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A Graphical User Interface (GUI) Based Method for Designing a Mini Hydro-Power

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Abstract: This research's study focuses on the creation of a Graphical User Interface (GUI) platform for designing a mini hydro-power plant. The GUI is developed to perform the designing procedure of the mini hydro-power system for Pahang River, Temerloh by considering the parameters of mass flow rate, net head, the efficiency of generator & turbine and penstock size for its desired outputs. This research discusses the proper selection of mini hydro-power plant components such as turbine type, penstock size, and net head length, which are the major components of the power station. The results obtained for the design of the mini hydro-power plant for Pahang River, Temerloh with a flow rate of 38.53 m^3/sec are as follows. The penstock length, penstock diameter, penstock minimum wall thickness and net head are 10m, 2230mm, 6.854mm and 3.24m respectively. The PVC was chosen as the penstock pipe material and the suitable turbine was Kaplan which is a reaction type. The mini hydro-power plant is a renewable energy plant that offers several benefits over wind and solar renewable energy plants of the same size. Hydro-power is completely pure, therefore it will never run out until the water supply is cut off, the power generation emits no pollution into the atmosphere, and it is the most dependable renewable energy source known. The developed GUI was able to identify the specifications of all the components that were to be utilized to create a mini hydro-power system. The GUI application was able to generate the same result as the manually computed design specifications.

Keywords: GUI, Mini Hydro-Power, Run-of-River (ROR)

1. Introduction

Energy storage and power management are becoming increasingly relevant as many countries place a greater focus on renewable energy generation [1]. Renewable energy which are derived from energy flows that are inherently recurrent and constant in the surrounding climate [2]. The use of non-fossil

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fuel and green energy has risen exponentially, with renewable energy's share of global overall energy rising from 2% to 7% in ten years mainly because of its reliability and sharp cost reduction [3], [4]. Renewable energy sources, such as wind and solar, have enormous ability to reduce the power sector's reliance on fossil fuels and greenhouse gas emissions [5], [6].

Hydropower is a sustainable and green energy source. It is currently the only renewable energy source that can be grown economically on a wide scale. Furthermore, it produces over 20% of all global energy and is used in over 150 countries [7]. Hydropower plants will provide clean water to farms, households, and industries while also helping to alleviate the effects of severe weather conditions including flooding and drought [8]. Projects like FIThydro are now working to enhance river ecosystems and add healthy fish populations to hydropower plant environments while also upgrading existing hydropower technology and devices [9]. Thus, a hydro-power plant is a great alternative renewable energy source to tackle the negative side effects of the conventional sources.

The production of hydroelectric power on a small scale to serve a small population or industrial facility is known as mini or small hydro. The description of a mini hydro project differs, although it is widely agreed to have a generating capacity of 100 to 1000 kilowatts (kW), which aligns with the principle of distributed generation [10]. To generate useful electricity, a mini hydropower scheme needs both water flow and a decrease in height known as a head. Water is called a source of power in nature because it can do useful work, such as spinning water wheels and producing electricity at a rate that makes for the most efficient and cost-effective production of power [11].

A graphical user interface, also known as GUI is a collection of interactive visual elements for computer applications. A GUI presents objects that express information and represent actions that the user may take [12]. Because commands do not need to be memorized, GUI operating systems are easier to learn and use. Furthermore, consumers do not need to be familiar with any programming languages. GUI operating systems can be applied in many sectors due to their ease of use and sleeker look.

2. Materials and Methods

The MATLAB Software with App Designer environment was used to create this Graphical User Interface (GUI) application. After the manual computations were completed successfully, work on the GUI began. This stage is critical for GUI development since it ensures that the application produces correct results.

2.1 GUI Development

This GUI contains three tabs which includes Calculation, Formula and Guidelines tabs. The final application includes Calculation and Formula tabs for calculating the projected value of a mini hydro-power generation system design. The Guidelines tab in this application also includes basic instructions on how to use this tool for the user’s convenience.

(a) Calculation tab

The first part of this GUI platform, which is the calculation tab, helps the user to obtain the design parameters such as the output power, penstock diameter and its thickness as shown in Figure 1. The *Generate Result* push button should be clicked after inserting the acquired data to get the results. For the turbine, the user has to select the classification of the turbine from the drop-down menu, for which the type of turbines can be used will be suggested. The user can click the *Reset* button in order to clear all the data and start over.

