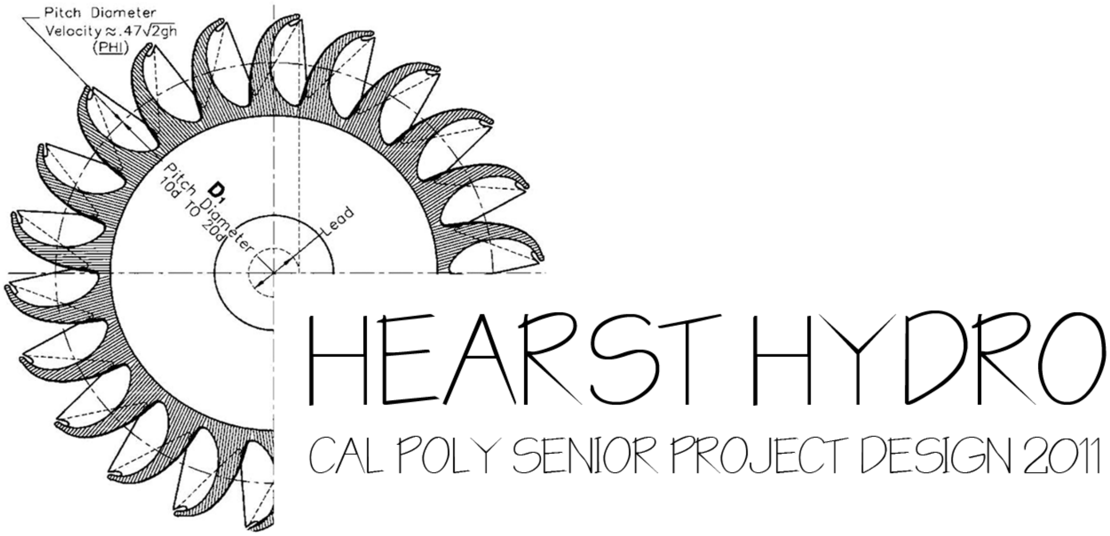

Hearst Hydroelectric Generation Facility

June 8, 2012

Sponsor: Hearst Ranch

Point of Contact: Cliff Garrison

By

Anthony Schifano: aschifan@calpoly.edu

Richard Wright: rswright@calpoly.edu

Nick Buchanan: ncbuchan@calpoly.edu

Corey Nakai: cnakai@calpoly.edu

Joshua Rutheiser: jrutheis@calpoly.edu

Project Advisors: Dale Dolan and Lee McFarland

Table of Contents

1. Acknowledgements 2
2. Abstract 3
3. Introduction 4
4. Background 5
5. System Specifications and Design Requirements 6
6. Design Development 7
   Types of Turbines 7
      Nozzle/Jet Configuration 7
   Turbine and Generator Housing 8
      Building Specifications 8
      Building Dimensions and Design 8
      Building Location 8
7. Concept Model Design Development 9
8. Economic Analysis 10
   Future Weather Prediction 10
   Initial Values and Assumptions 12
   System Cost Breakdown 13
   Cumulative Net Worth 14
9. Electrical Design 16
   Generator Selection 16
   Transformer Selection 16
   Cable Selection 16
   System Protection 18
   Generator Protection 18
   Transformer Protection 20
10. Conclusion 21
Appendix A: Senior Project Analysis 22
Appendix B: Power System Calculations 28
   Transformer Ratings 28
   Generator Protection 28
   Transformer Protection 29
Appendix C: Turbine Efficiency Analysis 30
Appendix D: References 31

1. Acknowledgements

We would like to thank all of our friends and families for their continuous motivation and tremendous support. We would also like to thank our Mechanical Engineering Advisor Lee McFarland who provided much help with communication and travel to Hearst Ranch. Lee was the primary agent in starting this project and built a strong relationship between the Hearst Corporation and Cal Poly.

Huge thanks to our Electrical Engineering Advisor Dr. Dale Dolan for helping the team with power analysis and implementation. His advice and practical knowledge of renewable power was an invaluable resource.

We would also like to acknowledge Cliff Garrison, the Hearst Ranch Manager who was the driving force for the project under the Hearst Corporation. We appreciate all the time he has taken to help us obtain the necessary data for our analysis.

2. Abstract

This project proposes a power plant design that provides a supplemental source of electricity for appliances, machinery, and lighting at Hearst Castle and Ranch. The design concept includes a turbine-generator combination to convert kinetic and gravitational potential energy from the existing water distribution system to electrical energy: also known as a hydroelectric plant. The electrical distribution system from the plant to the local grid takes advantage of power flow techniques utilized in current research and industry.

3. Introduction

The ranchland that provided the base for Hearst Castle and Ranch was purchased in 1865 by George Hearst. William Randolph Hearst inherited the land in 1919 and decided to build on it. "His simple instructions to famed San Francisco architect Julia Morgan in 1919: 'Miss Morgan, we are tired of camping out in the open at the ranch in San Simeon and I would like to build a little something'" [1].

The Castle was constructed without electricity. "Coal oil lanterns were used for light. Then [William] Hearst had a powerhouse and water wheel generator installed" [2]. This powerhouse allowed the castle to finally incorporate lights to be used during the day and night. A gasoline powered generator and hydroelectric generator were used throughout the day. The gasoline generator was powered off at midnight while the hydro generator took over the smaller load [2].

The powerhouse was shut down in 1928 [2] due to the availability of power from the PG&E grid. It was because of the maintenance labor, inconsistent power, and lack of room for electrical growth that Hearst decided to switch to the central grid.

Since the time of the powerhouse, the Hearst Corporation has continued to rely on the power from the PG&E grid. In the 2006-2007 school year the Ranch Manager contacted faculty at Cal Poly in hopes that a student could pursue a feasibility study for a new hydroelectric generation plant. A BRAE student finished a feasibility study in 2007 as a senior project [3]. The "recommendations" section stated that Hearst Ranch should pursue the "proposed hydroelectric generation facility to reduce [the ranch's] electrical costs."

In September, 2011, a team of five was put together, including three Mechanical Engineers and two Electrical Engineers. The original plan called for construction and implementation in May 2012. However, due to budgetary and timeline concerns, it was not possible to implement the full-scale design at Hearst Ranch.

