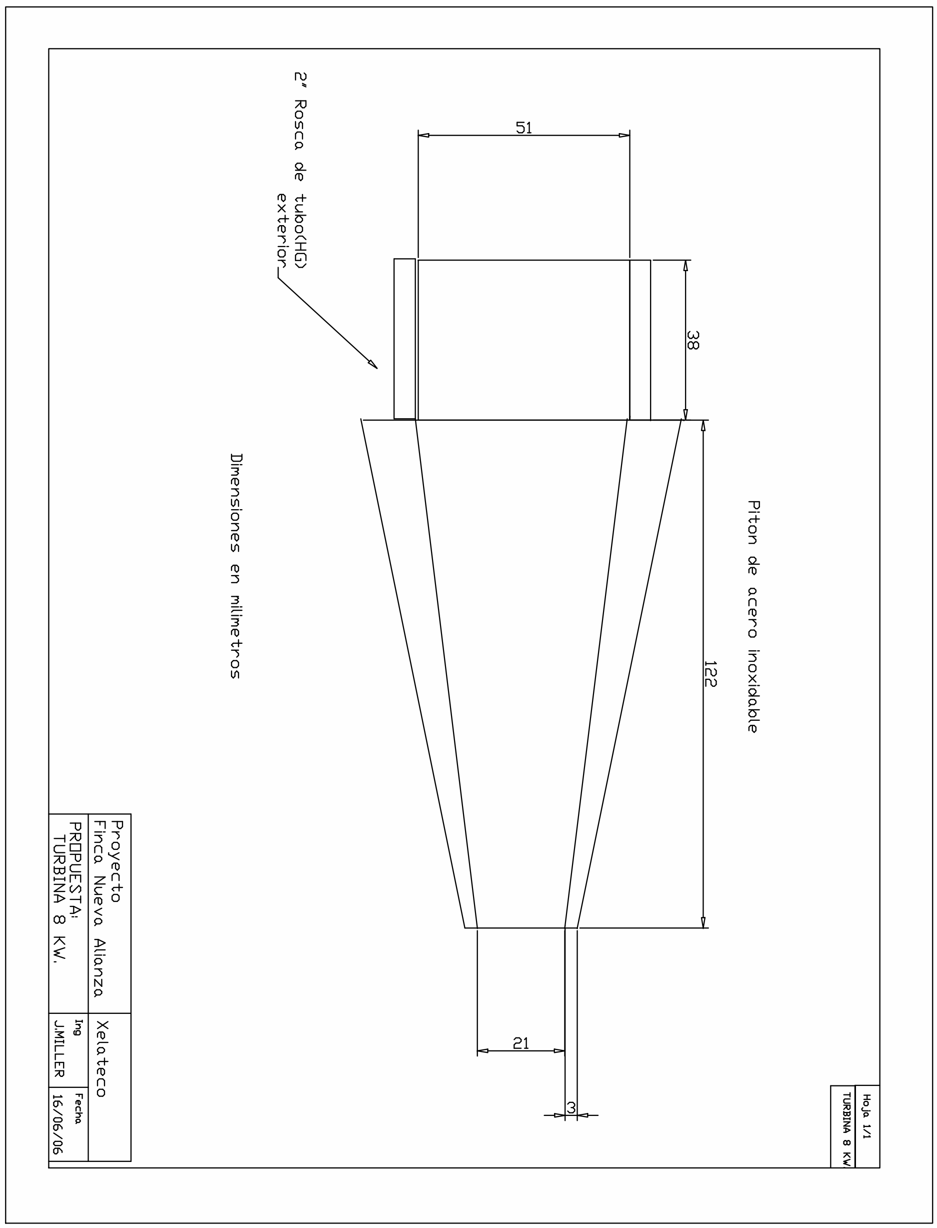

Notas
1. Todas las dimensiones son en metros.
2. Azul significa estructuras actuales para quitar
3. Para la estructura 'A' quitar 10 cm del lado marcado en azul, medido de la cima de la estructura.
4. Todo el concreto de estas estructuras debe estar quitado incluyendo lo que esta bajo la tierra.
5. Rojo significa estructuras nuevas.
6. Para detalles de las estructuras nuevas ver las hojas siguientes.
7. Ubicacion de estructuras 'B' y 'C': Primero, ubicar estructura 'B'; a las distancias indicadas de estructuras 'D' y 'E'. Despues, ubicar estructura 'C', a la distancia indicada de estructura 'F' y en la otra direccion igual como estructura 'B'.
8. Aumentar el ancho de hoyo 'G' hasta 30cm.
9. 'H' es un hoyo nuevo igual al 'G' modificado.
10. "I" son fosos en el canal, en el parte inmediatemnte abajo de las turbinas, con una profundidad de 16 cm abajo del piso del canal, para permitir el agua calmarse.
0,3
0,5
0,05
1,29
0,1
0,83
A
B
C
D
E
F
G
H
I
Hoja 1/4
Plan General
Proyecto
Finca Nueva Alianza
Casa de Turbinas
Xelateco
Ing
S. Crowe
Fecha
02/06/06

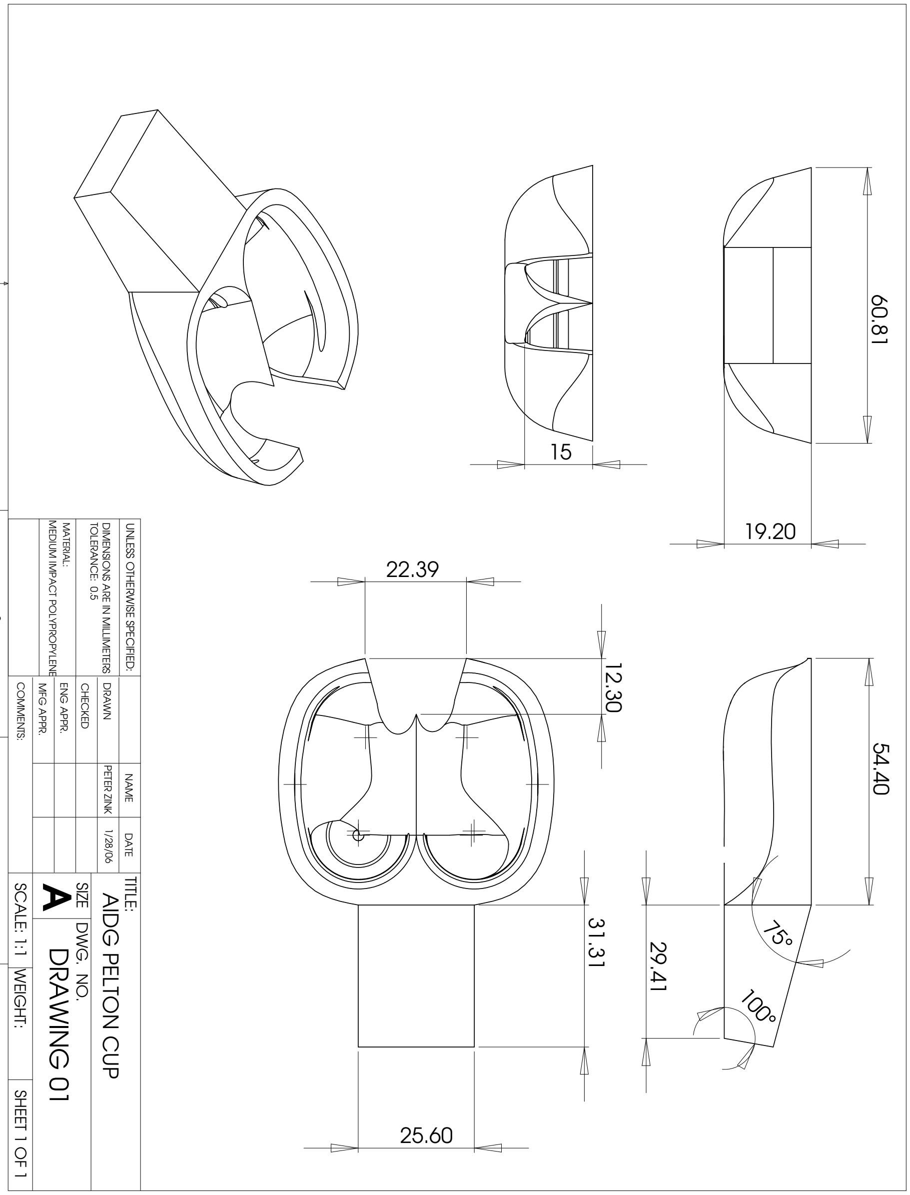

Notas
1. "A" es una plataforma nueva detallado en hoja 3.
2. "C" son plataformes actuales (no son de altura real).
3. "B" son las paredes del canal de drenaje.
4. Las paredes "B" extienden 10 cm abajo de la tierra y 15 cm arriba de ella.
5. Las paredes "B" llevan barras corrugadas de ⅜":
a. Una barra corre el largo de la pared, centrado entre los lados y a una distancia de 2 cm de la cima.
b. Tambien llevan barras perpendiculares a la cima de la pared, con un espacio de 20 cm entre cada barra. Estas barras deben estar dobladas en tal manera de conectar el piso del canal y las paredes, con el parte en el piso con un largo de 30 cm.
6. El piso de la pared va de una altura de 9 cm en el principio hasta el nivel del piso en la salida.
Planta
0,05
1,29
1
0,4
Perfil Derecho
Abajo de la Tierra
Vista Frontal
.5
.1
0,15
Abajo de la Tierra
Detalle de los Canales de Drenaje
Hoja 4/4
Proyecto
Finca Nueva Alianza
Xelateco
Casa de Turbinas
Ing
S. Crowe
Fecha
02/06/06


Notas
1. "A" son tornillos de anclaje, de un diametro de 5/8", con un largo de 5". Los tornillos seran fundido en el concreto hasta una profundidad de 3".
2. El concreto debe estar reforzado por barra de 3/8", con 4 barras verticas, una en cada esquina, ubicada 4 cm de la orilla de la plataforma. Cada 20 cm de altura de la plataforma debe correr barra horizontal alrededor de las barras verticales.
3. Tambien la barra debe correr paralelo con los pernos, una barra en cada lado de cada fila de pernos. Estas barras deben estar ubicadas en cada nivel del reforzamiento.
4. El cimiento debe extender hasta la profundidad en que se encuentra suelo firmo, con una profundidad de por lo menos 50 cm.
Vista Frontal
0,15
.5
1
<50 cm abajo del suelo
Perfil Derecho
0,85
Planta
0,665
A
1
20
0,04
0,85
Proyecto
Finca Nueva Alianza
Casa de Turbinas
Xelateco
Ing
S. Crowe
Fecha
02/06/06
Hoja 2/3
Detalle de Plataformas