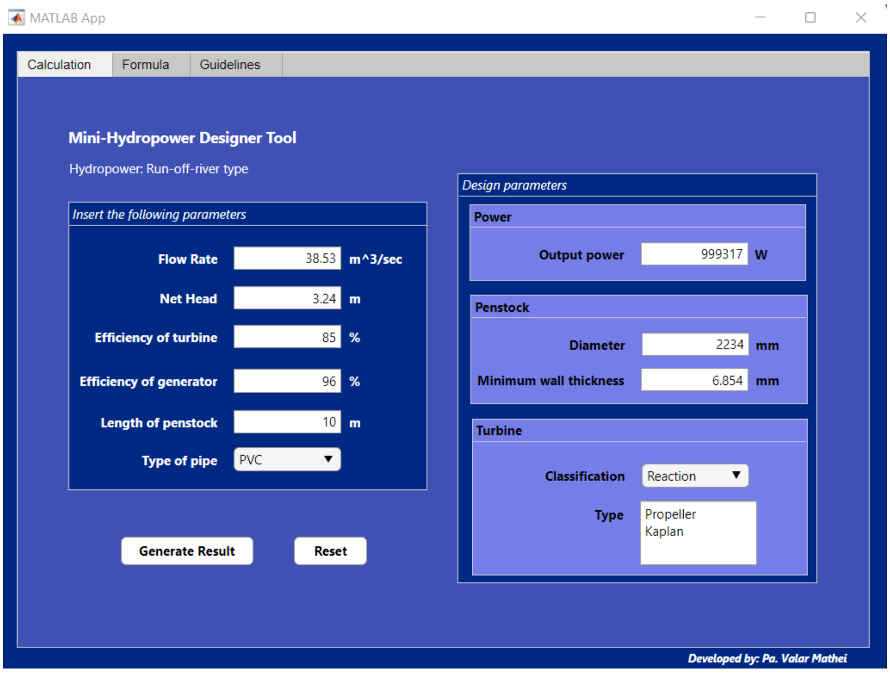

Figure 1: The calculation tab

The calculation tab is designed to calculate the output power, penstock diameter and its thickness when the physical data acquired from the installation site such as the flow rate of the river, penstock length, net head and the type of pipe material are inserted in the space provided. The power equation used in traditional hydropower plants is also can be applied in the mini hydro-power plants. The output power generated by the mini hydro-power plant is expressed in Eq. 1 [13].

$$P_{output} = \rho g H_{net} Q \eta_{turbine} \eta_{generator} \qquad Eq. 1$$

Where,

P_{output} = Generated output power (W)
ρ = Water density ($1000 kg/m^3$)
g = Acceleration of free fall ($9.81 m/s^2$)
H_{net} = Net head (m)
Q = Flow rate (m^3/sec)
$\eta_{turbine}$ = Efficiency of turbine
$\eta_{generator}$ = Efficiency of generator

The penstock not only transports water to the turbine, but it also serves as the container that generates head pressure as the vertical drop rises. The penstock directs all of the water power to the turbine at the bottom of the pipe. The penstock diameter and its minimum wall thickness is essential in this designing process. The Eq.2 shows the formula used to calculate the penstock diameter [14, 15].

$$D_e = 2.69 \left(\frac{n^2 Q^2 L}{H_{net}} \right)^{0.1875} \qquad Eq. 2$$

Where,

D_e = Penstock diameter (m)
n = Manning Coefficient
Q = Flow rate (m^3/sec)

L = Length of penstock (m)
H_{net} = Net head (m)

The Manning's Roughness Coefficient (n) represents the resistance to flood flows in channels and flood plains. The n value is calculated using the values of the elements influencing the roughness of channels and flood plains. The typical values of n are as given in the Table 1 [14, 15].

Table 1: Manning's coefficient n for several commercial pipes

Type of pipe/channel	n
Welded steel	0.012
Polyethylene (PE)	0.009
PVC	0.009
Asbestos cement	0.011
Ductile iron	0.015
Cast iron	0.014
Wood-stave (new)	0.012
Concrete (steel forms smooth finish)	0.014

The wall thickness of the penstock depends on the pipe materials, its tensile strength, pipe diameter and the operating pressure. The wall thickness computed should be more than the minimum wall thickness (t_{min}) of the penstock as stated in the Eq.3, 508 and 400 are constant [16, 17].

$$t_{min} = \frac{D_e + 508}{400} \qquad Eq.3$$

Where,
t_{min} = Minimum wall thickness (mm)
De = Penstock diameter (mm)

The turbine transforms water pressure into mechanical shaft power, which may be utilized to power an electricity generator or other electrically powered machinery. The conversion procedure consists of two major steps, the available fluid dynamic power in the water is first transformed to mechanical power and the mechanical power that is available is subsequently transformed into electrical power. The turbine type suggestion is made based on the net head length for the mini hydro-power as shown in Table 2 [13].