4. Background

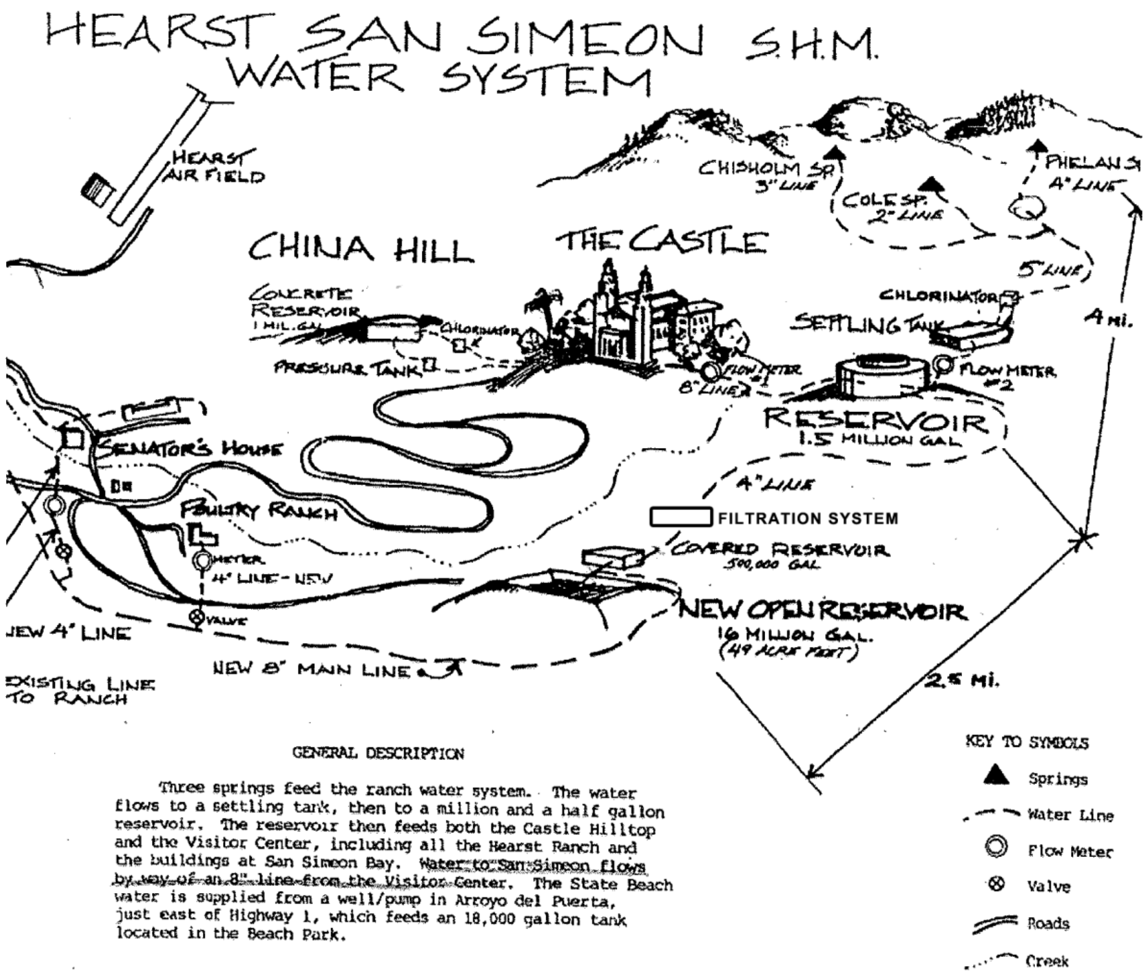

Figure 1: *Layout of The Hearst Ranch Water System [3]*

The original water supply system at Hearst Ranch can be seen above in Figure 1. A natural spring is located in the hills of Hearst Ranch which feeds water into a 1.5 million gallon reservoir. The water from this reservoir splits at the tank and flows to the filtration system and to Hearst Castle as seen in the figure above. The water from the filtration system is what Hearst Ranch uses for everyday tasks (crops, landscape irrigation, animal drinking water, and more). Therefore, when designing this project, one main specification is to allow the water to flow into the filtration system without disrupting ranch operations.

5. System Specifications and Design Requirements

The mechanical specifications and design requirements are based off of flow rates gathered from historical water data tabulated by the Hearst Castle State Park staff. This data indicates that flow rates range between 24 and 250 gallons per minute. These wide flow rate variations will require a dynamic turbine-nozzle layout to deliver consistent power. Electrical requirements and specifications are listed in Table 1.

Table 1: *Electrical Requirements and Specifications*

Marketing Requirements	Engineering Specifications	Justification
2	Generate power for Hearst Ranch grid without controlling water flow.	Hindering the water flow would impact both the Ranch and the Castle.
1, 2, 3	Have the ability to accept and source power at the PG&E source.	Management of Hearst Ranch would like the ability to sell back power to PG&E since there should be more than enough to cover the ranch at times.
5	Create a system that cannot be seen from the freeway and conforms to the style of architecture at Hearst Castle/Ranch.	The ranch had a hydroelectric plant in the past and this would provide some historic significance.
1, 2, 4	Minimal losses when distributing power to the ranch.	There are various transmission lines on the ranch and power losses will need to be minimal to insure the greatest efficiency of the generator.
1, 4	Have a real-time, sensor monitoring system that provides measurements of power flow, harmonic loss, and line losses.	This will allow the ranch and researchers to view important data regarding their local grid. It will help schedule maintenance times and also provide feedback on efficiency.
Marketing Requirements 1. Continuous Power 2. Economic 3. Durable 4. High Power Conversion 5. Aesthetically Pleasing		

6. Design Development

Types of Turbines

There are two types of hydraulic turbines designed to extract mechanical energy from fluid systems—reaction and impulse turbines [15]. Reaction turbines work similar to a ship's propeller but rather than impart energy, they extract it. These turbines require high flow rates and work with low to high head pressures. They also must be fully immersed in the water flow and require an encasement to properly contain and direct water. Reaction turbines are typically used in large-scale hydroelectric power plants. The most utilized designs are the Francis and Kaplan turbines.

On the contrary, impulse turbines work in situations with large head pressures and low to moderate flow rates. Rather than being fully immersed in water, impulse turbines are open to the atmosphere and utilize a high velocity jet of water to extract power from water flow. The jet pushes on the turbine's curved blades, resulting in momentum changes [15].

There are many types of impulse turbines designed to operate efficiently at different heads and flow rates. The two types suitable for implementation at the Hearst Ranch site are Pelton [16] and Banki (cross flow) turbines. These turbines allow utilization of high head pressures and a wide range of flow rates. Pelton turbines are much more commonly implemented than Banki turbines in the United States.

Nozzle/Jet Configuration

Optimal turbine geometry is a function of the range of jet diameters; the more nozzles in the configuration, the smaller the range of jet/nozzle diameters required to accommodate the flow, and hence turbine geometry that effectively and efficiently makes use of the wide range of flow rates [17]. A "needle nozzle" modulates jet diameter, which is two stainless steel conical shapes—male and female—that articulate relative to one another.

Turbine and Generator Housing

Building Specifications

The building has several key requirements. It must be large enough to hold and protect the proposed hydroelectric turbine system with all accompanying electronic components and a comprehensive spare parts collection (with ample space for installation and maintenance); maintain the architectural design of the ranch buildings; corrosion and wind resistant; durable; low cost; and contain necessary security.

Building Dimensions and Design

Structures cost in the neighborhood of $100 per square foot. Our required 30 ft x 30 ft single story building would cost about $90,000. This option is relatively expensive, although would hold up well to the elements and could be fitted with a façade in order to match some of the other ranch buildings.

Nunno Steel in Paso Robles was contacted to investigate building alternatives. Nunno offers fully customizable steel buildings that are high wind resistant and include a semi-oxidized siding, which will provide a fitting rustic look as well as prevent corrosion. Corrosion resistance is important in this application because Hearst Ranch is located on the coast. These buildings are priced at about $30,000 for a 30 ft x 30 ft single story, including slab and complete assembly, and do not require any permits because it will be constructed on agricultural land of more than 20 acres.

The electrical wiring coming from the generator will run across the ceiling to the protection system. Around the inside perimeter will be cabinets that house spare parts and other maintenance and safety items in order to minimize system down time. In order to ensure that large parts can enter and exit the building, two entrances (one garage door) will be added to the design. A small secondary story loft housing a desktop and file cabinet, for utility and maintenance record keeping, is accessed from a spiral staircase.

Building Location

An ideal site for the building location is approximately 100ft up the hill from the 49 acre reservoir. This site allows the water exiting the turbine to have enough head in order to flow into the filtration tank at the state park facility without the need for a pump. The building cannot be seen from the highway and is aesthetically pleasing to the Hearst Ranch employees.

7. Concept Model Design Development

Since a large scale model cannot be completed due to lack of budget, a concept model is created. The goals of the model are to show the inner-workings of the Pelton wheel turbine setup, including how the mechanical energy from the incoming water is transformed into electrical energy.

The Pelton wheel is about 8 inches in diameter and consists of 12 cups made from cast aluminum. The wheel is connected to a keyed shaft by use of keyed flanges that have the same bolt pattern as the center hub of the Pelton wheel. Keyways in the shaft hubs maintain alignment with the rotating wheel to prevent slip and ensure proper transmission of power. The flanges are affixed with the use of snap rings for proper alignment and to prevent run out.