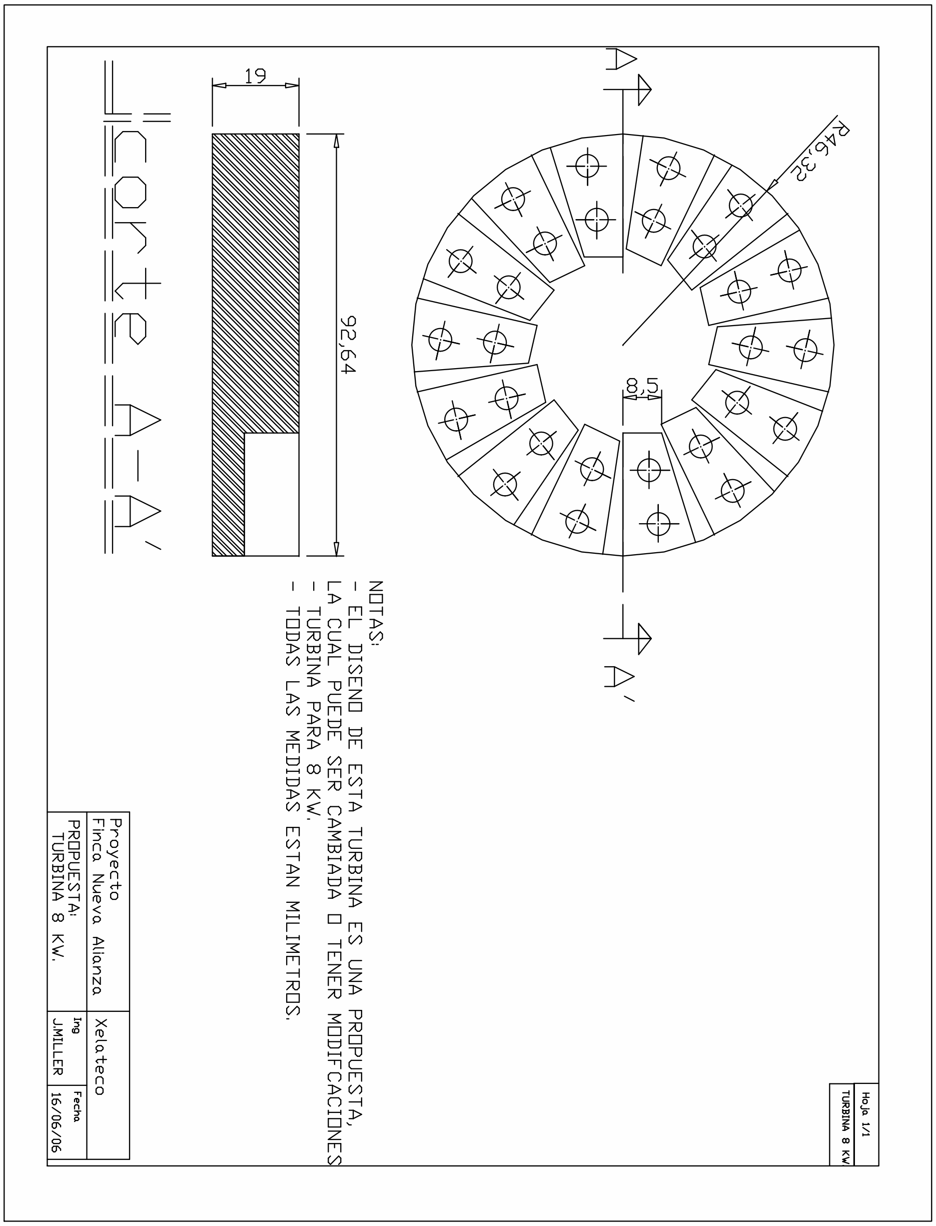

planta
elevacion
perfil der.
AGUJEROS DE PERNOS.
ENTRADA DE TUBOS.
CAJA DE TURBINA
PLATAFORMA DE GENERADOR
Notas:
1. Las cajas seran hechas con plancha de hierro de 1/2.
2. Ensamblar las cajas con soldadura electrica.
3. Cubrir las cajas con: cuatro capas de pintura anti-corrosiva.
Proyecto
Finca Nueva Alianza
Xelateco
contenido:
CAJA DE GENERADORES
Ing
S. CROWE
Fecha
16/06/06
DIBUJO
Hoja 1/3
CAJA DE GENERADORES

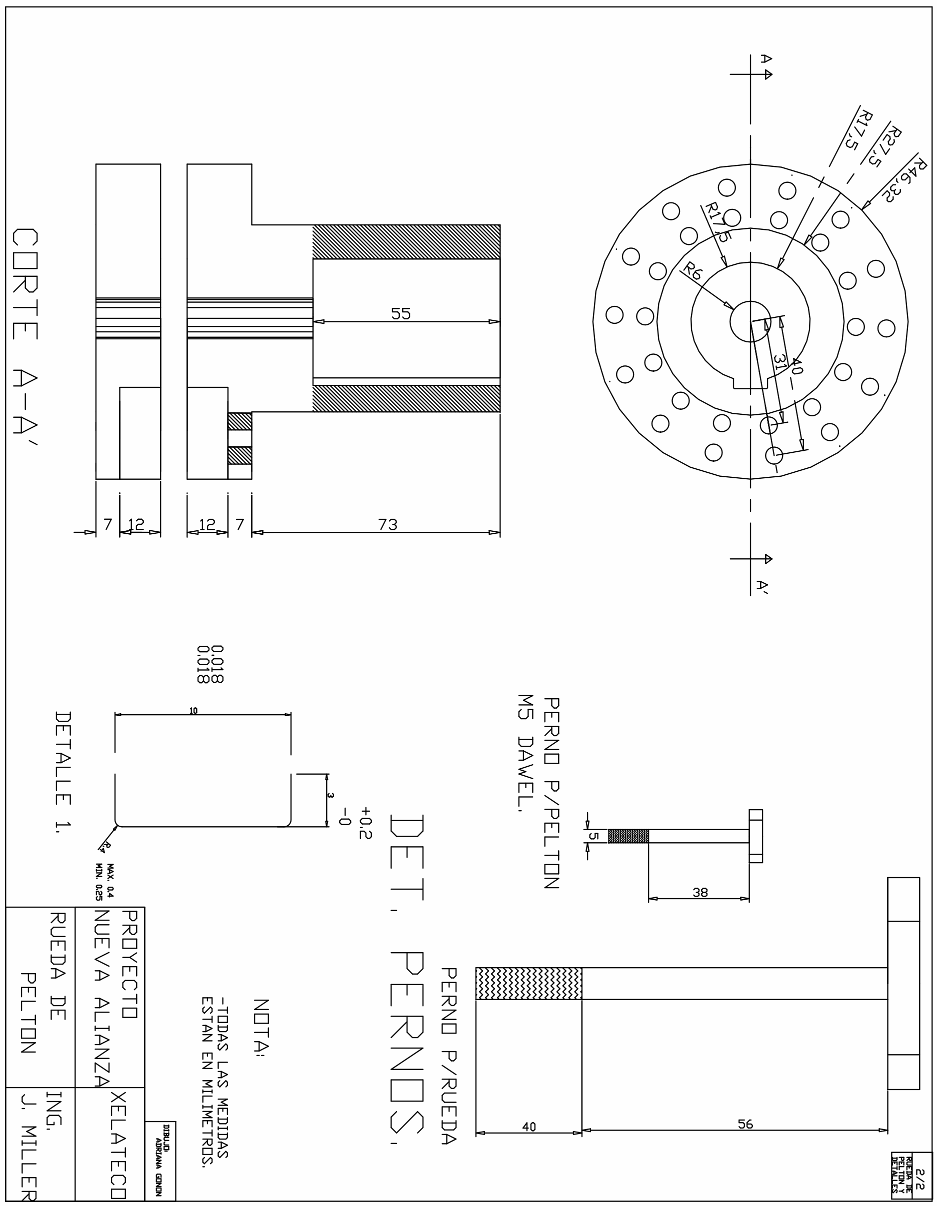

yee 4".
Reducidor campana de 4" a 3".
73,83
llave de compuerta 3".
233,74
caja de turbina
tuberia HG 3".
50,8
Copla 2"
Reducidor campana de 2,5" a 2"
Reducidor campana de 3" a 2,5"
codos 45° 3".
Proyecto
Finca Nueva Alianza
Xelateco
Tuberia de colector
Ing
S. Crowe
Fecha
17/07/06
Detalle de tuberia

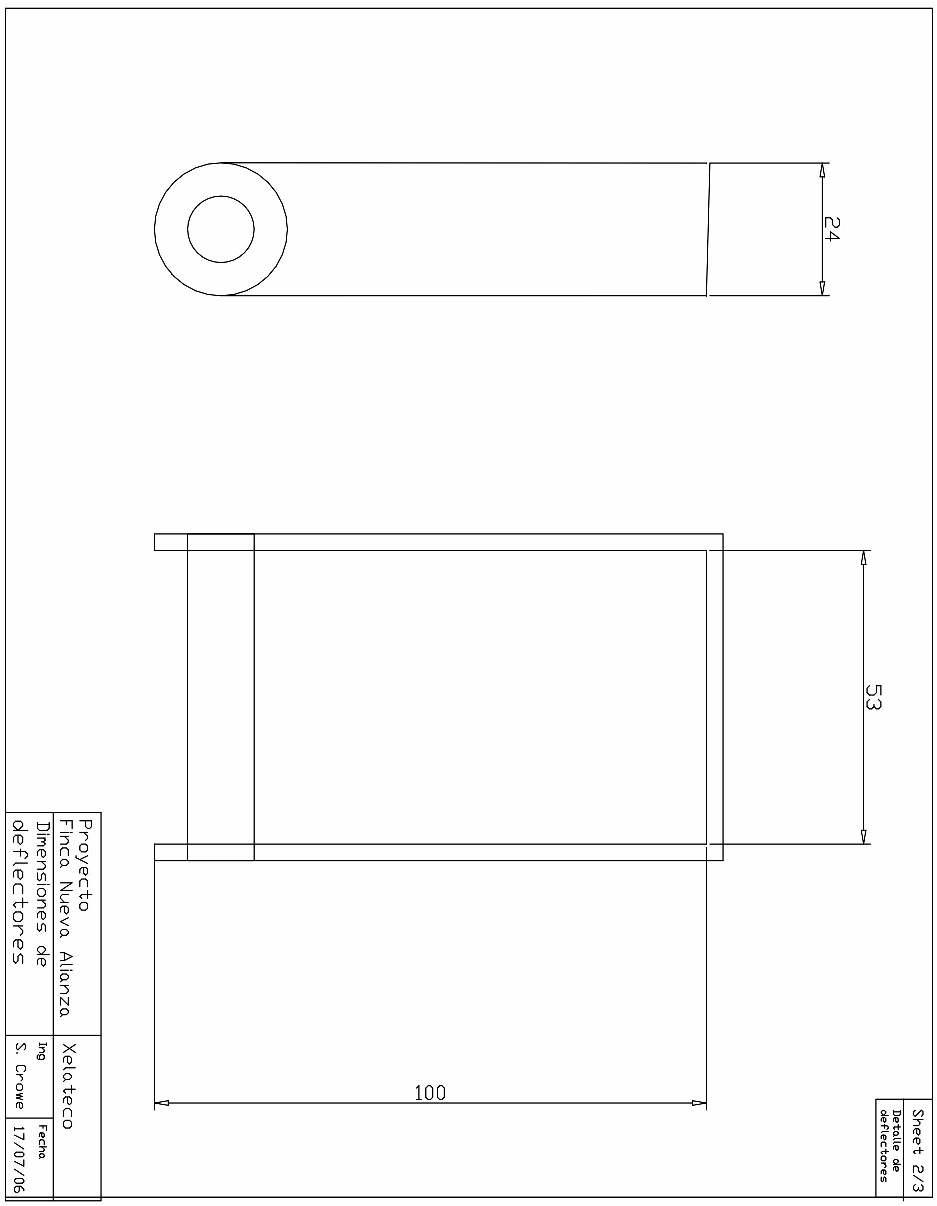

2" Rosca de tubo(HG)
exterior
51
38
122
21
3
Piton de acero inoxidable
Dimensiones en milimetros
Proyecto
Finca Nueva Alianza
PR□PUESTA:
TURBINA 8 KW.
Xelateco
Ing
JMILLER
Fecha
16/06/06
Hoja 1/1
TURBINA 8 KW

