

Economic Feasibility of Hydropower Systems: A Decision Support System Program

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ABSTRACT

Hydropower has played a dynamic role in meeting our population's energy needs. Because hydropower plants are reliable, low maintenance, and yield higher electrical gains as compared to wind power, it should be understood that the high initial cost can be justified using the right tools with a robust Decision Support Systems (DSS), Energy Management, hydropower systems, and Financial Engineering. By combing these fields, one can better understand the economic feasibility of a hydropower plant using a DSS to guide the average field surveyor with the right tools to find the economic feasibility of a hydropower project. In this work we combine many facets into one simple interface. The field surveyor would most likely measure the average water flow and head (water displacement), while the plant manager would enter the hours the plant would operate annually, In addition, the mechanical engineer/electrical engineer would be able to supply an accurate turbine efficiency, generator efficiency, and transformer current. This work will also provide a comprehensive background on current hydropower conditions in the world, as well as a general background on hydropower turbines, a glossary of hydropower terms, and the appropriate formulae to back up the calculations embedded in the DSS.

Keywords: Hydropower, Renewable Energy, Carbon Footprint

1. INTRODUCTION

About two-thirds of the freshwater flowing to the oceans is controlled by dams, and make up roughly 14 percent of all global runoff. Although currently hydropower provides at least half of the electric supply in more than sixty countries, the potential of worldwide hydropower has yet to be fully exploited. It is estimated that the theoretical potential of hydropower across the globe is 2.8 million MW, which is around four times greater than what has already been installed. Nearly half (46%) of the hydropower was created by large and diverse countries, such as China (15.4%), Brazil (11.9%), Canada (11.7%), and the United States of America (8%). Accessing the situation on a continental scale, Asia and the Pacific account for 873TW per year (over 27.3%), while other regions follow closely behind, with South and Central America producing 689 TWh, and North America producing 658 TWh.

China and Brazil, two of the largest hydropower giants in the world, both have appreciated the value of this renewable energy resource and have realized the potential by aggressively building hydropower plants across their country. Although by no means the richest countries in the world, both countries have been clever enough to see the true potential for hydropower. As will be detailed in this paper, hydropower has very low maintenance, high and predictable yields of energy, while remaining a promising and sustainable source of renewable energy. Brazil has been the leader in South and Central America, with a capacity of over 64,000 MW in hydropower, and with its aggressive construction of over 25,000 MW of additional hydropower currently in the works. A particularly large hydropower plant, the Belo Monte hydroelectric dam is under construction on the Xingu River in Pará, with

a capacity of 11,200 MW. The Belo Monte hydroelectric dam will become the third largest of its kind in the world. This trend is reflected in other countries in South and Central America, particularly in Argentina, Bolivia, Chile, Colombia, Guyana, Peru, and Venezuela. All of these additional countries have plans to produce around 9,700 MW worth of hydroelectric power in the coming years.

China, as noted, is the largest producer of hydropower in the world. China's engineers have dubbed this upcoming decade as the "golden age of hydro-damming". With 115,000 MW of hydropower as of 2008, China plans to nearly triple its capacity to 300,000 MW by 2020. Although China is rich in resources of hydropower, less than 10% have actually been developed. And not only are the metro areas been affected – rural areas will also enjoy the benefits of this nation's alternatively generated electricity grids.

The most obvious advantage is the fact that hydroelectricity completely eliminates the cost of fuel. It is no secret that hydropower plants directly emit no carbon dioxide or GHG's (Greenhouse Gasses). The fact that the operations of a hydroelectric plant are autonomous and almost always consistent makes this a very attractive alternative to our depleting nonrenewable energy sources. This autonomy is what makes hydropower a very consistent player on the energy crisis the world is currently facing. It allows the country to be more independent of fuel imports while remaining free of the economic fluctuations of fossil fuels (such as oil, coal, and natural gas). This resource is extremely reliable, and is not dependent on weather conditions which constrain solar and wind power very frequently.