The keyed shaft is supported by sealed, flanged bearings, which are press fitted into aluminum plates on either end of the shaft. To prevent water from leaking out, epoxy is added around the press fit of the bearings. Parts of the aluminum plate are cutout with a CNC machine and covered with Plexiglas to allow view of the inner-workings of the turbine. Each of the remaining four sides of the box is constructed with Plexiglas to provide additional viewing area. One ¼ inch nozzle is connected to each side of the Pelton wheel box. The nozzles are offset by 90 degrees and sealed with epoxy to prevent leaking. To ensure maximum efficiency, each nozzle is aimed directly at the buckets of the Pelton wheel. To complete the container, it is lined with epoxy to provide a solid and watertight enclosure for the Pelton wheel assembly. There is a large hole in the bottom of the Pelton wheel box to allow draining of the excess water.

Powering the Pelton wheel are four ¾ inch hoses, each of which is connected to its respective ¼ inch nozzle on the side of the enclosure. When the water hits the Pelton wheel, the mechanical energy is transmitted through a keyed and press fitted large sprocket on the end of the shaft. The Pelton wheel spins at 600rpm under normal operation. Therefore, a 1 to 6 gear ratio is used via chain and sprockets to step the speed up to approximately 3500rpm.

The small sprocket (rotating around 3500rpm) is press fitted onto the input shaft of an alternator that outputs between 175 and 200A at between 12 and 15VDC. The DC power is then converted to AC power via a 1500W continuous (3000 Watt peak) inverter that has three traditional 110V outlets. The conceptual design system generates about 0.5-1.0kW after subtracting mechanical and electrical losses.

The entire assembly sits on a steel tubular frame that is welded together. All of the pieces are held in place with welded tabs. The chain adjustment and alternator mounting is accomplished with an automotive slider bracket. Aluminum parts are powder coated to prevent rust. The model is easily transportable and can be brought to Hearst Ranch for presentation.

8. Economic Analysis

Future Weather Prediction

Historical weather data from 2000 to 2011 is used to help predict future trends in annual precipitation [4]. The 12 year range of historical data results in a cyclical graph as shown in Figure 2.

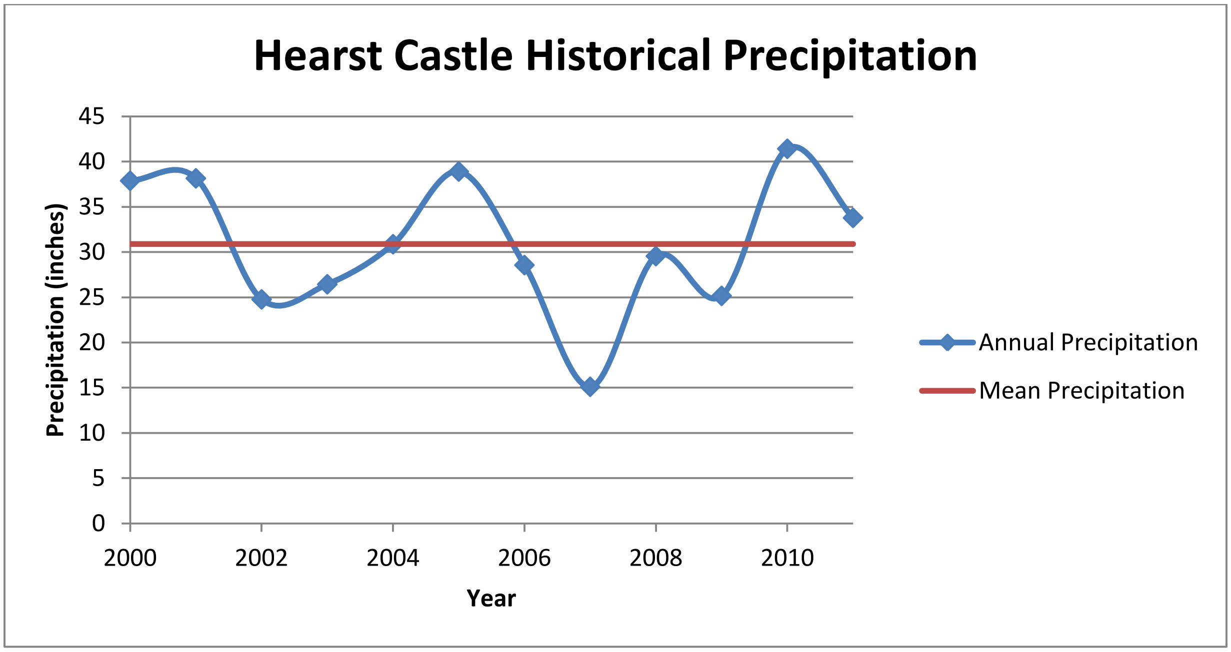

Figure 2: *Historical Precipitation Data Compared to Mean Precipitation*

Precipitation reports were generated form WeatherSource.com [4]. Maximum annual precipitation is 41.42 inches, minimum is 15.11 inches, and the mean precipitation is 30.88 inches. The percent deviation listed in Table 2 is the difference between the annual precipitation for the specified year and the mean precipitation for the past 12 years. The generation multiplier is a numerical representation of the percent deviation which is used when predicting the annual power generation of the system. It is assumed that the amount of precipitation is proportional to the water volume in the Hearst Ranch reservoir, and therefore proportional to the energy generated. The location utilized for data collection is San Simeon.

Table 2: *San Simeon, CA - 12 Year Precipitation Analysis*

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Annual Precipitation (Inches)	37.88	38.15	24.77	26.44	30.87	38.9	28.56	15.11	29.55	25.16	41.42	33.78
% Deviation From Mean	23%	24%	-20%	-14%	0%	26%	-8%	-51%	-4%	-19%	34%	9%
Generation Multiplier	1.23	1.24	0.8	0.86	1	1.26	0.92	0.49	0.96	0.81	1.34	1.09

Assuming the cycle repeats every 12 years, the set of power generation multipliers for 36 years will be:

$$Multipliers = \begin{Bmatrix} 1.23, 1.24, 0.8, 0.86, 1, 1.26, 0.92, 0.49, 0.96, 0.81, 1.34, 1.09, 1.23, 1.24, 0.8, 0.86, 1, 1.26, 0.92, \\ 0.49, 0.96, 0.81, 1.34, 1.09, 1.23, 1.24, 0.8, 0.86, 1, 1.26, 0.92, 0.49, 0.96, 0.81, 1.34, 1.09 \end{Bmatrix}$$

California State Park historical flow rate data and turbine analysis and efficiency [Appendix C] is used to calculate the average power generation per month for one year. Billing data collected from Hearst Ranch is used to estimate future energy consumption [5]. The results are shown in Table 3. The average flow rate efficiency is based on the average GPM per month (received from the state park). Power generation takes into account a worst-case generator efficiency of 95%.

Table 3: *Average Load and Power Generation*

Month	2010 Load (kWh)	Average Daily Flow (Gallons)	Average GPM	Average Turbine Efficiency (%)	Average Daily Energy Generated (kWh)	Average Monthly Generation (kWh)
January	17707	231713	173.2	84	937	29035
February	22278	153500	122.1	84	621	17401
March	18871	281845	208.8	80	1081	33505
April	18034	83058	70.2	77	309	9281
May	14380	83754	68.1	77	312	9374
June	13105	51123	44.6	72	177	5502
July	13088	42767	38.8	70	145	4502
August	13030	49340	43.3	72	171	5293
September	11263	34229	31.6	69	114	3407
October	12741	33745	32.3	69	111	3455
November	24691	90845	80.2	78	343	10289
December	19468	156750	122.4	84	636	19718

Annual energy consumption (base year 2010) is 198,655 kWh and the calculated annual power generated is 150,763 kWh.