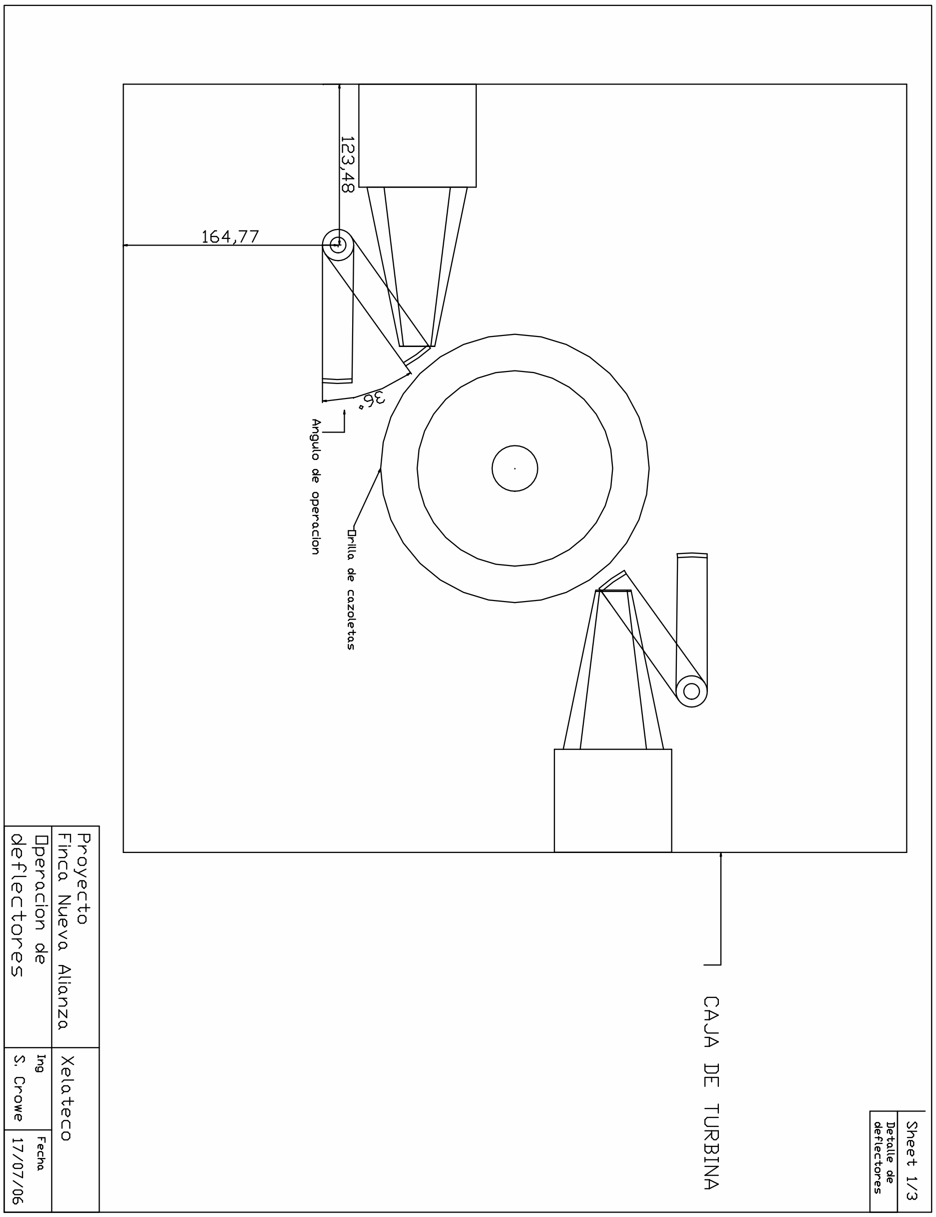


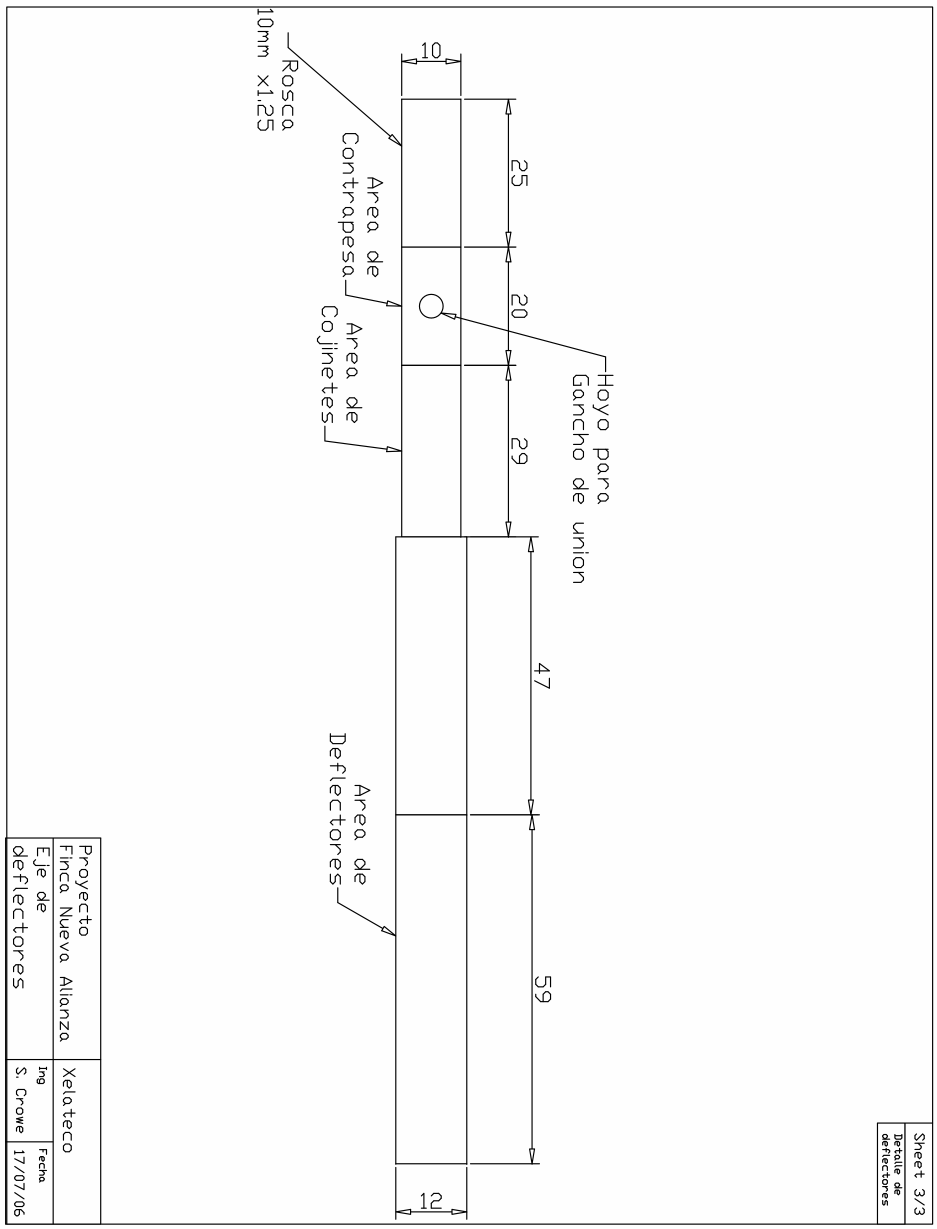
15
60.81
19.20
22.39
12.30
54.40
31.31
29.41
75°
100°
25.60
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: 0.5
MATERIAL:
MEDIUM IMPACT POLYPROPYLENE
NAME
DATE
DRAWN
PETER ZINK
1/28/06
CHECKED
ENG APPR.
MFG APPR.
COMMENTS:
TITLE:
AIDG PELTON CUP
SIZE
A
DWG. NO.
DRAWING 01
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1


A
R46,32
8,5
A´
19
92,64
Corte A-A´
NOTAS:
- EL DISENO DE ESTA TURBINA ES UNA PROPUESTA,
LA CUAL PUEDE SER CAMBIADA O TENER MODIFCACIONES
- TURBINA PARA 8 KW.
- TODAS LAS MEDIDAS ESTAN MILIMETROS.
Proyecto
Finca Nueva Alianza
PROPUESTA:
TURBINA 8 KW.
Xelateco
Ing
JMILLER
Fecha
16/06/06
Hoja 1/1
TURBINA 8 KW


CORTE A-A'
A
A'
R17,5
R27,5
R46,32
R6
55
73
7
12
31
40
DET. PERNOS.
PERNO P/PELTON
M5 DAWEL.
5
38
PERNO P/RUEDA
40
56
DETALLE 1.
0.018
0.018
10
3
+0.2
-0
NOTA:
-TODAS LAS MEDIDAS
ESTAN EN MILIMETROS.
PROYECTO
NUEVA ALIANZA
RUEDA DE
PELTON
XELATECO
ING.
J. MILLER
2/2

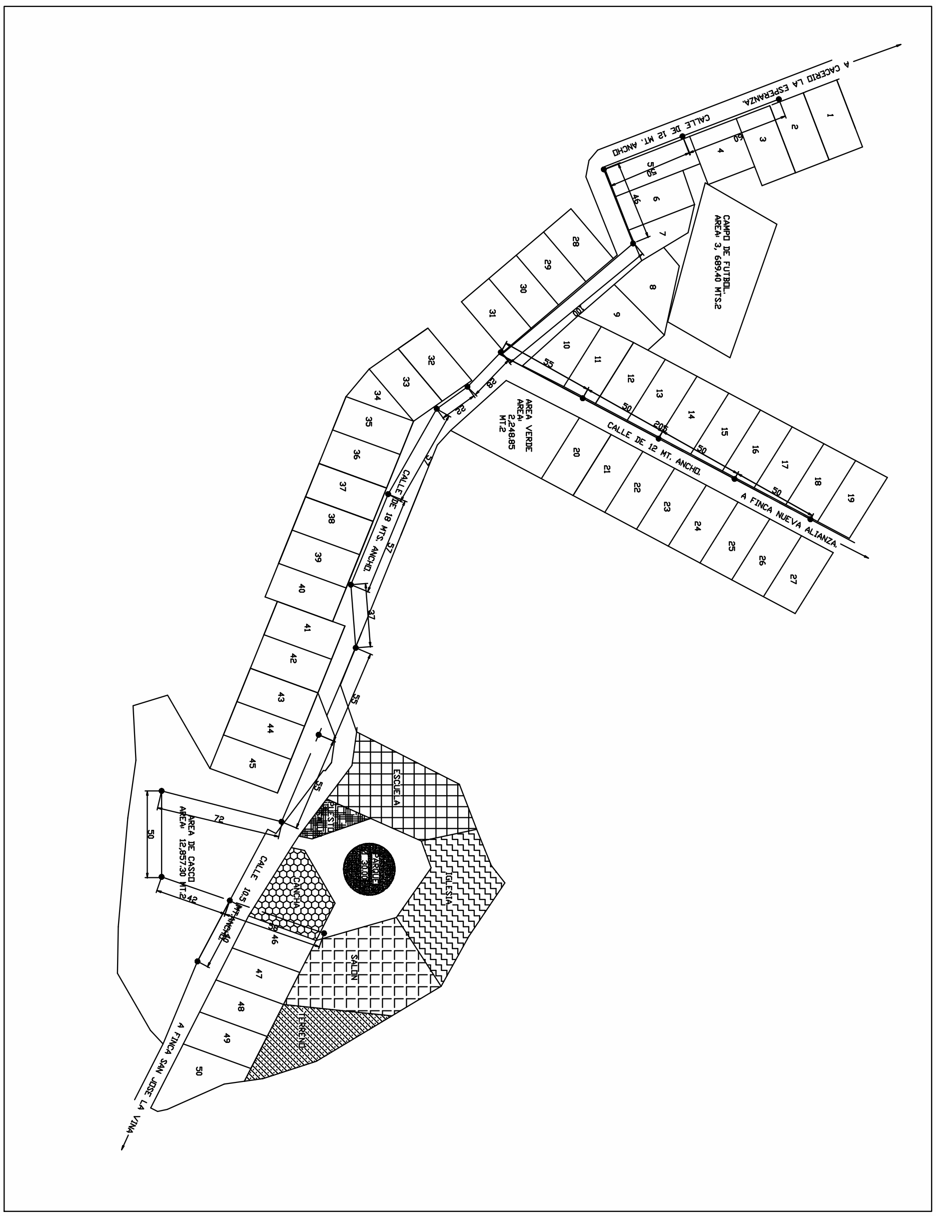

24
53
100
Proyecto
Finca Nueva Alianza
Dimensiones de
deflectores
Xelateco
Ing
S. Crowe
Fecha
17/07/06
Sheet 2/3
Detalle de
deflectores