Another major strength of hydropower is the fact that it has a higher product lifecycle than other alternative energy resources. There are hydroelectric plants which have remained in service over 100 years ago. Unlike wind farms, which frequently break over time and need parts (usually the turbines) replaced due to operating degradation, hydropower plants degrade at a considerably slower rate. Consider this: water is 832 times denser than air, making the required velocity to create the same amount of energy significantly smaller. While wind farms require velocities of at least 20-30 miles per hour (and utilize a controller which automatically shuts off the turbine in order to prevent damage at speeds of 55 miles per hour and greater), hydropower requires only 3.6-4.9 knots (or 4-5.5 miles per hour). The bottom line is that the kinetic energy of a small water current is equivalent to that of a high velocity of airflow, and it doesn't have to worry about hitting a 55 mph limit that wind power is currently constrained by. Operating the plant is relatively inexpensive, as the plant is automated and have fewer manpower requirements as, say, a nuclear plant would need to field. This reduction in operating costs helps to cover the initial high cost of building a hydropower plant. These costs are further reduced if a dam is already present. It is possible to build a hydropower plant in the location of the dam by making modifications. The financial strength of these projects have become more and more lucrative, with estimates of even Three Gorges Dam yielding an simple payback period of 5-8 years.

In addition to these advantages, there are also many additional factors that cannot be directly calculated or measured. For example, the reservoirs created by these hydroelectric dams are often used for water sports, tourism, the farming of both saltwater and freshwater organisms through aquaculture, and flood controlling. Some dams also provide a steady irrigation flow to farms and other agribusiness. Because over half of the world population lives within 200km of a coast (including 8 of the 10 largest cities in the world), it also helps to minimize power transmission costs which deter many sites from being set up. It is important to consider these additional factors, as it helps to completely utilize all of the advantages of hydropower.

Although the advantages to hydropower are numerous, there are many factors to consider before installing a hydropower plant. For the case of tidal barrages (which are hydropower dams built to utilize the power of the tide), there are a very limited number of locations where the plants can be situated. Landlocked countries also have little interest in hydropower unless a large enough river can be located. There is also the factor of a slower payback period. While China has benefitted greatly from cheap labor and a higher cost of fuel, many countries are deterred to invest in a hydropower plant when the payback period can extend to over 10 years long. Hydropower plants frequently disrupt feeding patterns in both bird and aqua life. Fish that need to swim upstream (like some

freshwater salmon) can be indefinitely deterred from stronger currents and moving turbine blades in these dams. Not only are many salmon unable to access their spawning grounds, but when salmon spawn to try go downstream, many are harmed by the turbines blades. A solution to this problem is achieved through the construction of a “Fish ladder” (also known as fishways, fish passes, or fish steps). This allow the diadromous fishes’ natural migration to be uninhibited by the artificial barrier created by a dam. These fish ladders provide just enough resistance to attract fish without being too strong to traverse. Species become permanently affected from these dams, which draws a lot of negative press that must be considered when a large dam is created.

Furthermore, it is important to realize that hydropower plants indirectly create a significant amount of Green House Gases (GHG’s). Although I previously stated that hydropower plants don’t *directly* emit these gasses, they unfortunately cause trouble in the reservoirs they create. As the reservoirs are holding large quantities of water, the decay of the biomass in this reservoir is trapped. Additional biomass is captured by the natural flowing river or stream feeding it. Normally, much of this biomass would either rot in the open air or in a well oxygenated river, thereby creating a small portion of carbon dioxide. However, when biomass is trapped under water, anaerobic processes cause not only carbon dioxide to be produced, but also methane. Because it fetid water isn’t apt at absorbing this methane, it quickly bubbles to the surface and is released to the air. Because methane is 20 times more potent as a GHG than carbon dioxide, this is very important to consider. It is important enough to cause many scientists like Fred Pearce to write that “Reservoirs magnify the greenhouse effect of the rotting of the Earth’s vegetation”. Without proper oxygenation, the anaerobic threat of these reservoirs can ironically make hydropower plants a propagator of climate change.