An average precipitation year is assumed for calculations of the cyclical power generation. Table 4 provides results for estimated power generation in a single 12 year cycle.

Table 4: *Weather Corrected Power Using Generation Multipliers For One Cycle*

Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Annual Generation (MWh)	*150.8*	*150.8*	*150.8*	*150.8*	*150.8*	*150.8*	*150.8*	*150.8*	*150.8*	*150.8*	*150.8*	*150.8*
Weather Corrected Power (MWh)	*184.9*	*186.2*	*120.9*	*129.1*	*150.7*	*189.9*	*139.4*	*73.8*	*144.3*	*122.8*	*202.2*	*164.9*

Initial Values and Assumptions

The inflation rate is an average percentage of the US Inflation Rates from 2000-2011 [6]. The United States offers Renewable Energy/Investment Tax Credit (ITC) of 10% for microturbines (< 2MW) and a Production Tax Credit (PTC) of $0.022/kWh for hydropower under the Energy Policy Act of 1992 [7, 8]. The utility increase rate was assumed to be 4% based on MPR historical data [9]. The AG4E Utility Charge is the average cost of electricity for Hearst Ranch from data provided by the ranch for 2010 and 2011 billing [5]. Summary of this data is shown in Table 5.

Table 5: *Initial Economical Analysis Values*

Present Worth Variables	
Inflation Rate	2%

Tax Incentives	
Investment Tax Incentive	10%
Production Tax Credit ($/kWh)	$ 0.02

Utility	
Market Price Referent ($/kWh)	$ 0.09
Increase Rate	4%
AG4E Utility Charge ($/kWh)	$ 0.24

System Cost Breakdown

The greatest cost of the proposed system is the steel penstock and earth work ($402,000) required to replace a portion of the existing PVC pipes with galvanized steel—due to pressure increase from turbine flow restrictions. The complete cost breakdown is shown in Table 6.

Table 6: *Proposed System Cost Breakdown*

Expense	Cost
Turbine-Generator	$ 75,000
Steel Building and Site Work	$ 50,000
Steel Penstock and Earth Work	$ 402,000
Trenching and Backfill for Wire	$ 9,000
Electrical Costs	$104,220
Total	$ 640,220

Table 7: *Electrical System Cost Breakdown*

Expense	Cost
1200ft of Three Phase Cable and Conduit	$ 85,000
Transformer	$ 15,000
Labor For 80 Hours at $34/hr	$ 2,720
System Protection Relays	$ 1,500
Total	$ 104,220

Cumulative Net Worth

Table 8 provides yearly cost analysis for the proposed hydroelectric power plant for 30 years. The Power Savings is equal to the Power Generation multiplied by the AG4E utility charge, capped at the average load usage (base year 2010).

Table 8: *System Cash Flow Analysis*

Year	System Cost	Power Generation (kWh)	Power Savings	Tax Credit	Present Worth	Cumulative Net Worth
0	$626,000			$62,600	($563,400)	($563,400)
1		184924	$44,382	$4,068	$47,500	($515,900)
2		186242	$46,486	$4,097	$48,619	($467,281)
3		120923	$31,390	$2,660	$32,086	($435,195)
4		129075	$34,846	$2,840	$34,816	($400,379)
5		150702	$42,312	$3,315	$41,326	($359,053)
6		189903	$55,451	$4,178	$52,949	($306,104)
7		139425	$42,340	$3,067	$39,530	($266,574)
8		73764	$23,297	$1,623	$21,268	($245,306)
9		144258	$47,382	$3,174	$42,303	($203,003)
10		122827	$41,957	$2,702	$36,636	($166,367)
11		202205	$71,385	$4,449	$60,990	($105,376)
12		164908	$60,928	$3,628	$50,902	($54,474)
13		184924	$71,056	$4,068	$58,074	$3,600
14		186242	$74,425	$4,097	$59,510	$63,110
15		120923	$50,256	$2,660	$39,317	$102,428
16		129075	$55,790	$2,840	$42,708	$145,136
17		150702	$67,743	$3,315	$50,747	$195,883
18		189903	$88,779	$4,178	$65,085	$260,968
19		139425	$67,788	$3,067	$48,637	$309,605
20		73764	$37,299	$1,623	$26,193	$335,798
21		144258	$75,861	$3,174	$52,145	$387,943
22		122827	$67,174	$2,702	$45,199	$433,142
23		202205	$114,290	$4,449	$75,299	$508,441
24		164908	$97,548	$3,628	$62,904	$571,345
25		184924	$113,764	$4,068	$71,822	$643,167
26		186242	$119,158	$4,097	$73,655	$716,821
27		120923	$80,461	$2,660	$48,698	$765,519
28		129075	$89,321	$2,840	$52,935	$818,454
29		150702	$108,459	$3,315	$62,941	$881,395
30		189903	$142,138	$4,178	$80,777	$962,172

Figure 3 is the resulting graph, showing the proposed system's payback period. The graph indicates that the hydroelectric plant will break even in 12 years.

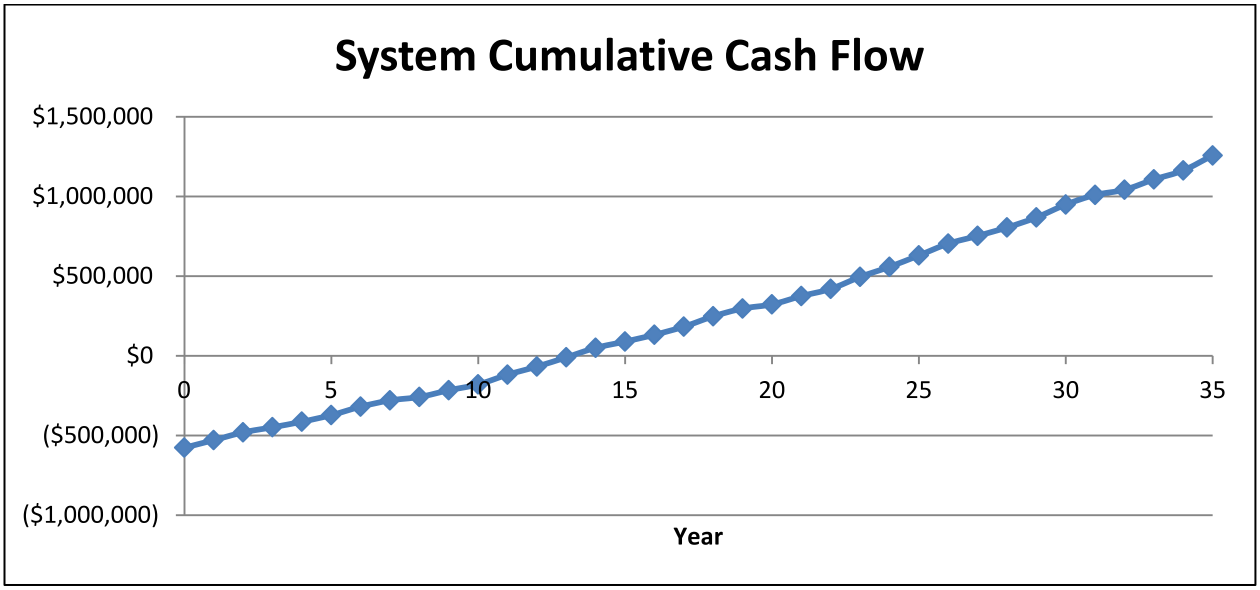

Figure 3: *Proposed Hydroelectric Plant Cash Flow*

9. Electrical Design

Generator Selection

To choose the correct generator, the water flow from Pacific Gas & Electric as well as potential energy available is taken into account. Based on the Pacific Gas & Electric data received, in a wet year, the highest power generated is approximately 63kW and the average is approximately 45kW. Table 3 values are used to simulate the output power at various loads. Taking the highest power output in the table (1081kWh) the average daily output power for March is approximately 45kW. A 50kW generator is a reasonable size that will meet the output power needs. Canyon Industries sent a quote stating that the generator has a three phase, 480V rating.