123,48
164,77
36°
Angulo de operacion
□rilla de cazoletas
CAJA DE TURBINA
Proyecto
Finca Nueva Alianza
□peracion de
deflectores
Xelateco
Ing
S. Crowe
Fecha
17/07/06
Sheet 1/3
Detalle de
deflectores


Rosca
10mm x1.25
Area de
Contrapesa
Area de
Cojinetes
Hoyo para
Gancho de union
Area de
Deflectores
10
25
20
29
47
59
12
Proyecto
Finca Nueva Alianza
Eje de
deflectores
Xelateco
Ing
S. Crowe
Fecha
17/07/06
Sheet 3/3
Detalle de
deflectores

8.5 Appendix C - CAD Drawings - Electrical Distribution

Note: El dibujo se desarollo por Heber Martinez (Enero 2006) y se actualizo por Xelateco



8.6 Appendix D - Charts - Tank Release Schedules

One Generator Operating With Only The Original 200,000 Liter Tank

Flow Rate (l/s)	Start Time Cycle 1	Cycle 1 Finishes (Tank Empty)	Begin Refill By:	Start Time Cycle 2	Cycle 2 Finishes	Begin Refill For Morning By:	Generating Time Available (hr)
9	6:00 AM	9:05 AM	9:35 AM	3:45 PM	6:50 PM	11:20 PM	6:10
10	6:00 AM	9:16 AM	9:46 AM	3:19 PM	6:35 PM	11:57 PM	6:32
11	6:00 AM	9:28 AM	9:58 AM	3:01 PM	6:29 PM	12:27 AM	6:56
12	6:00 AM	9:42 AM	10:12 AM	2:49 PM	6:31 PM	12:53 AM	7:24
13	6:00 AM	9:58 AM	10:28 AM	2:44 PM	6:42 PM	1:14 AM	7:56
14	6:00 AM	10:16 AM	10:46 AM	2:44 PM	7:00 PM	1:32 AM	8:32
15	6:00 AM	10:37 AM	11:07 AM	2:49 PM	7:26 PM	1:48 AM	9:14
16	6:00 AM	11:03 AM	11:33 AM	3:01 PM	8:04 PM	2:02 AM	10:06
17	6:00 AM	11:33 AM	12:03 PM	3:19 PM	8:52 PM	2:14 AM	11:06
18	6:00 AM	12:10 PM	12:40 PM	3:45 PM	9:55 PM	2:25 AM	12:20
19	6:00 AM	12:56 PM	1:26 PM	4:21 PM	11:17 PM	2:35 AM	13:52
20	6:00 AM	1:56 PM	2:26 PM	5:12 PM	1:08 AM	2:44 AM	15:52
21	6:00 AM	3:15 PM	3:45 PM	6:13 PM	2:52 AM	2:52 AM	17:53
22	6:00 AM	5:06 PM	5:36 PM	7:20 PM	2:59 AM	2:59 AM	18:44
23	6:00 AM	7:53 PM	8:23 PM	9:22 PM	3:06 AM	3:06 AM	19:36
24	6:00 AM	12:31 AM	1:01 AM	1:15 AM	3:12 AM	3:12 AM	20:27
25	6:00 AM	------	------	------	------	3:46 AM	21:46
26	6:00 AM	------	------	------	------	4:38 AM	22:38
27	6:00 AM	------	------	------	------	------	24:00
28	6:00 AM	------	------	------	------	------	24:00
29	6:00 AM	------	------	------	------	------	24:00
30	6:00 AM	------	------	------	------	------	24:00
31	6:00 AM	------	------	------	------	------	24:00
32	6:00 AM	------	------	------	------	------	24:00
33	6:00 AM	------	------	------	------	------	24:00
34	6:00 AM	------	------	------	------	------	24:00
35	6:00 AM	------	------	------	------	------	24:00
36	6:00 AM	------	------	------	------	------	24:00
37	6:00 AM	------	------	------	------	------	24:00
38	6:00 AM	------	------	------	------	------	24:00
39	6:00 AM	------	------	------	------	------	24:00
40	6:00 AM	------	------	------	------	------	24:00
41	6:00 AM	------	------	------	------	------	24:00
42	6:00 AM	------	------	------	------	------	24:00
43	6:00 AM	------	------	------	------	------	24:00
44	6:00 AM	------	------	------	------	------	24:00
45	6:00 AM	------	------	------	------	------	24:00
46	6:00 AM	------	------	------	------	------	24:00
47	6:00 AM	------	------	------	------	------	24:00
48	6:00 AM	------	------	------	------	------	24:00
49	6:00 AM	------	------	------	------	------	24:00
50	6:00 AM	------	------	------	------	------	24:00
51	6:00 AM	------	------	------	------	------	24:00
52	6:00 AM	------	------	------	------	------	24:00
53	6:00 AM	------	------	------	------	------	24:00
54	6:00 AM	------	------	------	------	------	24:00

Two Generators Operating With Only The Original 200,000 Liter Tank

Flow Rate (l/s)	Start Time Cycle 1	Cycle 1 Finishes (Tank Empty)	Begin Refill By:	Start Time Cycle 2	Cycle 2 Finishes	Begin Refill For Morning By:	Generating Time Available (hr)
9	6:00 AM	7:14 AM	7:44 AM	1:54 PM	3:08 PM	11:20 PM	2:28
10	6:00 AM	7:15 AM	7:45 AM	1:18 PM	2:33 PM	11:57 PM	2:30
11	6:00 AM	7:17 AM	7:47 AM	12:50 PM	2:07 PM	12:27 AM	2:34
12	6:00 AM	7:19 AM	7:49 AM	12:26 PM	1:45 PM	12:53 AM	2:38
13	6:00 AM	7:21 AM	7:51 AM	12:07 PM	1:28 PM	1:14 AM	2:42
14	6:00 AM	7:23 AM	7:53 AM	11:51 AM	1:14 PM	1:32 AM	2:46
15	6:00 AM	7:25 AM	7:55 AM	11:37 AM	1:02 PM	1:48 AM	2:50
16	6:00 AM	7:27 AM	7:57 AM	11:25 AM	12:52 PM	2:02 AM	2:54
17	6:00 AM	7:30 AM	8:00 AM	11:16 AM	12:46 PM	2:14 AM	3:00
18	6:00 AM	7:32 AM	8:02 AM	11:07 AM	12:39 PM	2:25 AM	3:04
19	6:00 AM	7:35 AM	8:05 AM	11:00 AM	12:35 PM	2:35 AM	3:10
20	6:00 AM	7:38 AM	8:08 AM	10:54 AM	12:32 PM	2:44 AM	3:16
21	6:00 AM	7:41 AM	8:11 AM	10:49 AM	12:30 PM	2:52 AM	3:22
22	6:00 AM	7:44 AM	8:14 AM	10:45 AM	12:29 PM	2:59 AM	3:28
23	6:00 AM	7:47 AM	8:17 AM	10:41 AM	12:28 PM	3:06 AM	3:34
24	6:00 AM	7:51 AM	8:21 AM	10:39 AM	12:30 PM	3:12 AM	3:42
25	6:00 AM	7:54 AM	8:24 AM	10:37 AM	12:31 PM	3:17 AM	3:48
26	6:00 AM	7:59 AM	8:29 AM	10:37 AM	12:36 PM	3:22 AM	3:58
27	6:00 AM	8:03 AM	8:33 AM	10:36 AM	12:39 PM	3:27 AM	4:06
28	6:00 AM	8:08 AM	8:38 AM	10:37 AM	12:45 PM	3:31 AM	4:16
29	6:00 AM	8:13 AM	8:43 AM	10:37 AM	12:50 PM	3:36 AM	4:26
30	6:00 AM	8:18 AM	8:48 AM	10:39 AM	12:57 PM	3:39 AM	4:36
31	6:00 AM	8:24 AM	8:54 AM	10:41 AM	1:05 PM	3:43 AM	4:48
32	6:00 AM	8:31 AM	9:01 AM	10:45 AM	1:16 PM	3:46 AM	5:02
33	6:00 AM	8:38 AM	9:08 AM	10:49 AM	1:27 PM	3:49 AM	5:16
34	6:00 AM	8:46 AM	9:16 AM	10:54 AM	1:40 PM	3:52 AM	5:32
35	6:00 AM	8:55 AM	9:25 AM	11:00 AM	1:55 PM	3:55 AM	5:50
36	6:00 AM	9:05 AM	9:35 AM	11:07 AM	2:12 PM	3:58 AM	6:10
37	6:00 AM	9:16 AM	9:46 AM	11:16 AM	2:32 PM	4:00 AM	6:32
38	6:00 AM	9:28 AM	9:58 AM	11:25 AM	2:53 PM	4:03 AM	6:56
39	6:00 AM	9:42 AM	10:12 AM	11:37 AM	3:19 PM	4:05 AM	7:24
40	6:00 AM	9:58 AM	10:28 AM	11:51 AM	3:49 PM	4:07 AM	7:56
41	6:00 AM	10:16 AM	10:46 AM	12:07 PM	4:23 PM	4:09 AM	8:32
42	6:00 AM	10:37 AM	11:07 AM	12:26 PM	5:03 PM	4:11 AM	9:14
43	6:00 AM	11:03 AM	11:33 AM	12:50 PM	5:53 PM	4:13 AM	10:06
44	6:00 AM	11:33 AM	12:03 PM	1:18 PM	6:51 PM	4:15 AM	11:06
45	6:00 AM	12:10 PM	12:40 PM	1:54 PM	8:04 PM	4:16 AM	12:20
46	6:00 AM	12:56 PM	1:26 PM	2:38 PM	9:34 PM	4:18 AM	13:52
47	6:00 AM	1:56 PM	2:26 PM	3:36 PM	11:32 PM	4:20 AM	15:52
48	6:00 AM	3:15 PM	3:45 PM	4:54 PM	2:09 AM	4:21 AM	18:30
49	6:00 AM	5:06 PM	5:36 PM	1:12 PM	12:18 AM	4:22 AM	22:12
50	6:00 AM	7:53 PM	8:23 PM	4:58 PM	4:24 AM	4:24 AM	1:18
51	6:00 AM	12:31 AM	1:01 AM	11:30 PM	4:25 AM	4:25 AM	23:25
52	6:00 AM	------	------	------	------	4:38 AM	22:38
53	6:00 AM	------	------	------	------	5:04 AM	23:04
54	6:00 AM	------	------	------	------	------	24:00