2. GENERAL BACKGROUND

There is much to be said on the usage of the right turbine when constructing the hydropower station. The turbine is really the heart of the hydropower plant, and much consideration should be taken when purchasing one. The two philosophies of hydropower turbines include Impulse and Reaction types. I will explain both in greater detail because both have many strengths and weaknesses to consider. Once the right investment is made, one will enjoy a highly efficient turbine with the capabilities to last a lifetime.

Let us begin by discussing the Impulse Turbine. This turbine works by changing the velocity of a water jet. The jet then collides with the turbine’s curved blades which manipulate the direction of the flow. This sudden change in momentum causes a substantial force to occur on the turbine blades. Since the turbine is spinning, the force utilizes the distance while the diverted water flow is left with diminished energy. This change in momentum creates an impulse which is what this turbine is named after. By utilizing Newton’s second law of physics we change the potential energy into kinetic energy in this system. Because no pressure change occurs at the turbine blades, it does not require a casing for the turbine, making this a very unique. Because a substantial amount of water is required to push the turbines, impulse drives are ideal for very high head water resources with low flow.

There are two types of impulse turbines which adjust this procedure slightly. For example, the Pelton hydropower turbine has one or more free jets which collide with the spoon-shaped buckets of a runner. As the water makes contact with the bucket, the water exerts pressure on the bucket, and as the water decelerates it turns 180 degrees as it travels through the runner. It is in this way that the water’s momentum is transferred to the turbine. Since the bucket is being emptied at the same rate it is being filled, water flow is very stable and consistent. This water turbine is one of the most efficient types available. The other type of impulse turbine includes the Cross-Flow turbine. This turbine is shaped like a drum, and uses an elongated, rectangular-section nozzle which is positioned in front of curved vanes on a runner. This runner is in the shape of a cylinder, and rotates as the water jet pushes against it. The advantages of this turbine occur because the water is allowed to flow through the blades twice, as the water again flows through the blades on its way out. A guiding vane near the entrance of the turbine makes sure the limit the flow to the runner. This specifically contrasts the Pelton design by working ideally in a higher water flow situation, where the head may not be as large as the Pelton’s application. Reaction turbines, on the other hand, rely on both pressure and moving water to achieve the same purpose. The runner is positioned in the middle of the water stream, allowing the water to flow over the blades instead of striking each turbine blade

individually. As a whole, reaction turbines are ideal for sites that have lower head but higher flows, which an impulse turbine (even a Cross-Flow) cannot efficiently handle the higher flow.

There are three types of Reaction turbines, which help to handle the variety of challenges water flow may present. For instance, a propeller turbine will have a runner with three to six blades which the water is pushing constantly. Remember that Reaction turbines blades are all constantly interacting with the water flow, instead of individual blades. The water is lead through a pipe which pushes the propeller turbine with the help of the focused, pressurized water flow created by the pipe. There are furthermore four variations on the propeller turbine, which include the Bulb turbine, Straflo turbine, Tube turbine, and Kaplan turbine. Although they have slight changes in their adjustments and design, they all work fairly similarly. The Francis turbine, on the other hand, uses a runner with fixed vanes. Instead of three or six vanes, the France turbine uses nine or more vanes on the runner. The water is introduced above the runner, and inundates the turbine from the top down using gravity. The design of the Francis turbine allows the water to actually spin, which effectively captures the kinetic energy of the water flow. The final type of reaction turbines include the Kinetic energy turbines (also known as free-flow turbines). These turbines generate electricity from the kinetic energy already present in flowing water instead of relying on the potential energy inherited by the head. This system is a favorite in rivers, tidal waters, ocean currents, and manmade channels. They do not require the diversion of water like other turbines do, but can be added to existing structures like bridges, channels, and water wheels. This system requires the least amount of work but is far from being the most efficient type of hydropower turbine.