Transformer Selection

The grid transformer is connected to a 12kV line. Therefore, a step up transformer is used to step the 480 V from the generator to 12kV. The calculations in Appendix B are used to find the transformer rating. A power factor of 0.9 is assumed as a worst case scenario for the generator. The rating of the transformer is calculated to be 55.6 kVA (see Appendix B).

Cable Selection

To find the correct cable size, the secondary current is used along with the voltage rating across the line. The calculations in Appendix B show how the secondary current is found. The theoretical value for the current is 2.67A and the voltage across the line is roughly 12kV. Taking both of these values into account (and being limited to the products available for purchase) a size of 350kcmil is used. A single line diagram of this three phase system can be seen in Figure 4. This simulation is generated using ETAP and shows the currents as well as the voltages at each bus. The currents and voltages in the system change with each load. As the load decreases, the current at bus two also decreases, which causes the voltage at bus two to increase.

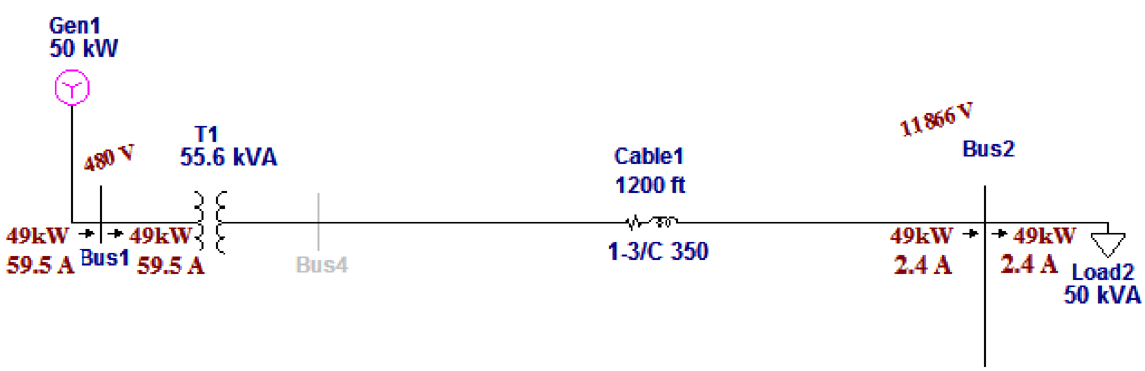

Figure 4: *Single Line ETAP Simulation of System at Maximum Generator Output*

Figure 5 shows the ETAP simulation in which the maximum load (taken from PG&E billing in 2010-2011) is 34.29kW/day. It shows the difference of the load current compared to the initial current of the generator as well as the deviation from a nominal 12kV rating at bus two.

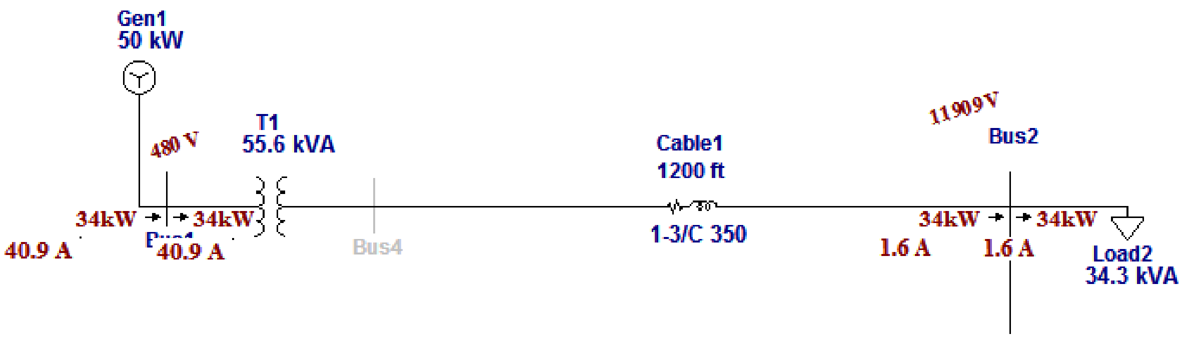

Figure 5: *Single Line ETAP Simulation of System at Maximum Load*

Figure 6 below shows the same system settings, but with the minimum daily load obtained from the PG&E data at 15.6kW/day. The current in this system is the smallest of the three because the load is the smallest.

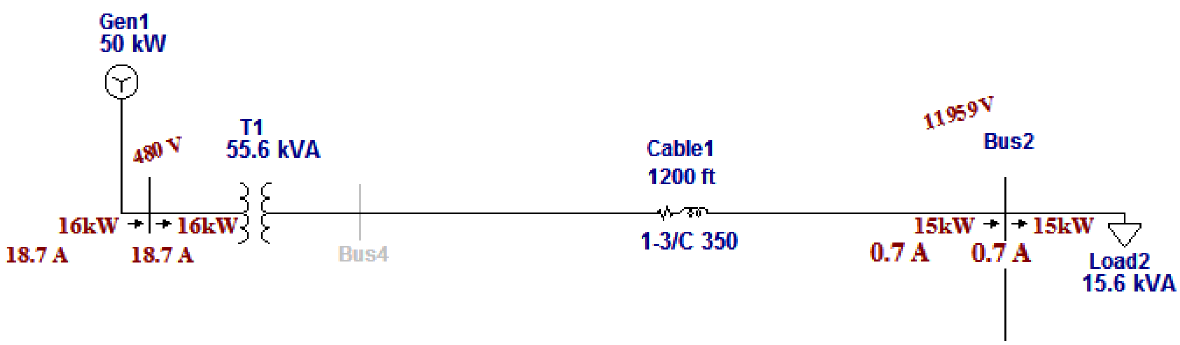

Figure 6: *Single Line ETAP Simulation of System at Minimum Load*

System Protection

Generator Protection

Generator protection requires a more complex design than other system elements. Generators must be protected for internal faults and abnormal operation. Internal faults require the use of phase and ground protection to protect against faults in the rotor and stator windings. In order to protect against abnormal conditions, negative sequence protection schemes are considered. Since the generator in this system is connected in Wye, differential relays (also connected in Wye) are used for generator protection (see Figure 7). In order to choose the proper CT ratios for each generator, the rated load current must be determined. Using the rated load current, the CT ratio is set to the next highest available ratio above the rated current. The CT ratio then determines the secondary current that flows directly through each of the relay coils. The operating coil pick up current is set to 0.3A, which is the lowest setting possible and provides the fastest tripping time for internal faults. These calculations can be seen in Appendix B. Table 9 below shows the summary of the differential protection for the system's generator.

Table 9: *Generator Differential Protection Summary*

	Voltage [V]	kVA	I_{rated} [A]	CT Ratio	I_{Relay} [A]	$I_{OP\ Pick\text{-}Up}$ [A]
Generator	480	58.8	70.8	80:5	4.4	0.3

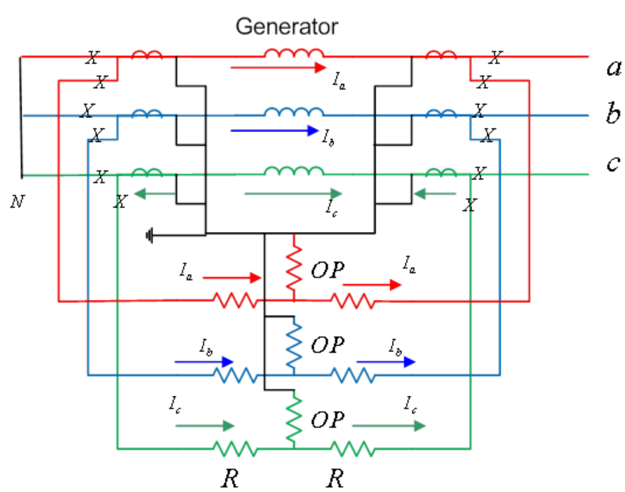

Figure 7: *Differential Protection For a Wye Connected Generator*

Another important aspect in generator protection is the phase and ground protection. To protect the generator from being excessively overloaded, the phase overcurrent protection (backup overcurrent) is set to trip at approximately 150% of the rated load current. Typically, the ground current through the neutral of the generator is 0A. But when a ground fault occurs, a zero sequence current is present and current flows through the neutral of the generator. Therefore, the ground operating coil pick up current is set to 0.5A, and the ground CT ratio is rated at 25% of the rated load, which is deemed the maximum allowable neutral current through the generator. Calculations for phase overcurrent relay protection are shown in Appendix B. A summary is provided below in Table 10.