One Generator Operating With Only The Original 400,000 Liter Tank

Flow Rate (l/s)	Start Time Cycle 1	Cycle 1 Finishes (Tank Empty)	Begin Refill By:	Start Time Cycle 2	Cycle 2 Finishes	Begin Refill For Morning By:	Generating Time Available (hr)
9	6:00 AM	12:10 PM	12:40 PM	3:40 PM	5:10 PM	5:10 PM	7:40
10	6:00 AM	12:32 PM	1:02 PM	4:24 PM	6:24 PM	6:24 PM	8:31
11	6:00 AM	12:56 PM	1:26 PM	4:58 PM	7:24 PM	7:24 PM	9:21
12	6:00 AM	1:24 PM	1:54 PM	5:25 PM	8:15 PM	8:15 PM	10:13
13	6:00 AM	1:56 PM	2:26 PM	5:49 PM	8:58 PM	8:58 PM	11:04
14	6:00 AM	2:32 PM	3:02 PM	6:10 PM	9:34 PM	9:34 PM	11:55
15	6:00 AM	3:15 PM	3:45 PM	6:34 PM	10:06 PM	10:06 PM	12:46
16	6:00 AM	4:06 PM	4:36 PM	7:01 PM	10:34 PM	10:34 PM	13:38
17	6:00 AM	5:06 PM	5:36 PM	7:35 PM	10:58 PM	10:58 PM	14:28
18	6:00 AM	6:20 PM	6:50 PM	8:20 PM	11:20 PM	11:20 PM	15:20
19	6:00 AM	7:53 PM	8:23 PM	9:21 PM	11:40 PM	11:40 PM	16:11
20	6:00 AM	9:52 PM	10:22 PM	10:46 PM	11:57 PM	11:57 PM	17:02
21	6:00 AM	12:31 AM	1:01 AM	12:50 AM	12:13 AM	12:13 AM	17:53
22	6:00 AM	4:13 AM	4:43 AM	3:55 AM	12:27 AM	12:27 AM	18:44
23	6:00 AM	------	------	------	------	2:02 AM	20:02
24	6:00 AM	------	------	------	------	2:54 AM	20:54
25	6:00 AM	------	------	------	------	3:46 AM	21:46
26	6:00 AM	------	------	------	------	4:38 AM	22:38
27	6:00 AM	------	------	------	------	------	24:00
28	6:00 AM	------	------	------	------	------	24:00
29	6:00 AM	------	------	------	------	------	24:00
30	6:00 AM	------	------	------	------	------	24:00
31	6:00 AM	------	------	------	------	------	24:00
32	6:00 AM	------	------	------	------	------	24:00
33	6:00 AM	------	------	------	------	------	24:00
34	6:00 AM	------	------	------	------	------	24:00
35	6:00 AM	------	------	------	------	------	24:00
36	6:00 AM	------	------	------	------	------	24:00
37	6:00 AM	------	------	------	------	------	24:00
38	6:00 AM	------	------	------	------	------	24:00
39	6:00 AM	------	------	------	------	------	24:00
40	6:00 AM	------	------	------	------	------	24:00
41	6:00 AM	------	------	------	------	------	24:00
42	6:00 AM	------	------	------	------	------	24:00
43	6:00 AM	------	------	------	------	------	24:00
44	6:00 AM	------	------	------	------	------	24:00
45	6:00 AM	------	------	------	------	------	24:00
46	6:00 AM	------	------	------	------	------	24:00
47	6:00 AM	------	------	------	------	------	24:00
48	6:00 AM	------	------	------	------	------	24:00
49	6:00 AM	------	------	------	------	------	24:00
50	6:00 AM	------	------	------	------	------	24:00
51	6:00 AM	------	------	------	------	------	24:00
52	6:00 AM	------	------	------	------	------	24:00
53	6:00 AM	------	------	------	------	------	24:00
54	6:00 AM	------	------	------	------	------	24:00

One Generator Operating With Only The Original 400,000 Liter Tank

Flow Rate (l/s)	**Start Time Cycle 1**	**Cycle 1 Finishes** (Tank Empty)	**Begin Refill By:**	**Start Time Cycle 2**	**Cycle 2 Finishes**	**Begin Refill For Morning By:**	**Generating Time Available** (hr)
9	6:00 AM	12:10 PM	12:40 PM	3:40 PM	5:10 PM	5:10 PM	7:40
10	6:00 AM	12:32 PM	1:02 PM	4:24 PM	6:24 PM	6:24 PM	8:31
11	6:00 AM	12:56 PM	1:26 PM	4:58 PM	7:24 PM	7:24 PM	9:21
12	6:00 AM	1:24 PM	1:54 PM	5:25 PM	8:15 PM	8:15 PM	10:13
13	6:00 AM	1:56 PM	2:26 PM	5:49 PM	8:58 PM	8:58 PM	11:04
14	6:00 AM	2:32 PM	3:02 PM	6:10 PM	9:34 PM	9:34 PM	11:55
15	6:00 AM	3:15 PM	3:45 PM	6:34 PM	10:06 PM	10:06 PM	12:46
16	6:00 AM	4:06 PM	4:36 PM	7:01 PM	10:34 PM	10:34 PM	13:38
17	6:00 AM	5:06 PM	5:36 PM	7:35 PM	10:58 PM	10:58 PM	14:28
18	6:00 AM	6:20 PM	6:50 PM	8:20 PM	11:20 PM	11:20 PM	15:20
19	6:00 AM	7:53 PM	8:23 PM	9:21 PM	11:40 PM	11:40 PM	16:11
20	6:00 AM	9:52 PM	10:22 PM	10:46 PM	11:57 PM	11:57 PM	17:02
21	6:00 AM	12:31 AM	1:01 AM	12:50 AM	12:13 AM	12:13 AM	17:53
22	6:00 AM	4:13 AM	4:43 AM	3:55 AM	12:27 AM	12:27 AM	18:44
23	6:00 AM	------	------	------	------	2:02 AM	20:02
24	6:00 AM	------	------	------	------	2:54 AM	20:54
25	6:00 AM	------	------	------	------	3:46 AM	21:46
26	6:00 AM	------	------	------	------	4:38 AM	22:38
27	6:00 AM	------	------	------	------	------	24:00
28	6:00 AM	------	------	------	------	------	24:00
29	6:00 AM	------	------	------	------	------	24:00
30	6:00 AM	------	------	------	------	------	24:00
31	6:00 AM	------	------	------	------	------	24:00
32	6:00 AM	------	------	------	------	------	24:00
33	6:00 AM	------	------	------	------	------	24:00
34	6:00 AM	------	------	------	------	------	24:00
35	6:00 AM	------	------	------	------	------	24:00
36	6:00 AM	------	------	------	------	------	24:00
37	6:00 AM	------	------	------	------	------	24:00
38	6:00 AM	------	------	------	------	------	24:00
39	6:00 AM	------	------	------	------	------	24:00
40	6:00 AM	------	------	------	------	------	24:00
41	6:00 AM	------	------	------	------	------	24:00
42	6:00 AM	------	------	------	------	------	24:00
43	6:00 AM	------	------	------	------	------	24:00
44	6:00 AM	------	------	------	------	------	24:00
45	6:00 AM	------	------	------	------	------	24:00
46	6:00 AM	------	------	------	------	------	24:00
47	6:00 AM	------	------	------	------	------	24:00
48	6:00 AM	------	------	------	------	------	24:00
49	6:00 AM	------	------	------	------	------	24:00
50	6:00 AM	------	------	------	------	------	24:00
51	6:00 AM	------	------	------	------	------	24:00
52	6:00 AM	------	------	------	------	------	24:00
53	6:00 AM	------	------	------	------	------	24:00
54	6:00 AM	------	------	------	------	------	24:00

8.7 Appendix D - Charts - Maintenance Schedules

Monthly Flow Rate Chart

This chart is a guide for using the generating time chart. The approximate flow rate can be taken from the monthly flow rate chart and then used to determine valve operation times.

Charts for Maintenance Log

Daily Maintenance

Component	Activity	Results	Date	Signature
Trashrack	Clean Thoroughly			
Turbine/Generator	Listen for unusual noises			
	Feel the box for inusual vibrations			

Monthly Maintenance

Component	Activity	Results	Date	Signature
Sluice Gate	Open completely before closing			
Penstock Purge Valve	Open Completely			
Turbine Shut-off Valves	Close Completely			
Nozzle Valves	Open and Close Completely			
	Return the valves to their original positions			

Tri-monthly Maintenance

Component	Activity	Results	Date	Signature
Aqueduct	Inspect for obstructions			
	Inspect for damage			
Tanques	Inspect the tank for damage			
	Inspect the area around initial penstock piping			
Penstock	Inspect the cement for damage and			

	signs of leakage			
Manifold	Inspect the piping for leaks			
	Inspect the tubing for signs of rust			
Drainage Channel	Inspect the cement for damage			
Turbine Platform	Verify that the anchor bolts are tight			
	Inspect the concrete for signs of damage			
Emergency Deflectors	Activate the system with switch in deflector circuit			
	Move the deflectors by hand and listen to the bearings for any unusual noises			
Electrical Connections in the Turbine House	Visually inspect the connections			
	Verify that all bolted connections are tight			
Knife Switches	Verify that they move up and down			
Electrical Connections in the Control House	Visually inspect the connections			
	Verify that all bolted connections are tight			
Breaker Box	Inspect all Connections			
	Inspect the box for oxidization			
	Verify that the breakers move correctly			
Overhead Wires	Inspect the clearance circle and remove anything that violates the 1.5m radius			

Yearly Maintenance

Component	Activity	Results	Date	Signature
Tank	Inspect for cracks			
Sand Trap	Inspect for cracks			
Trash Rack	Inspect for oxidization			
	Verify that the screen is securely attached			
Sluice Gate	Inspect for oxidization			
Pelton	Verify that all the bolts are tightened			
	Inspect the wheel for damage			
	Inspect the spoons for erosion			

8.8 Appendix E - Safety Regulations

TACOMA POWER
TACOMA PUBLIC UTILITIES

March 10, 2005

Customer Requirements
Conduit Installations

C-UG-1100

Types of Conduit

The type of conduit for each application shall be determined by the Tacoma Power Electrical Engineer. The standard acceptable types are:

Conduit Type	Requirements
PVC	UL-listed electrical grade, and gray in color. • Schedule-40 PVC • Schedule-80 PVC
Steel	Galvanized Schedule 40 electrical grade steel

Application

Conduits and encasement provide various ***levels of protection*** for cables. This table lists the different levels and typical applications. The Tacoma Power Engineer will specify which level(s) will be required.

Installation	Typical Application
Sch-40 PVC	Standard for direct burial of conduit.
Sch-80 PVC or Steel	For areas exposed to the public (such as above ground), where minimum cover is not possible, and/or heavy duty applications. ***Sch-80 is preferred***. Steel is used if the local permitting jurisdiction requires it.
Sch-40 PVC Encased in CDF	Controlled Density Fill (CDF) encasement provides some added protection, and is used: • For instant compaction when installation time is a factor. • Local permitting jurisdiction, or third party, requires it. • Under foundations as required.
Sch-40 PVC Encased in Concrete	Rarely used any more, only special conditions such as: • Where a geotechnical analysis requires it, for example very heavy traffic in poor soils. • Local permitting jurisdiction, or third party, requires it.
Warning Ribbon	Warning ribbon is installed 12” above the top of the conduit or encasement in those locations where future trenching by other entities is very likely.
Red Dye Encasement	Local permitting jurisdiction, or third party, requires it.

TACOMA POWER
TACOMA PUBLIC UTILITIES

March 10, 2005

Customer Requirements
Conduit Installations

C-UG-1100

Conduit Components

Elbows

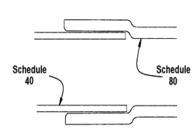
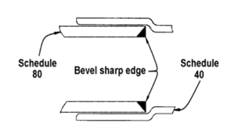
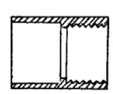
- All elbows shall be made to comply with ANSI Standard C80.1-83 and/or ASTM Standards F512, as appropriate.
- Steel elbows may be required for large pulling tensions.
- Elbow saddle blocks may be required on some bends depending on soils and pulling tensions.

The minimum radius of elbow used in all conduit installations, unless otherwise specified by the Tacoma Power Engineer, shall be:

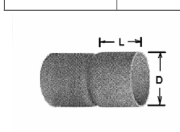
Trade size	2.5"	4"	5"
Minimum radius	24"	36"	48"

Type Transitions

The most common examples of conduit type transitions are at pole risers.

Sch-40 PVC **to** **Sch-80 PVC**	 Preferred transition with Sch-80 bell end	 Alternate transition with Sch-40 bell end, the sharp edge on the Sch-80 end must be beveled or filed down.
Sch-40 PVC **to** **Steel**	 **Adapter PVC to Steel**	Use this adapter when transitioning from PVC to steel

Couplings

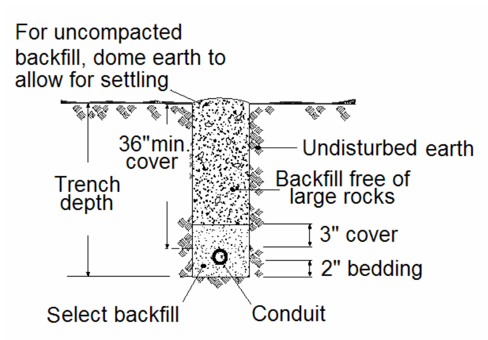


L = D

Deep socket couplings are required, where ***the socket depth (L) equals the conduit diameter (D)***.