3. THE PROPOSED DECISION SUPPORT SYSTEM

The main focus of this work has lead us to create a DSS for hydropower from an Industrial Engineering (IE) perspective. This tool has been specifically designed for an Industrial Engineer or project manager to get a large scale view of the hydropower plant in almost every aspect, from the type of water coming in to the voltage output or annual revenue generated by the plant, the entire system is analyzed with this program.

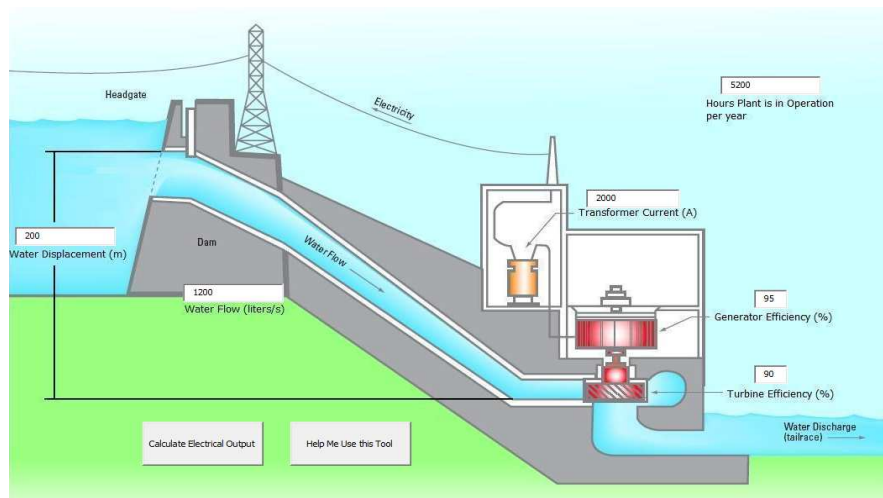


Figure 1. This is the main user interface when the program is loaded. There are multiple inputs that the user can change around until he or she is satisfied with the metrics.

3.1 Text Boxes

Water Displacement: This is sometimes referred to as the “head”. This dictates not only the distance above the datum plane (in our case the bottom of the dam), but it also shows the total energy at a given point in a fluid. Using Bernoulli’s principle, the increase in the speed of the fluid causes a decrease in either the pressure or the fluid’s potential energy (measured in meters).

Water Flow: This component reveals the rate at which the water is travelling as it runs through the dam. This is directly related to the energy capacity in our hydropower application because it provides a kinetic energy in addition to the potential energy supplied by the Water Displacement. (Measured in liters/second).

Turbine Efficiency: From an IE standpoint, the efficiency of the turbine tells the user the bottom line impact the turbine will have on the energy in the system. Whether it be a reaction turbine or impulse turbine, the efficiency this turbine delivers creates a small impediment in the true energy being calculated by the Water Flow and Water Displacement (listed as a percentage).

Generator Efficiency: The efficiency of the generator is just as vital as the turbine as it aids in the conversion of mechanical energy into electrical energy. This also creates another decrease in the true value of energy depending on the efficiency due to energy losses (listed as a percentage).

The components listed are the transformer is a device that helps transfer the electrical energy created by the Electric Generator from one circuit to another using conductors. The current created by the transformer helps us to complete our equation in finding our Voltage. Also needed is the number of Hours the plant is in Operations Per Year. This textbox is critical as it allows us to calculate the kilowatt hours being produced. While it is important to know the load demand given by the system, kilowatt hours are vital to help calculate and regulate the sale of power to the end user. (Measured in Hours/Year).

3.2 The Electric Output

The Calculate Electrical Output button computes the electrical output and loads the Hydro Power Calculated Results Window. It takes all of the values entered and commits to extensive error checking to make sure all values are numerical, nonnegative, and that the efficiency values are between 0-100. These error checking codes are throughout the program to avoid crashes. The Help Me Use This Tool button opens the Help Form, which guides the user with various entries on hydropower topics. All of them are shown in Figure 1.