Table 10: *Summary of Phase Overcurrent Relay Protection*

	Voltage [V]	I_{rated} [A]	$I_{150\% rated}$ [A]	CT Ratio	I_{Relay} [A]	Tap	$I_{ACTTRIP}$ [A]	Actual % of I_{Rated}
Generator	480	70.8	106.1	80:5	6.6	7	112	158.3

Figure 8 is an example of typical phase and ground protection for a Wye connected generator. The protection scheme shown in Figure 8 accounts for every type of fault except three phase faults.

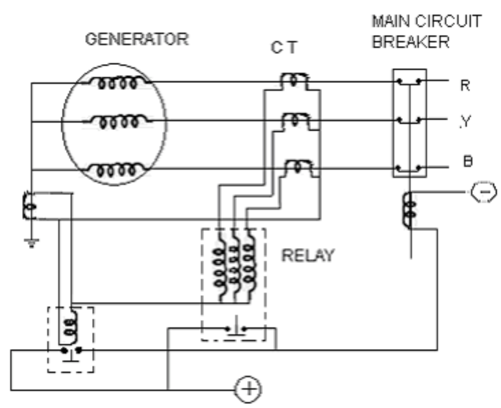

Figure 8: *Phase and Ground Protection For Wye Connected Generator*

The calculations for the ground protection can be seen in Appendix B and Table 11 below provides a summary of these values.

Table 11: *Summary of Ground Relay Protection*

	Voltage [V]	I_{rated} [A]	$I_{25\% rated}$ [A]	CT Ratio	I_{Relay} [A]	Tap
Generator	480	70.8	17.7	50:5	1.8	2

Transformer Protection

Since the transformer is under 10MVA, differential protection is not used. Setting a fuse at 150% of the rated current through the transformer is sufficient for overcurrent protection of a transformer this small. The calculations for the overcurrent protection can be seen in Appendix B and Table 12 provides a summary of the specified values.

Table 12: *Summary of Transformer Overcurrent Protection*

	Primary Voltage [V]	I_{Prated} [A]	$I_{150\%rated}$ [A]	CT Ratio	I_{Fuse} [A]	Fuse Rating [A]
Transformer	480	66.9	100.3	70:5	4.8	5

Since our system will not output high current through the distribution cable and the cable can handle up to 200 A, overcurrent protection is not needed.

10. Conclusion

The steel penstock and earth work required for replacing a portion of the existing pipe accounts for approximately 2/3 of the entire system. The capital cost for a system with pipe replacement and one without is $12,520/kW and $4,480/kW respectively. The department of energy stated in 2010 that the average cost of hydro plants less than 20MW in size is "$4,000 to $6,500 per kW installed" [14]. The only system within this range is the one without pipe replacement. However, the pressure buildup created by the system will cause existing pipes to burst—The system cannot be safely built at the proposed location without pipe replacement.

The payback period as stated in the *Economic Analysis* section is 12 years. Permits, construction equipment rentals, contractor rates, and unforeseen (margin of error) costs are not taken into account in the economic analysis. When these expenses are accrued, the capital cost and payback period of the system will rise.

The team recommends that Hearst Ranch does not pursue this project due to high installation costs and a long payback period. Instead, we recommend that the Ranch conducts a feasibility study of placing a hydroelectric plant further up the hill where steel pipes are already installed.

Appendix A: Senior Project Analysis

1. Summary of Functional Requirements

A turbine generator controls water flow. Power coming out of the generator will connect to the PG&E main line of Hearst Ranch to provide power to the PG&E grid as well as the local ranch grid.

2. Primary Constraints

The Hearst Corporation budget committee acts as a limiting factor to our project. We have submitted a rough estimate to them; however, we will have to wait till the end of the month to hear whether or not they approved it. Another challenge is going to be obtaining the schematics and blueprints for the current local grid design. PG&E created the design and it is proprietary information.

3. Economic

The project will impact financial capital, manufactured or real capital, and natural capital. The components and industrial parts will be made from natural resources such as aluminum and copper for transmission lines. Initially the project will impact the finances of the ranch, however, there will be a payback time frame as noted in the "Economic Analysis" section of this report.

A smart meter will be used to compare the energy supplied by PG&E with the energy sourced. This will allow the customers and stakeholders to analyze the economic impact of the system. Protection components are necessary since the generator is above 50hp and could impact the local grid during abnormal operation.

The system should take a maximum of 12 years before it has covered its cost. After the cost is covered, any additional savings of electricity will lower the power bills for Hearst Ranch.

The Hearst Ranch Corporation will cover all costs for the project. Any profits will go directly to the Hearst Ranch Corporation.

Project construction was originally planned to begin and end in May. However, due to budget and time constraints, implementation has been pushed back a full year. The following Gantt charts provide detailed information on the timeline and milestones necessary for project completion. The Gantt chart outlines planning for gathering requirements and specifications; performing research; creating and analyzing design; building and installing; documenting; and testing. There will be very little maintenance; the turbine will have to be checked for lubrication and cracks once every two years.