Table 2: Different classifications of turbine based on the net head

Turbine Type	Head		
	High < 40m	Medium 20-40m	Low 5-20m
Impulse	Pelton Turgo	Crossflow Pelton Turgo	Crossflow
Reaction	Null	Francis Pump-as-Turbine (PAT) Kaplan Propeller	Propeller Kaplan

(b) Formula tab

Figure 2 shows the Formula tab, which is the next tab the user can switch to after the initial Calculation tab. This tab displays how the calculation for the design parameters are made with the formula used for those calculations are also stated, which gives the target user a learning opportunity.

The calculation based on Eq.1, Eq.2, and Eq.3 are demonstrated in this tab. When the *Generate Result* button is clicked in the previous tab, this app automatically displays the values in the space for calculation demonstration. The *Reset* button in the previous tab will also clear all the data displayed here.

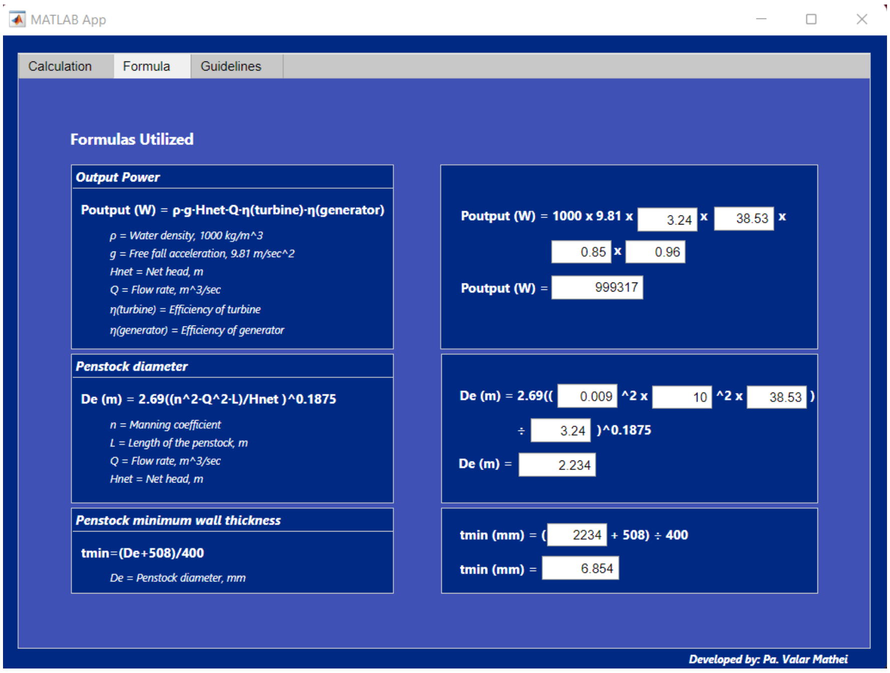

Figure 2: The formula tab

(c) Guidelines tab

The Guidelines tab as shown in Figure 3, provide the user with the crucial information with clear instruction and illustration on how to use this application. The illustration provided will help the user to visualize the values obtained with the dimension of the penstock. The table, efficiency of the turbines, will help the user to select one turbine from the suggested list for their desired efficiency.