The most key formulae are used in this form, which create the basis of the energy creation for further exploitation in the following steps in the program. The following were utilized in their respective calculations:

$$P = x * f * g * t_{eff} * r_{eff}$$

Where P is Power in Watts (or Joules / second), x is the water displacement (in meters), f is the water flow (in liters / second), g is the coefficient of gravity (in meters / second ^2), t_{eff} is the turbine efficiency, and r_{eff} is the generator efficiency. In addition:

$$P = x * f * g * t_{eff} * r_{eff} * h$$

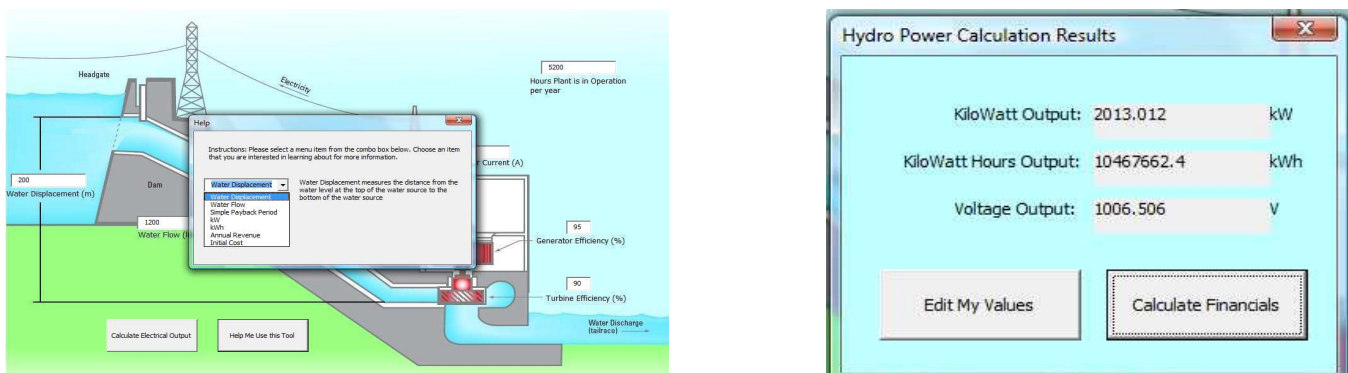


Figure 2. At the left the Help window, with Water Displacement, Water Flow, Simple Payback Period, kW, kWh, Annual Revenue, and Initial Cost. On the right the Calculation results are displayed

Where P is Power in Watt Hours, and h is the annual operational hours. The Voltage is calculated as:

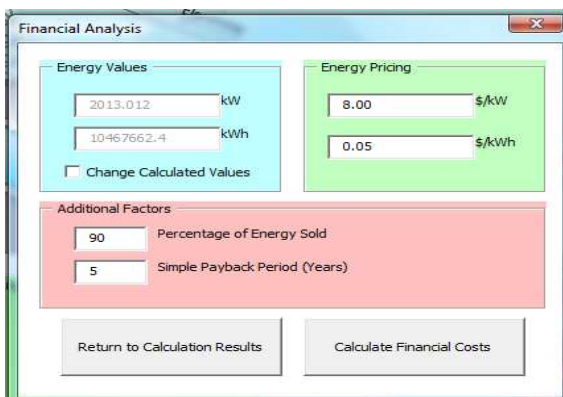
$$V = \frac{P}{I}$$

Where P is the Power in Watts, I is the value of Current (In Amperes), V is the value of Voltage (In Volts).

3.3 COMMAND BUTTONS

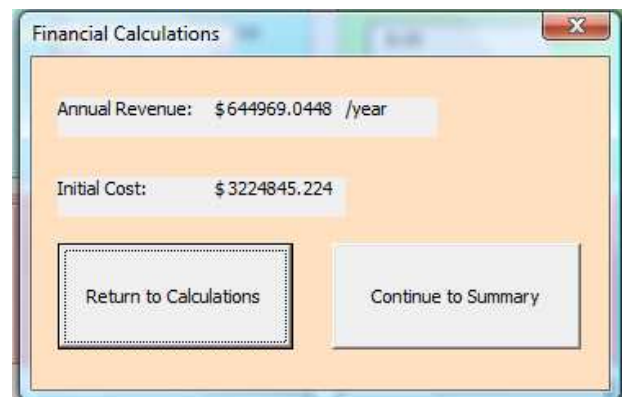
Edit My Values: This button allows the user to return to the Main Form and edit the values as he or she sees fit. The current form is unloaded to enable the user to alter the values without any errors.