Trenches for Conduit

Fig A Typical Trench



General

- The trench shall be straight from point to point.
- The bottom of all trenches shall be flat, smooth, uniform, and free of any and all rocks exceeding ***2 inches***, obstructions, sharp objects, buried timbers and pilings, and other debris encountered.
- Water in the trench shall be removed by pumping or draining as necessary.

Conduit Minimum Total Cover

The minimum conduit total cover shall be ***36 inches***, or the requirement of the local permitting jurisdiction, whichever is greater. Total cover is measured vertically from the final grade to the top of the conduit. At Tacoma Power Engineer's direction, the burial depth may be more or less than the standard 36-inch depth in order to accommodate installation. The Customer is responsible for determining finished grades to assure that minimum burial depth requirements are met ***after*** conduit installation.

For secondary or service conduits, refer to these Customer requirement standards for cover requirements:

- C-SV-1200, Residential Underground Service Boxes
- C-SV-3200, Commercial Secondary Services

Pole Requirements (continued)

Round vs Square

The meter pole must be one of the two types below:

Round Pole	Square Timber Dimensions	
Tapered per ANSI Standard O5.1 with a **6" minimum top** diameter	Service length less than 100 feet	Service length greater than 100 feet
	6" x 6"	**8" x 8"**

Pole Length & Setting Depth

Pole must be a **minimum 20-feet long**. The pole height must be confirmed by Tacoma Power prior to service connection.

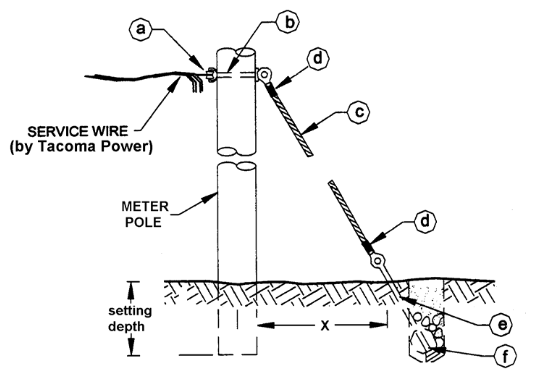
This table will assist in determining the adequate meter pole length and pole setting depth based on the clearances required for the service conductor to pass over.

IF the meter pole is…	…and the service conductor…	THEN the minimum pole length is …	…and the pole setting depth is….
Within 50 feet of Tacoma Power's pole…	Does not pass over a driveway or parking area	20 feet	4 feet
	Passes over a driveway or parking area	25 feet	4 ½ feet
Between 50 feet and 100 feet of Tacoma Power's pole …	Does not pass over a driveway or parking area	25 feet	4 ½ feet
	Passes over a driveway or parking area	30 feet	5 feet
	Crosses over a city or county road or state highway	35 feet	5 ½ feet
Between 100 feet and 150 feet of Tacoma Power's pole …	Does not pass over a driveway or parking area	30 feet	5 feet
	Passes over a driveway or parking area	35 feet	5 ½ feet
	Crosses over a city or county road or state highway	35 feet	5 ½ feet

Guying (continued)

Guys & Anchors

Guy lead "X" should be as long as possible, but not less than **10 feet**.



The anchor (item f) should be set to a minimum setting depth of **5 feet** and installed in line with the service line

Guy Materials

Item	Qty	Description
a	1	Clevis insulator
b	1	5/8" eyebolt, w/nut, or machine bolt with eye-nut
c	as req'd	Guy wire, 5/16" minimum
d	2	Preformed wire grip (or wire rope clamps)
e	1	Anchor rod, ½" min diameter, 6' to 8' long
f	1	The anchor may be any approved type of anchor normally available from electrical supplier (helix, expanding type, plate type, etc.).

Customers desiring to use different materials should check with the Electrical Inspector in advance.

TACOMA POWER
TACOMA PUBLIC UTILITIES

April 14, 2006

Customer Requirements
Pole Conduit Riser

C-UG-1200

Conduit Requirements

Conduit Properties

- All conduit shall be either Schedule 40 PVC, Schedule 80 PVC, or Rigid Galvanized steel. If steel conduit is required, it shall be hot-dip, Schedule 40 galvanized steel.
- All conduits shall be listed and labeled per NEC Article No. 100.
- Only ***gray*** color PVC will be acceptable for electrical risers. ***Green*** PVC is preferred for data conduit risers but gray may be substituted if green is unavailable.

Conduit Applications

- For electrical risers, a full 10-foot rigid conduit piece shall be used to carry the conductors from the trench bottom up the pole to at least 8 feet above the ground line. ***Both the sweep and the 10' piece shall be Schedule 80 PVC unless the permitting jurisdiction requires steel***. The remaining portion of the riser shall be Schedule 40 PVC.
- For Tacoma Power data risers, all conduits shall be Schedule 40 PVC.

Conduit Sweeps / Elbows

The minimum radius of sweeps used in all electrical conduit installations, unless otherwise specified by the Tacoma Power Engineer, shall be:

TRADE SIZE	2 ½ "	4"	5"
Sweep Radius	24"	36"	48"

The minimum radius of sweeps used in all Tacoma Power ***data*** conduit installations shall be **24"**.

All sweeps shall be made to comply with ANSI Standard C80.1-83 and/or ASTM Standards F512, as appropriate.

TACOMA POWER
TACOMA PUBLIC UTILITIES

April 14, 2006

Customer Requirements
Pole Conduit Riser

C-UG-1200

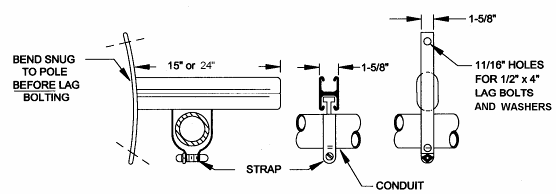
Standoff Brackets Requirements

Standoff Brackets Requirements

Approved stand-off brackets, with 2-piece steel galvanized binding member clamps suited to pipe size and type, will be firmly lag-bolted to pole as shown below. Wire clamps are not acceptable. Install one bracket at the point shown and fit bracket closely to pole shape by bending straps before lag-bolting. See Fig# 1 for more information.

Conduits will be supported by brackets evenly spaced along the pole and no more that ***10 feet apart***. A stand-off bracket should be mounted within 6 inches of the top end of the conduit. Refer to Fig# 3.

Fig# 1



Installations Practices

Number of Risers Allowed

If standoff brackets are already installed on the pole, the new riser(s) shall be attached to these standoffs.

Note: The total number of conduits on a pole for all the utilities shall not be more than **six**. If additional space is required for risers, contact the *Tacoma Power Construction Office* for assistance.

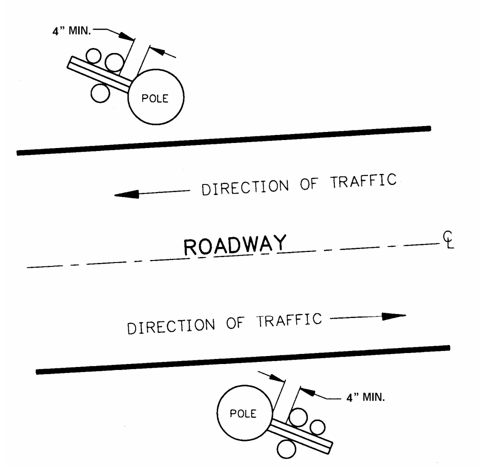
Installations Practices (continued)

Riser Location

If a riser is not already on the pole, the ***T&D Construction Inspector*** will approve the riser location. Some location guidelines are:

- Locate new riser so as to not violate pole climbing space. Refer to NESC Rule 236G and WAC 296-44-21273.
- When practical, risers will be located on the field side of the pole, and the pole quadrant most protected from traffic. See Fig# 2.