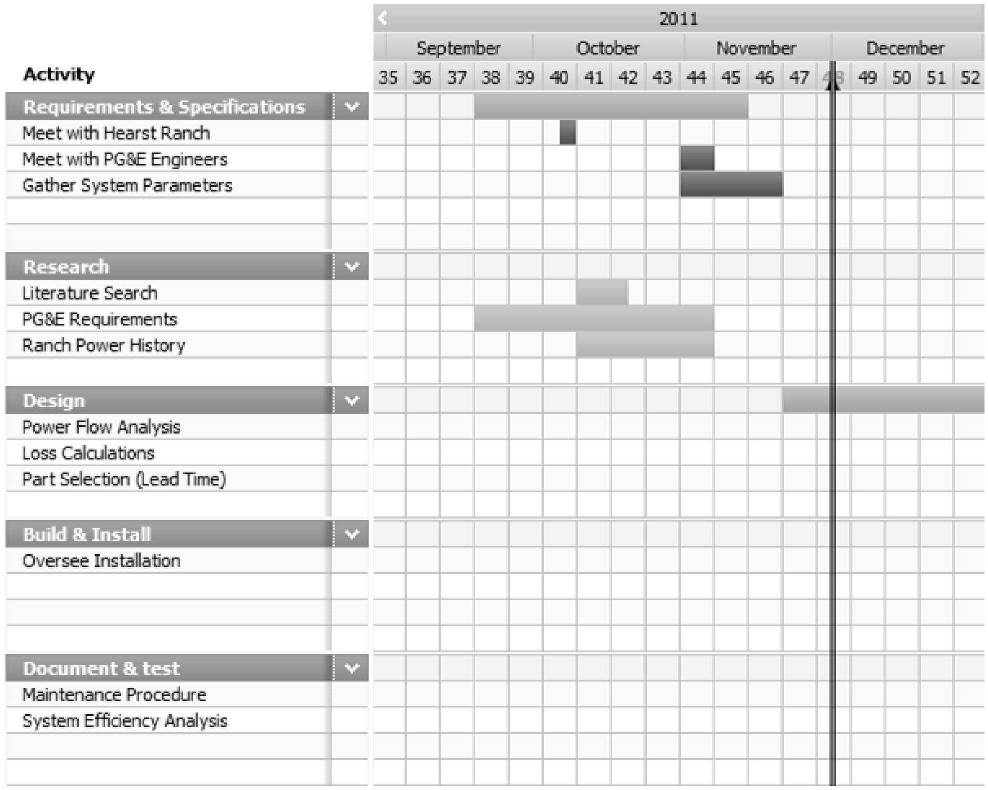

Figure 9: *Project Gantt Chart For 2011*

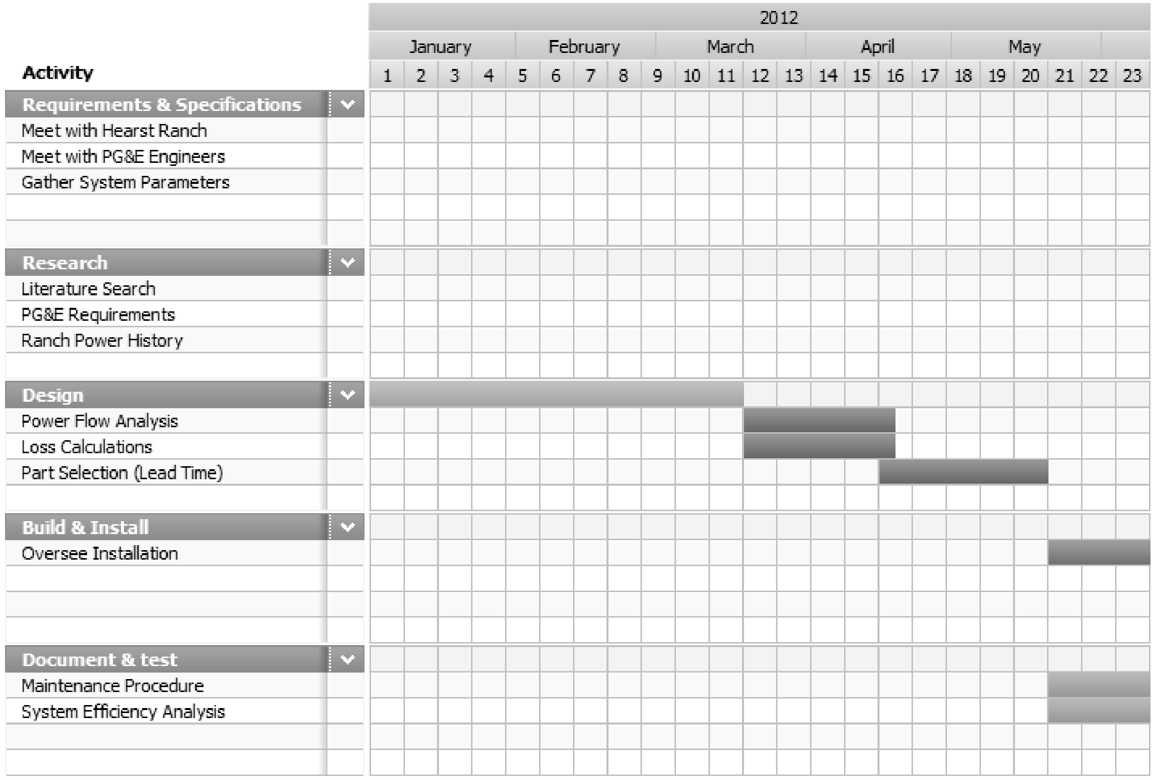

Figure 10: *Project Gantt Chart For 2012*

4. If manufactured on a commercial basis

If this product was manufactured on a commercial basis, there would be a few great marketing opportunities that go along with it. The main marketing focus would be directed towards houses and communities near water sources (such as rivers, streams, etc.). Also, areas where it would be beneficial and profitable to switch to hydroelectric power would also be a main focus of marketing. If this product is ever manufactured on a commercial basis, it has the opportunity to be very successful and could possibly become one of the largest energy distributors around.

5. Environmental

Potential environmental impacts are explained in Table 13. The entire system obtains the water from a natural spring at a higher altitude. Our project has the potential of serious environmental impacts if failure and destruction of the materials occurs. There is also an associated impact with production and material gathering.

Table 13: *Potential Environmental Impacts, Duration, and Significance*

Item	Potential Impact	Duration of Impact	Significance of impact
Transformer	Fluid: "Petroleum hydrocarbons, halogens and silicone can be harmful if released into the environment" [10].	Long Term	Significant Local
Transformer	Electromagnetic Fields: Possible increased risk of cancer to surrounding animals [11].	Long Term	Significant Local
Transformer	Manufacturing Pollution: The creation of a transformer creates both air and land pollution [10]. This includes gathering materials from natural resources, synthesizing chemicals, and utilizing industrial production methods.	Long Term	Significant
Power Line Metal	Metal Mining: When mining for metals, there is a release of chemicals; especially when acid mining and erosion occurs [12]. This affects small areas, however, it can also have a large impact on the local environment.	Long Term	Significant Local
Power Line Pole	Habitat Disruption: Adding a giant mass will disturb the local animal habitats. This includes plants, animals, and insects. Clearing a location to install a pole requires disturbing an area of the environment.	Long Term	Significant Local
Power Line Pole	Contributes to deforestation. Cutting down additional trees in small instances will eventually add up to a more significant impact.	Short Term	Insignificant
Human Labor	Damaging the local environment during construction and testing.	Short Term	Insignificant
Generator Housing	Habitat Disruption: Constructing housing for the generator and equipment will decrease the habitable area.	Long Term	Insignificant

6. Manufacturability

Since this project requires the team to order parts from third party vendors, and as to be installed by trained electricians, the manufacturability should not give us any issues. The only challenges foreseen for this portion would be making sure all the load calculations as well as line loss calculations are correct. As long as they are correct we will be able to finish this project with very few speed bumps. Installers may have problems when it comes to installing the generator and/or cable. When running cable, a main concern is making sure there is minimal lag in the line as well as making sure the poles are stable. Since this system is being installed on ranch property, it may be difficult to stabilize the poles as well as make sure they are the same height off the ground. The generator has a lot of heavy moving parts; so naturally, an issue for the installers could have to move it to the correct position. This could be difficult as well as time consuming if the generator has to be moved multiple times.

7. Sustainability

The greatest attribute of this project is that it is highly sustainable due to its use of water from a natural spring [3]. The only maintenance that will be needed is to service the turbine and generator. The maintenance manual will be distributed to the ranch manager as the project is completed.

8. Ethical

According to the IEEE code of ethics found in [13], there are many possibilities of ethical concerns regarding a project of this magnitude. When constructing the plant and associated power lines, it is important to follow correct federal, state, and county procedures related to permits, environmental requirements, and safety requirements. In this process, some contractors may have the desire to expedite the processing or attempt to push through paperwork in order to complete construction to schedule.

All those engineering and constructing this project need to be aware that it is our responsibility to make decisions that are "consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment" [13]. If something occurs, it is our responsibility to inform the correct authorities or organizations and make immediate changes. Having a proactive approach to this project, with the code of ethics in mind, will help prevent potential issues.

9. Health and Safety

Safety is a huge concern any time there is this much power involved. It is very important that the electricians use all the NEC required tools to install the products. Also, the ranch manager should take high precaution in maintaining the system. High voltages located at the transformers, power lines, and possibly even the meter may cause injury or even death.