Calculate Financials: This button saves the values the user is shown for use in the financial calculations which helps provide a manager/industrial engineer’s point of view. This also opens up the Financial Analysis Form.



The screenshot shows a window titled "Financial Analysis" with a close button (X) in the top right corner. It is divided into several sections: "Energy Values" (with input fields for 2013.012 kW and 10467662.4 kWh, and a "Change Calculated Values" checkbox), "Energy Pricing" (with input fields for 8.00 \$/kW and 0.05 \$/kWh), and "Additional Factors" (with input fields for 90 Percentage of Energy Sold and 5 Simple Payback Period (Years)). At the bottom, there are two buttons: "Return to Calculation Results" and "Calculate Financial Costs".

Figure 3. The Financial Analysis Tool.



The screenshot shows a window titled "Financial Calculations" with a close button (X) in the top right corner. It displays the results of the calculations: "Annual Revenue: \$ 644969.0448 /year" and "Initial Cost: \$ 3224845.224". At the bottom, there are two buttons: "Return to Calculations" and "Continue to Summary".

Figure 4. The Financial Calculations output.

The kW value was saved and transferred from the previous Output form. If the user decides that the values just aren't what he or she wanted, or if the user knows the kW value but doesn't know about the Water Displacement or Water Flow values, this can be manually altered by clicking the "Change Calculated Values" check box. The kWh, similar to kW, this value was saved and transferred from the Output form. If the user decides to change these values for any particular reason, he or she can do so by clicking the "Change Calculated Values" check box.

Energy Pricing – Dollars / kW: This value allows the user to set a cost for the Energy Demand, kW. This demand is very important for high load facilities, such as a factory, and the cost is factored into our financial calculations as an important component. In addition, the Energy Pricing – Dollars / kWh: This value allows the user to set a cost for the Energy rate, kWh. This is the rate which most households have meters of. This is another important factor that provides the backbone of our calculations.

Percentage of Energy Sold: This model assumes that there is a chance that not all of the energy will be sold. If the power company cannot find another competitor who wants to buy the excess power, then the power is left unsold, as it is not feasible to store excess power.

Simple Payback Period: This is simply the desired breakeven point the investor would like to recoup the initial investment. This will be a key factor in calculating the maximum initial investment the investor can afford in the creation of this hydropower plant.

The user can restart calculations, as a way for the user to unload the current values and return back to the Output Form. The Calculate Financial Costs: This button takes all of the values entered into the Financial Analysis Form and computes both the Annual Revenue as well as the Maximum Initial Cost. The calculations are performed using the following calculations:

$$R = (12 * kW * kW_{Price} + kWh * kWh_{Price}) * S_{percentage}$$

Where, R is the Annual Revenue (in Dollars / Year), kW is the kilowatts, kW_{price} is the cost per kilowatt. kWh is the kilowatt hours, kWh price is the cost per kilowatt hour, Spercentage is the percentage of Power sold

$$IC = SPP * R$$

Where: IC is the Initial Cost (in Dollars), SPP is the Simple Payback Period (in Years), R is the Annual Revenue (in Dollars / Year).

In this form, the Financial Calculations form, the results of our previous calculations are displayed. This is the final step on our journey in creating a solid foundation for our decision support system in whether or not to create a hydropower plant based off of the conditions of the system as well as the financial climate – all set by the user and alterable with the click of a button. Additional Labels are:

Annual Revenue: As described and calculated in Formula 4, this value allows the user to see how much revenue can be generated on average in one year.

Initial Cost: This tool is useful in providing the user a maximum initial investment that can be allotted given a specific payback period. This helps give the user an idea of the time it will take to breakeven in the investment of this plant once it gets running.