Fig# 2



8.9 Appendix F - Design Components Considered - Head Loss Program

Head Loss Scilab Written Computer Program

```
//Micro-hydro head loss calculation
//Finca Nueva Alianza
//22-06-06
//
disp("Head loss calculation for Finca Nueva Alianza Pelton turbine")
disp(" ")
disp(" ")
//
//
//
//
Qtotal=input("What is the initial total flow rate at the turbine for calculation(l/s)?")
ntotal=input("How many nozzles are in the turbine?");
//
//
numcon=input("How many configurations will be tested?");
numcomp=input("How many piping components are in the penstock/manifold?");
//
//
//Set up matrices and variables for configuration comparison loop
compar=1;  //Boolean variable for configuration comparison while loop
compmat=zeros(8,numcon);  //Configuration comparison matrix
con=0;  //Comparison vector storage counter
//
//
// Begin loop
while con<numcon do
  con=con+1;
//
//
//Head loss/price calculation loop
   x=1;  //Boolean variable for head loss/price calculation loop
//
//
//Set up storage vectors for individual configuration data
    if con==1 then
      ch=zeros(7,numcomp); //Pipe characteristics storage vector
      vel=zeros(1,numcomp); //Pipe velocity storage vector
```

```
      hl=zeros(1,numcomp); //Head loss storage vector
      pr=zeros(1,numcomp); //Price storage vector
      fr=zeros(1,numcomp);  //Friction factor storage vectore
      Q=zeros(1,numcomp);  //Flow rate storage vector
    end
//
//
    p=0;  //Head loss and price storage counter
//
//
//  Begin loop
    while x==1 do
      p=p+1;  //Start counter for storage
//
//
//    Modify configuration for comparison
      if con>1 then
        p=input("What number component would you like to change?");
      else disp(p,'Component #')
      end
//
//
//
//
//    Variable Aquisition
//
      M=input("Enter 1 for major loss, 2 for minor loss");
//
//
//    Minor loss variables
      if M==2 then
        fit=input("Accessory type, enter 1 for Y, 2 for Forty-five, 3 for Ninety, 0 for
        if fit==0 then
          fit=input("4 for Gate Valve, 5 for Ball Valve, 6 for Reducer.");
        end
//
        if fit==6 then
          D1=input("What is D1(in)?");
          D2=input("What is D2(in)?");
            D=(D2+D1)/2; //Net reducer diameter
            DR=D2/D1;    //Diameter of reducer exit to entrance diameter
        else D=input("What is the diameter of the pipe(in)?");
        end
//
        if fit==4 then
```

```
          C=input("Is the valve 0, .25, .5, or .75 closed?");
        end
//
        if fit==1 then
          B=input("Is it 1)Line flow or 2)Branch flow?");
        end
//
        Z=input("How many accessories of this type are there?");
      end
//
//
//    Major loss variables
      if M==1 then
        D=input("What is the diameter of the pipe(in)?");
//
        L=input("What is the pipe length(m)?");
//
//      Surface roughness of pipe
        mat=input("What is the pipe material, 1)Galvanized, 2)PVC?");
          if mat==1 then
            e=.00015;
          elseif mat==2 then
            e=.00001;
          end
//
      end
//
//
      n=input("How many nozzles are on this section of pipe?");
//
//
//  Set constants
//
//  Acceleration due to gravity(m/s^2)
      g=9.81;
//
//  Density of water(kg/m^3)
      ro=1000;
//
//  Absolute viscosity of water(Pa-s)
      visc=.001;
//
//
//  Minor loss coefficients
      if M==2 then
```

```
        if fit==1 then
          if B==1 then
            k=.30;
          elseif B==2 then
            k=.50;
          end
//
        elseif fit==2 then
          k=.20;
//
        elseif fit==3 then
          k=.40;
//
        elseif fit==4 then
          if C==0 then
            k=.39;
          elseif C==.25 then
            k=1.10;
          elseif C==.5 then
            k=4.8;
          elseif C==.75 then
            k=27;
          end
//
        elseif fit==5 then
          k=.05;  //assuming all ball valves in the system are always completely open
//
        elseif fit==6 then
          if DR>=.65 then
            k=.18;
          elseif DR>=.35 then
            k=.37;
          elseif DR>=0 then
            k=.49;
          end
        end
      end
//
//
//  Define variables that do not apply to the specific equations
//  as zero to fill up the matrix
      if M==1 then
        k=0;
        Z=0;
      elseif M==2 then
```

```
        L=0;
        e=0;
      end
//
//
//  Conversions
//
//  Convert diameter to meters
      Dm=D*.0254;
//
//  Convert Q to m^3/s
      Qm=Qtotal/1000;
//
//
//  Store pipe characteristics
      ch(1,p)=M;
      ch(2,p)=L;
      ch(3,p)=k;
      ch(4,p)=Dm;
      ch(5,p)=Z;
      ch(6,p)=n;
      ch(7,p)=e;
//
//
//     Cost Calculations
//
//
//Pipe costs are costs per 6m tube/6 to get cost per meter, x length
//
      if M==1
        if D==2 then
          price=(390/6)*L;
        end
//
        if D==2.5 then
          price=(490/6)*L;
        end
//
        if D==3 then
          price=(640/6)*L;
        end
//
        if D==4 then
          price=(930/6)*L;
        end
```

```
        if D==6 then
          price=(480/6)*L;
        end
      end
//
//
//Accessories
//  ***Z of Y is divided by two in the cost calculations, because each Y is calculated
//  ***twice in the head loss calcs, once for branch flow and once for line flow.
//  ***This will prevent the cost of each Y being calculated twice.
//
      if M==2 then
        if fit==1 then
          if D==3 then
            price=(Z/2)*180.00;
          elseif D==4 then
            price=(Z/2)*275.00;
          end
        end
//
        if fit==2 then
          if D==2 then
            price=Z*17.10;
          elseif D==2.5 then
            price=Z*44.55;
          elseif D==3 then
            price=Z*67.65;
          elseif D==4 then
            price=Z*115.65;
          end
        end
//
        if fit==3 then
          if D==2 then
            price=Z*17.10;
          elseif D==2.5 then
            price=Z*37.40;
          elseif D==3 then
            price=Z*57.00;
          end
        end
//
        if fit==4 then
          if D==2 then
```

```
            price=0 //We already have 2" gate valves
          elseif D==2.5 then
            price=Z*286.70;
          elseif D==3 then
            price=Z*555.00;
          end
        end
//
        if fit==5 then
          if D==3 then
            price=0  //We already have 3" ball valves
          elseif D==4 then
            price=Z*550.00;
          end
        end
//
        if fit==6 then
          if D1==4 then
            price=Z*81.90;
          elseif D1==3 then
            if D2==2.5 then
              price=Z*45.30;
            elseif D2==2 then
              price=Z*44.55;
            end
          end
        end
      end
//
//
//  Store price
      pr(p)=price;
//
//  Calculate Initial Flow Rate in Pipe Section
      Q(p)=Qm*(ch(6,p)/ntotal);
//
//
      if con==1 then
        if p>=numcomp then
          x=2;
        else disp('Next Component')
        end
      else x=input("Would you like to change another component? 1)Yes, 2)No");
      end
    end  //End of component characteristic storage loop
```

```
//
//
//  Head loss-velocity iteration loop
//
//
//  Set variables for loop
  count=0;  //Number of iterations
  Qnew=Q;  //Initial flow rate
  Qt=Qtotal;
//
//
//Begin loop
  while abs((Q(2)-Qt))>.000001 do  //Epsilon value for exiting from loop, assuming that
    count=count+1
    Q=Qnew; //Q from bottom of this loop
//
//
//  Calculate head loss
      for pnew=1:numcomp
        vel(pnew)=Q(pnew)/(%pi*(ch(4,pnew)/2)^2);
        if ch(1,pnew)==1 then
//        Reynold's Number
          Re=(vel(pnew)*ro*ch(4,pnew))/visc;
//        Friction Factor
          fr(pnew)=(.25/(log10((ch(7,pnew)/(3.7*(ch(4,pnew))))+(5.74/(Re^.9))))^2);
//        Head loss
          hl(pnew)=fr(pnew)*(ch(2,pnew)/ch(4,pnew))*((vel(pnew)^2)/(2*g));
        else hl(pnew)=ch(5,pnew)*ch(3,pnew)*((vel(pnew)^2)/(2*g));
        end
      end
//
//
//  Total head loss
      totalloss=sum(hl(:));
//
//
//  Jet Velocity
//    Set constants
        Cd=.96; //discharge coefficient
        h=57; //static head in meters
//
      Vj=Cd*sqrt(2*g*(h+((vel(11)^2)/(2*g))-totalloss));
//
//
//  Area of Nozzle
```

```
//    Set constants
        x=.46; //ratio of jet velocity to runner velocity
        N=1800; //rpm of runner (optimum generator rpm)
//
//    Pitch Circle Diameter
        PCD=(60*Vj*x)/(%pi*N);  //60 and pi convert rpm to rad/s
//
//    Diameter of the nozzle
        Dn=.140*PCD;  //ratio given by Thake book
//
      An=%pi*(Dn/2)^2;
//
//
//  Flow rate at nozzle
      Qn=Vj*An;
//
//
//  Total turbine flow rate
      Qt=Qn*ntotal
//
//
//  Recalculate flow rate
      Qnew=Qn*(ch(6,:));
//
//
    end
//
//
//  Calculate Power
//    Set constants
        effgen=.85;
        efftur=.75;
//
      Pow=ro*g*(h+((vel(11)^2)/(2*g))-totalloss)*Qt*effgen*efftur;  //Assumes component
//
//
//  Convert flow rate to l/s
      Qconv=Qt*1000;
//
//
//  Convert diameters to mm
      Dnconv=Dn*1000;
      PCDconv=PCD*1000;
//
//
```

```
//  Convert power to kW
      Powconv=Pow/1000;
//
//
//  Store results
  //Configuration #
  compmat(1,(con))=con;
  //Total head loss(m)
  compmat(2,(con))=totalloss;
  //Jet velocity(m/s)
  compmat(3,(con))=Vj;
  //Nozzle diameter(mm)
  compmat(4,(con))=Dnconv;
  //Pitch circle diameter(mm)
  compmat(5,(con))=PCDconv;
  //Flow rate(l/s)
  compmat(6,(con))=Qconv;
  //Theoretical power(kW)
  compmat(7,(con))=Powconv;
  //(8,1)='Price(Q)
  compmat(8,(con))=sum(pr);
//
//
//  Save data matrices  ***Look for a more efficient way to do this***
//
  if con==1 then
    save('ch1.dat',ch);
    save('vel1.dat',vel);
    save('hl1.dat',hl);
    save('pr1.dat',pr);
  elseif con==2 then
    save('ch2.dat',ch);
    save('vel2.dat',vel);
    save('hl2.dat',hl);
    save('pr2.dat',pr);
  elseif con==3 then
    save('ch3.dat',ch);
    save('vel3.dat',vel);
    save('hl3.dat',hl);
    save('pr3.dat',pr);
  elseif con==4 then
    save('ch4.dat',ch);
    save('vel4.dat',vel);
    save('hl4.dat',hl);
    save('pr4.dat',pr);
```

```
  elseif con==5 then
    save('ch5.dat',ch);
    save('vel5.dat',vel);
    save('hl5.dat',hl);
    save('pr5.dat',pr);
  elseif con==5 then
    save('ch5.dat',ch);
    save('vel5.dat',vel);
    save('hl5.dat',hl);
    save('pr5.dat',pr);
  elseif con==6 then
    save('ch6.dat',ch);
    save('vel6.dat',vel);
    save('hl6.dat',hl);
    save('pr6.dat',pr);
  elseif con==7 then
    save('ch7.dat',ch);
    save('vel7.dat',vel);
    save('hl7.dat',hl);
    save('pr7.dat',pr);
  elseif con==8 then
    save('ch8.dat',ch);
    save('vel8.dat',vel);
    save('hl8.dat',hl);
    save('pr8.dat',pr);
  elseif con==9 then
    save('ch9.dat',ch);
    save('vel9.dat',vel);
    save('hl9.dat',hl);
    save('pr9.dat',pr);
  elseif con==10 then
    save('ch10.dat',ch);
    save('vel10.dat',vel);
    save('hl10.dat',hl);
    save('pr10.dat',pr);
  end
//
//
  if con<numcon then
    disp('Next Configuration');
    disp(' ');
  end
end
//
//
```

```
//Save Comparison Matrix
save('comparison.dat',compmat);
//
//
//Display comparison matrix
compmat
//
//
//Plot power vs price of manifold
plot(compmat(8,:),compmat(7,:),'^');
xtitle('Comparacion Entre Potencia Teoretico y Precio de Configuraciones Diferentes de C
p=get("hdl");
p.line_mode="off";
```

8.10 Appendix F - Design Components Considered - Hydraulic efficiency of a Pelton Bucket Program

```
//Calculation of the hydraulic efficiency of a Pelton Bucket

R1=.075;  //Radius of pitch circle diameter
rsj=.12;  //Ratio of length of splitter extending beyond PCD to PCD
Rs= R1+(2*R1*rsj); //Radius at splitter end
thetaA=acos(R1/Rs);  //Angle of bucket when it cuts off the jet, measured from the line
dn=.021;  //Diameter of nozzle (m)
nmin=(%pi*R1)/dn;  //Minimum number of buckets required
nmin=ceil(nmin);  //Round nmin up to next integer

for n=nmin:22; //Number of buckets on the runner
  k=n  //Counter
  delta=(2*%pi)/n;  //Angle between buckets
  x=.46;  //Ratio of runner speed to jet speed

//Interval bisection code to solve for thetaB
//thetaB is the angle where the last piece of jet cut off by the bucket that follows enc
  eps=.0001; //epsilon factor for exiting loop
  M=(x*tan(thetaA))-thetaA+delta;
  a=.01;
  b=thetaA; //theta
  while b-a>eps
    thetaB=(a+b)/2;
    if thetaB-(x*tan(thetaB))>M then
      b=thetaB;
    else a=thetaB;
    end
  end

zeta=.80;  //efficiency factor for flow loss inside the bucket
gama=.26;  //Angle of side walls of bucket
eta=((2*x*(1+(zeta*cos(gama))))/delta)*(thetaA+thetaB+(x*(x-2)*(tan(thetaA)+tan(thetaB))
end
```

8.11 Appendix F - Design Components Considered - Single Phase Electrical Distribution

Single Phase Voltage Drop Calculation

A simple voltage drop calculation for a single phase electrical distribution system can be calculated as follows,

$$V_{drop} = \frac{2 \times K \times A \times D}{CM}$$

Where

$$\begin{aligned} V_{drop} &= \text{single phase voltage drop (V)} \\ K &= \text{resistance in ohms} \\ A &= \text{current in amps} \\ D &= \text{distance (m)} \\ CM &= \text{circular mills - wire size} \end{aligned}$$

From the generator to the control house, the calculation of the single phase voltage drop is as follows,

$$\begin{aligned} V_{drop} &= \tfrac{2\times12.9\times24\times590}{26800} \\ &= 13.63V \end{aligned}$$

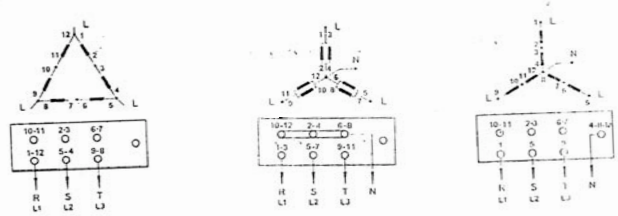
Therefore, from the generator to the control house, a single phase voltage distribution design contains a 5.68% voltage drop assuming a 240 voltage system. From the control house to the houses, the calculation of the single phase voltage drop is as follows,

$$\begin{aligned} V_{drop} &= \tfrac{2\times21.2\times24\times3520}{108036} \\ &= 33.15V \end{aligned}$$

Therefore, from the control house to the household loads, a single phase voltage distribution design contains a 13.81% voltage drop assuming a 240 voltage system.