10. Social and Political

The only social issue involved with the project is that the state is requiring that the new building holding the turbine generator cannot be seen from the freeway. If it is, then we are not allowed to put the building in. The project impacts PG&E, Hearst Ranch owners, and the people who work at Hearst Ranch [3]. The direct stakeholders include the Hearst Ranch owner and the Hearst Ranch manager. It will benefit both parties by possibly providing revenue as well as using a sustainable energy system to power their houses. PG&E (who is another direct stakeholder) may benefit as well by receiving free energy at more rainy times of the season.

With this project, everyone will benefit equally if all goes to plan for various reasons. The main reason is because we will have proven that it is possible to use the ranch natural spring to create energy to power up multiple buildings. Another reason is because the castle (which is owned by the state) may be able to obtain power from this system as well (if enough energy can be provided) [3].

11. Development

This project is extremely valuable in that it allows us, as students, to follow an entire engineering procedure from start to finish for a real-world project. In achieving our goals, we will learn to coordinate and communicate with customers, engineers, and each other. Aside from team experience, it will also provide a practical Electrical Engineering application. We will be able to use theories and calculations derived from class to design, analyze, and test the final product.

Appendix B: Power System Calculations

Transformer Ratings

P = S * pf => S = P/pf

S = 50kW / 0.9 = **55.6 kVA**

$I_{Primary}$ = 55.6kVA / 480V = **66.8A**

$I_{Secondary}$ = 66.8 * ($V_{primary}/V_{secondary}$) = 66.8 * (480V/12kV) = **2.67A**

This is because it is the lowest setting possible and provides fastest tripping time for internal faults.

Generator Protection

<u>Phase and Ground Protection</u>

Phase

Ground

CT ratio rated at 25% of load; deemed maximum allowable neutral current through generator.

Negative Sequence Protection

Transformer Protection

Set the fuse to be rated at 101 Amps.

Appendix C: Turbine Efficiency Analysis

The load efficiency of the turbine was calculated and is displayed in Table 14 below.

Table 14: *Turbine Efficiency With Varying Loads*

Load Percentage	Turbine Efficiency
10%	64.2%
20%	74.7%
30%	78.2%
40%	80.2%
50%	82.2%
60%	83.2%
70%	84.3%
80%	84.2%
90%	84.2%
100%	83.2%

The data from Table 14 is plotted in the graph of Figure 11. The resulting polynomial equation for average turbine efficiency is

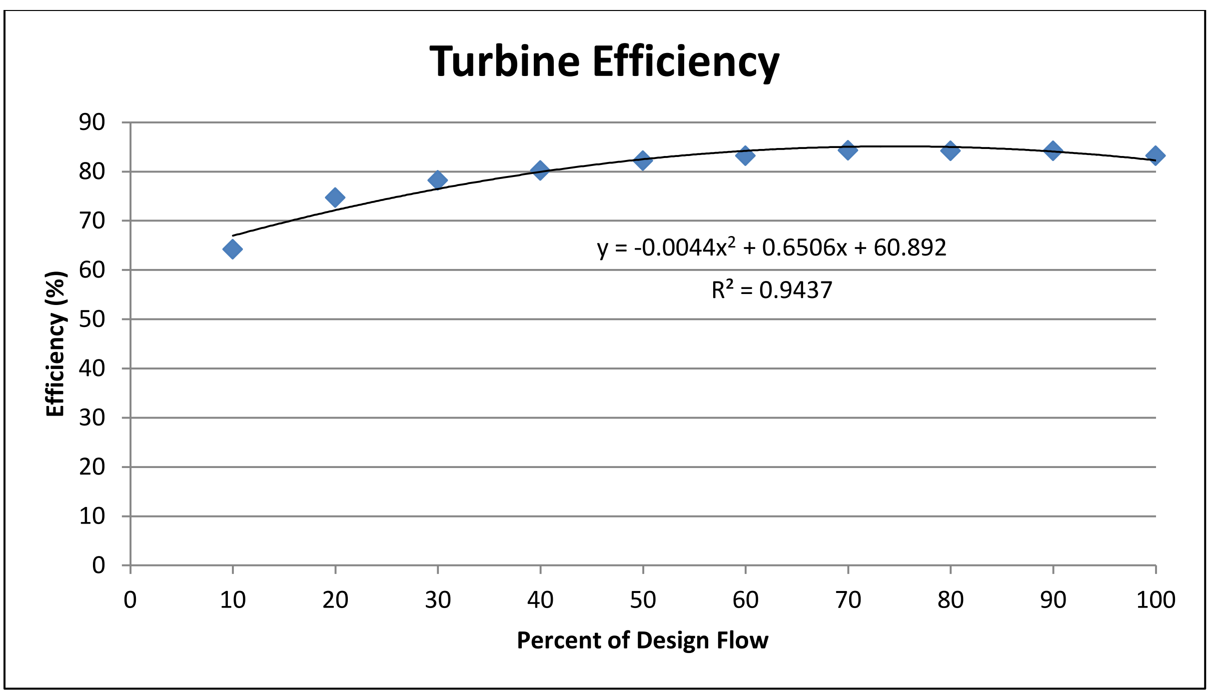

Figure 11: *Turbine Efficiency Analysis With Varying Percentages of Design Flow*

Appendix D: References

[1] California State Parks. *The Castle* [Online]. Available: http://www.hearstcastle.org/history-art/castle

[2] H. Fields. (2006, Feb. 7). *The Old Powerhouse* [Facsimile]. From: Hoyt Fields, Museum Director. Message: "Cliff - Working on collecting additional information for you"

[3] C. Poff, "Design of a Hydro Electric Power Deliver Facility at Hearst Ranch," Senior Project, California Polytechnic State University, San Luis Obispo, 2007.

[4] WeatherSource. *Official Weather | Weather Resource* [Online]. Available: http://weathersource.com

[5] C. Garrison. "FW: Billing and Usage History" Personal E-mail (Oct. 17, 2011)

[6] US Inflation Calculator. *Current Inflation Rates 2002-2012* [Online]. Available: http://www.usinflationcalculator.com/inflation/current-inflation-rates/

[7] Database of State Incentives for Renewables & Efficiency. *Federal Business Energy Investment Tax Credit (ITC)* [Online]. Available: http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F

[8] Database of State Incentives for Renewables & Efficiency. *Federal Renewable Electricity Production Tax Credit (PTC)* [Online]. Available: http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=US13F

[9] Market Price Referents. *Final Resolution E-4442* [Online]. Available: http://docs.cpuc.ca.gov

[10] J. Ray. (2011, May 9). *The Environmental Impacts of Electrical Transformers* [Online]. Available: http://www.ehow.com/info_8388486_environmental-impacts-electrical-transformers.html

[11] National Cancer Institute. (2005, April 21). *Magnetic Field Exposure and Cancer: Questions and Answers* [Online]. Available: http://www.cancer.gov/cancertopics/factsheet/Risk/magnetic-fields

[12] W. Salomons. "Heavy Metal Aspects of Mining Pollution and Its Remediation," *J. Geochemical Exploration.*, vol. 52, issues 1-2, Pages 5-23, January 1995.

[13] R. Ford and C. Coulston, *Design for Electrical and Computer Engineers*, McGraw-Hill, 2007, p. 216

[14] D. Olis. (2010, September 15). *Intro. To Renewable Energy Technologies - Hydropower Addendum* [Online]. Available: http://apps1.eere.energy.gov/femp/training/course_detail_ondemand.cfm/CourseId=40

[15] J.B. Calvert. (2010, February 11). *Turbines* [Online]. Available: http://mysite.du.edu/~jcalvert/tech/fluids/turbine.htm

[16] D. Stern. (2010, October 21). *(35a) Planetary Gravity-Assist and the Pelton Turbine* [Online]. Available: http://www-spof.gsfc.nasa.gov/stargaze/Spelton.htm

[17] *Design of Pelton Turbines* [Online]. Available: http://www.ivt.ntnu.no/ept/fag/tep4195/innhold/Forelesninger/2007/Forelesning%205/Pelton%20Turbine.ppt