Return to Calculations: Much like the other buttons that allow the user to “step backwards” in the calculations. The reasoning behind this is to allow the user to have a fully customized and unrestrained model to alter at his or her will. This unloads the current values for further revision through the previous form, Financial Analysis.

The screenshot shows a window titled "Summary Page" with two main sections: "Energy Summary" and "Financial Summary".

| Energy Summary | | Financial Summary | |
|------------------------|----------------|-------------------|---------------------|
| KiloWatt Output: | 2013.012 kW | Revenue: | \$644969.0448 /year |
| KiloWatt Hours Output: | 10467662.4 kWh | Initial Cost: | \$3224845.224 |
| Voltage Output: | 1006.506 V | | |

At the bottom of the window, there are three buttons: "Back to Financial Results", "Print Summary Page", and "Start Over at Beginning".

Figure 5. The Summary of Calculations Page showing the additional options Buttons

Continue to Summary: This button allows the user to proceed to the final page, the Summary form. This takes all of the most important results the user has calculated and sets them up for evaluation.

This final form is the Summary Form. Something to note here is the fact that the form takes dual perspectives. On the engineering level (Energy Summary), one can easily see the kW outputs, as well as the kWh and Voltage outputs. In the Financial Summary, which takes on more of an investor or management perspective, we see all of the financials here. As detailed in the previous sections, in the Energy Summary we are again showed the kW

Output, kWh Output, and Voltage Output. In the Financial Summary, we are also repeatedly given the Annual Revenue as well as the Initial Cost.

Back to Financial Results: This button allows the user to go back to the previous page, unloading all of the results and alter the Financial Factors before returning back to the Summary form. The Print Summary button allows the user to print out the page by use of a printing prompt. The user is then able to keep a copy of the results he or she calculated. The Start Over at the Beginning button not only steps the user back, but steps him or her back to the very beginning of the DSS. This keeps the user from having to “step backwards” repeatedly just to get to the beginning. A completely new hydropower DSS can then be customized from here.

3.4 VALIDATION

Using various online sources, I was able to test my DSS Hydropower Calculator in order to help validate my results and ensure that my formulae are in line with other experts. The following sources for validation were used: *Renewable Energy UK*, and the *DoradoVista, Baipatra*. In each of these examples I will calculate the results and their associated percentage errors. The standard metrics (control) in this case study includes a hydropower plant running at 100% efficiency with 200 meters of head and 1,200 liters/second of water flow. The resulting power output calculated by my DSS was **2354.4 kW**.

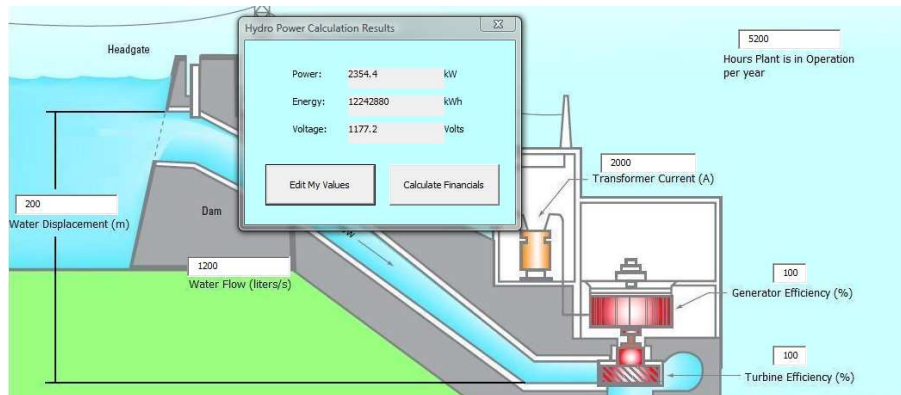


Figure 6. Results obtained for the Validation of Results for the subroutine.