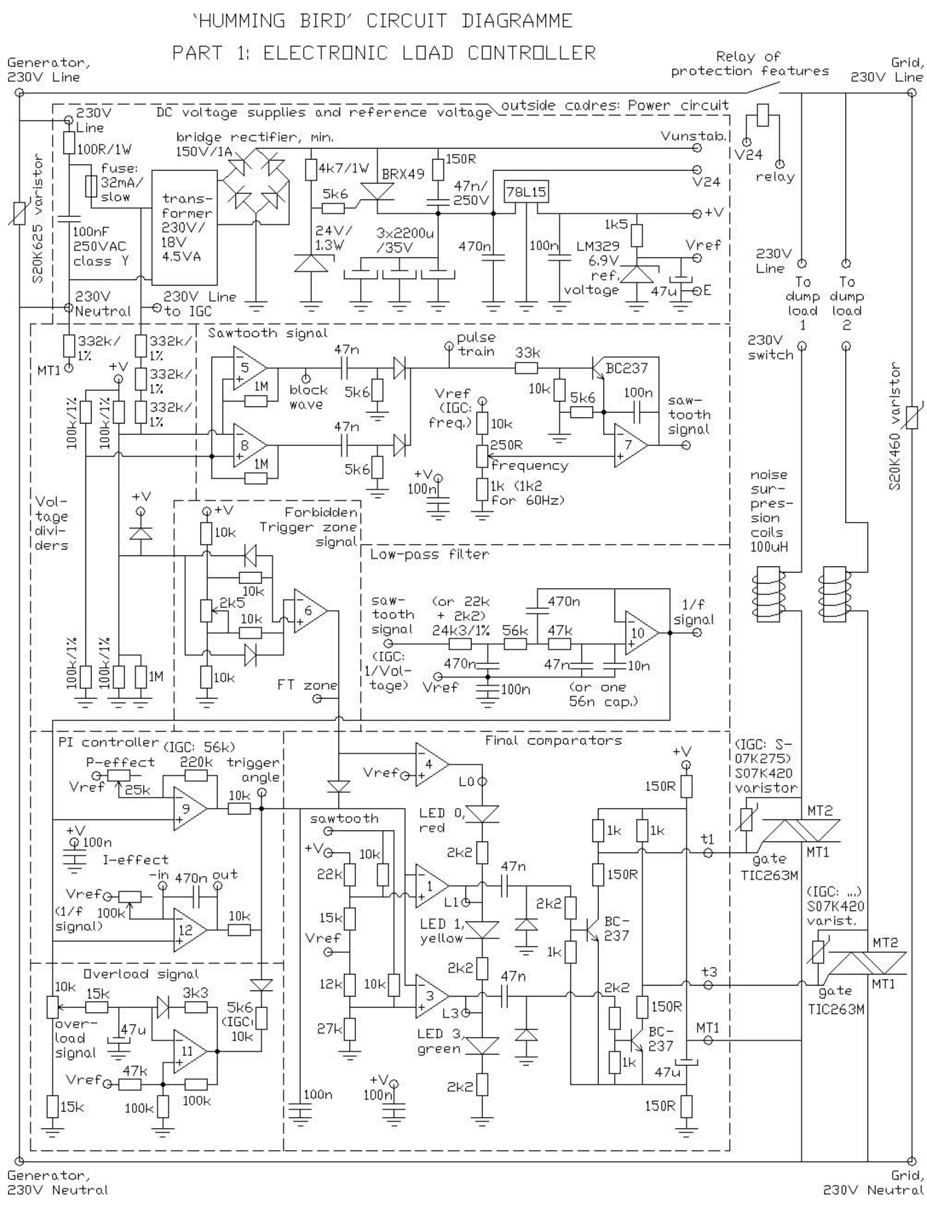
8.12 Appendix F - Design Components Considered - Generator Phase Control Circuit Configurations

VOLTMASTER 12 WIRE RECONNECTABLE 3 PHASE CONNECTIONS



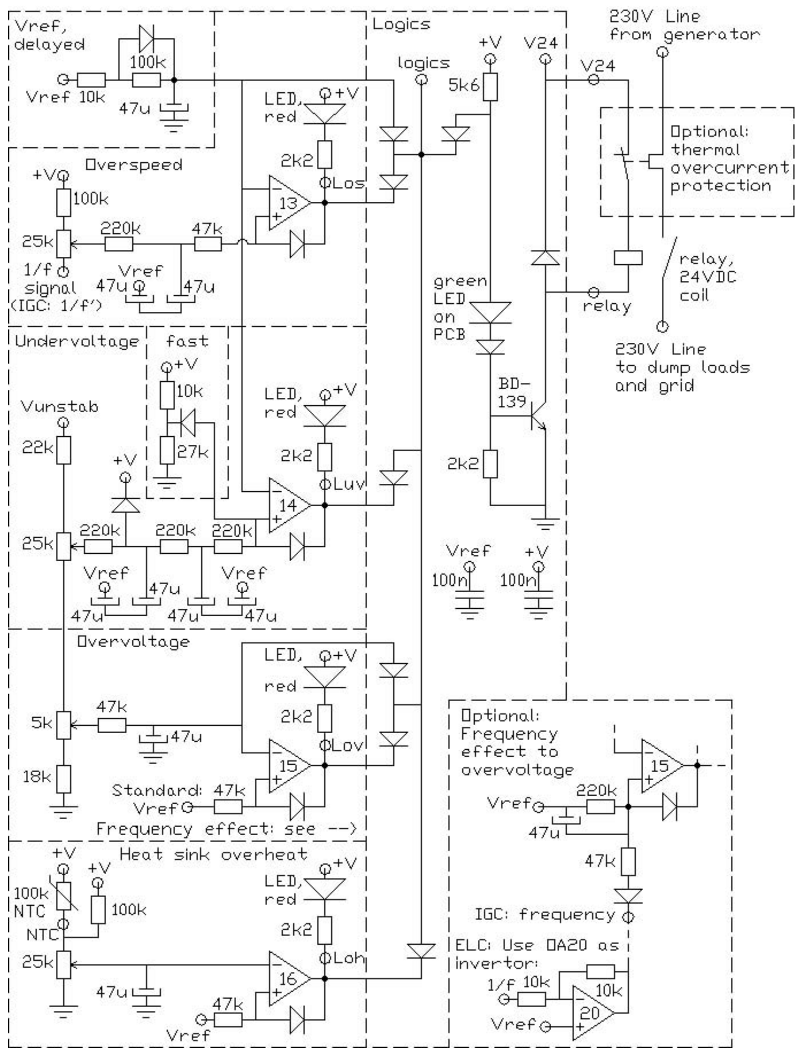
THREE PHASE 240 V SERIES DELTA CONN	THREE PHASE 120/208 V PARALLEL STAR	THREE PHASE 480 V SERIES STAR
1-12 TO 2-3=120 V	1-3 TO N(10-12-2-4-6-8)= 120 V	1 AND 5 AND 9=480 V
5-4 TO 2-3=120V	5-7 TO N(10-12-2-4-6-8)= 120V	
1-12 AND 5-4 AND 9-8=240V	9-11 TO N(10-12-2-4-6-8)= 120V	
	1-3 AND 5-7 AND 9-11= 240V.	

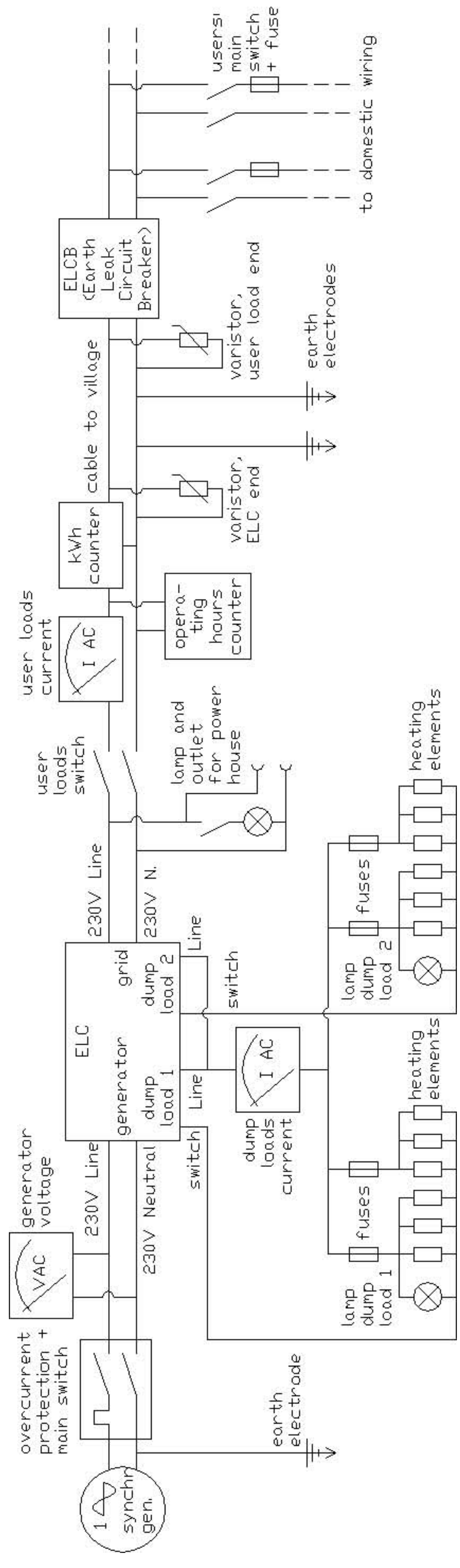
8.13 Appendix F - Design Components Considered - ELC Circuit Configurations


'HUMMING BIRD' CIRCUIT DIAGRAMME
PART 1: ELECTRONIC LOAD CONTROLLER
Generator, 230V Line
Relay of protection features
Grid, 230V Line
DC voltage supplies and reference voltage
outside cadres: Power circuit
230V Line
100R/1W
fuse: 32mA/ slow
S20K625 varistor
100nF 250VAC class Y
trans- former 230V/ 18V 4.5VA
bridge rectifier, min. 150V/1A
4k7/1W
BRX49
150R
47n/ 250V
78L15
Vunstab.
V24
+V
relay
5k6
24V/ 1.3W
3x2200u /35V
470n
100n
1k5
LM329 6.9V ref. voltage
Vref
47u
E
230V Neutral
230V Line to IGC
230V Line
To dump load 1
To dump load 2
230V switch
332k/ 1%
MT1
Sawtooth signal
47n
pulse train
33k
BC237
block wave
5k6
10k
100n
saw- tooth signal
1M
Vref (IGC: freq.)
250R
frequency
1k (1k2 for 60Hz)
S20K460 varistor
noise sur- pres- sion coils 100uH
100k/1%
Vol- tage divi- ders
Forbidden Trigger zone signal
2k5
FT zone
Low-pass filter
(or 22k + 2k2)
24k3/1%
56k
47k
470n
1/f signal
(IGC: 1/Vol- tage)
(or one 56n cap.)
PI controller (IGC: 56k)
P-effect
220k
trigger angle
25k
I-effect
-in
out
(1/f signal)
100k
Overload signal
15k
3k3
5k6 (IGC: 10k)
over- load signal
Final comparators
L0
LED 0, red
2k2
sawtooth
22k
12k
27k
L1
LED 1, yellow
L3
LED 3, green
150R
BC- 237
t1
t3
(IGC: S- 07K275) S07K420 varistor
MT2
gate TIC263M
(IGC: ...) S07K420 varist.
Generator, 230V Neutral
Grid, 230V Neutral

[h]

PART 2: PROTECTION FEATURES




users' main switch + fuse
to domestic wiring
ELCB (Earth Leak Circuit Breaker)
varistor, user load end
earth electrodes
cable to village
varistor, ELC end
kWh counter
user loads current
I AC
opera-ting hours counter
user loads switch
lamp and outlet for power house
heating elements
230V Line
230V N.
fuses
Line
grid
dump load 2
switch
lamp dump load 2
ELC
generator
dump load 1
Line
I AC
dump loads current
heating elements
generator voltage
VAC
230V Line
230V Neutral
switch
fuses
lamp dump load 1
overcurrent protection + main switch
earth electrode
1 synchr gen.