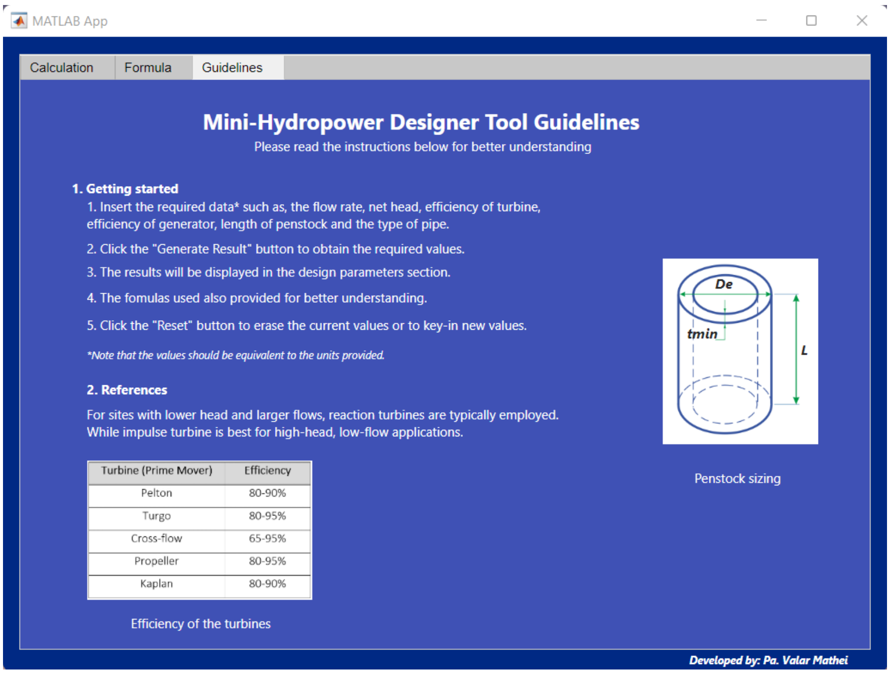

Figure 3: The guidelines tab

3. Results and Discussion

This sub-chapter discuss the manual calculation for designing the mini hydro-power plant at Pahang River. The design computation was done by utilizing all the data collected from various reliable sources. Some values such as the net head and the length of penstock needed to be calculated assuming a constant output power of 1000kW for the mini hydro-power plant. The acquired data for predicting the design parameters for the mini hydro-power plant is specified in Table 3.

Table 3: Acquired data for design parameter prediction for mini hydro-power plant for Pahang River

Item	Value
Flow Rate	38.53m^3/sec
Output power	1000kW
Net head	3.24m
Efficiency of turbine	85%
Efficiency of generator	96%
Length of penstock	10m
Type of pipe	PVC

The output power, penstock diameter and the minimum wall thickness of the penstock were calculated by using the Eq.1, Eq.2, and Eq.3 respectively. Table 4 shows the comparison result between manual calculation and GUI result for the primary estimation of the mini hydro-power plant for Pahang River. The obtained result has very minute margin of difference, which confirms the proper function of the GUI.

Table 4: Computational result obtained compared to GUI application

	Manual result	GUI result
Output power	999.3kW	999317W
Penstock diameter	2.23m	2234mm
Penstock minimum wall thickness	6.845mm	6.845mm
Turbine classification	Reaction	Reaction
Turbine type	Kaplan	Propeller, Kaplan

Table 5 shows the comparison result between manual calculations with three different variables and their respective GUI results. This computation was performed to demonstrate that the GUI is capable of operating at any data value specified by the user. The river flow rate (38.53m^3/sec), the turbine efficiency (85%) and the generator efficiency (96%) is maintained as controlled variable while the remaining data was used as independent variables.

Table 5: Computational result obtained compared to GUI application

Item	Manual result			GUI result		
Net head	*2m*	3.24m	3.24m	*2m*	3.24m	3.24m
Length of penstock	10m	*12m*	10m	10m	*12m*	10m
Type of pipe	PVC	PVC	*Concrete*	PVC	PVC	*Concrete*
Output power	616.86kW	999.3kW	999.3kW	616862W	999317W	999317W
Penstock diameter	2.45m	2.31m	2.64m	2445mm	2311mm	2636mm
Penstock minimum wall thickness	7.395mm	7.045mm	7.87mm	7.383mm	7.049mm	7.861mm
Turbine classification	Reaction			Reaction		

Turbine type	Kaplan	Propeller, Kaplan

4. Conclusion

The results demonstrate that the Graphical User Interface (GUI) application was able to perform the designing method for a mini hydro-power system. The GUI has been integrated with all of the sizing techniques and formulae. Furthermore, this GUI can accomplish any value that the user enters manually, such as the flow rate, net head, efficiency of generator & turbine and the penstock length to produce a suitable design recommendation. Furthermore, this GUI application can show how to use formulae in the design process, which is a good learning opportunity.

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