4. CASE STUDIES

4.1 Case Study #1: A comparison with the *Renewable Energy UK* software (see Figure 7).

NEW Automatic Hydro Power Calculator

Below is our automated **hydro-power calculator**. Simply enter the *head* in metres, and the *flow rate* in litres per second, and the calculator will work out the amount of **power** carried by the water and the amount of power which can realistically be extracted from it to generate electricity.

Head: 200 (metres), Flow Rate: 1200 (litres per second)
Hydro Power: 2354400 (Watts)

Figure 7. Results for the Cases study using the Renewable Energy UK.

Input: 200 as the water displacement and 1,200 as the water flow. The output of 2,354,400 Watts, which can be converted to 2354.4 kW. After calculating the percentage error using $\frac{|My\ Calculated\ Value - Their\ Calculated\ Value|}{My\ Calculated\ Value}$, I determined a 0% error with Renewable Energy UK’s calculator. Output is shown in Figure 7

4.2 Case Study: A comparison with the *DoradoVista* software results (see Figure 8).

Hydro Power Calculator for KW Power = f(Head, Flow):

Enter head in ft and flow in CFS, then press "Calculate KW."

| | | | |
|------------|-----------|--------------|--------------------|
| 656.16798 | Head (ft) | | |
| 42.3776000 | Flow(CFS) | Calculate Kw | 2356.5105245125424 |

Figure 8. Results for the Cases study using the Dorado Vista program.

Since the units were dissimilar, we had to convert the units for both the head and flow.

The head was converted by the following calculation: $\frac{3.2808399 \text{ feet}}{1 \text{ meter}} \times 200 \text{ meters} = 656.16798 \text{ feet}$

The conversion of water flow was solved in a similar calculation: $\frac{0.0353146667 \text{ ft}^3}{1 \text{ liter}} \times 1,200 \text{ liters} = 42.3776 \text{ ft}^3$

The calculated result was 2356.51kW. The associated error was 8.96%.

4.3 Case Study: A comparison with the *Baipatra* software results (see Figure 9).

Hydro Power Calculator
A very small script that will calculate the theoretical potential hydropower of a certain stream.If Discharge Carrying Capacity(cubic meter/sec) of the stream,available Head(meter) and specific weight of water is given(kg/cubic meter), the calculator will calculate the potential hydropower(P) of the stream in m kg/sec.The same value can be found in horse power or in kilowatt if the unit is changed.If 'hp' is written in place of given unit of the calculated potential power, then P will be in horse power and if 'kW' is written,P will be in kilo watt.

Cost: \$ 0

Calculate Reset Print

| | | | |
|---|-------------------------------------|-----------------------------------|----|
| Discharge Carrying Capacity of the Stream | <input type="text" value="1.2"/> | m ³ /sec | |
| Head | <input type="text" value="200"/> | m | |
| Specific Weight of Water | <input type="text" value="1000"/> | kg/m ³ | |
| Potential Power of the Stream | <input type="text" value="240000"/> | mkg/sec | |
| | | <input type="text" value="2352"/> | kW |

Figure 9. Results for the Cases study using the Baipatra code.

The conversion of water flow was solved in the following calculation: $\frac{1 \text{ m}^3}{1000 \text{ liters}} \times 1,200 \text{ liters} = 1.2 \text{ m}^3$

The calculated result was 2352 kW. The associated percentage error was approximately 0.1019%.

6. CONCLUSIONS

We have presented a DSS tool for calculating the size, engineering details, and economic analysis calculations for Hydropower projects. We developed a subroutine that can be used in a variety of projects sizes. We described the DSS tool thoroughly, and the main windows have been explained, and tested. Help and Error checks have been also addressed. To validate our tool we have compared our results through three case studies, with those coming from three very well known codes available in the market today. In all three cases the associated error turns out to be very low. Some results were within 0.1% error. The lack of deviation between results, and the low errors indicate that our calculator is very accurate. Therefore, results are very encouraging since we compare our results with those coming from 3 very well know programs. The subroutine will be included in ANTU, an Industrial Energy Management program, as part of the renewable section.

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