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Comparison Between Computational Design Method with Particle Swarm Optimization Algorithm for Mini Hydro Power Plant

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Abstract: This project's study focuses on the creation of a Particle Swarm Optimization (PSO) platform for designing a mini hydro-power plant. The usage of non-fossil fuel and green energy has increased dramatically, with renewable energy's proportion of worldwide overall energy increasing from 2% to 7% in 10 years, owing to its dependability and sharp cost reduction. 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. Hydropower 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. This paper 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 basis of the findings of the design of a mini hydro-power plant for Tebing Tinggi River in Perak, with a flow rate of 0.1650 m^3/sec. The length, diameter, minimum wall thickness, and net head of the penstock are 467m, 334mm, 2.085mm, and 125m, respectively. The penstock pipe was made of welded steel, and the appropriate turbine was the Turgo, which is an impulse type. The PSO method created was able to discover the specifications of all the components that would be used to build a mini hydro-power plant. For this objective, the PSO algorithm was developed using the MATLAB program and the coding algorithm environment. The PSO algorithm was able to produce the same results as the design specifications that were calculated.

Keywords: PSO, Mini Hydro-Power, Run-of-River

1. Introduction

Electricity is one of the essential energy sources in the world. Currently, energy consumption issues are a global concern. In developing countries such as Malaysia, there has been a tremendous rise in energy use. The conventional method of generating electricity uses fossil fuels such as natural gas and oil. Carbon emissions are produced when fossil fuels are used to generate energy, then utilized to power

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industrial buildings and machinery [1]. Carbon emissions contribute to climate change by trapping heat and respiratory ailments caused by smog and air pollution [2]. Therefore, renewable energy has been implemented to help increase energy consumption while reducing carbon emissions. Malaysia's National Renewable Energy Policy and Action Plan were introduced in 2010 to expand the use of renewable energy. In 2014, the Eleventh Malaysia Plan had a total installed capacity of 243 MW, including solar photovoltaic, biomass, small hydro, and biogas [3]. Furthermore, switching to renewable energy sources is essential for all countries, particularly those with a significant reliance on coal, oil, and gas, to achieve long-term growth [4]. Solar, wind, and hydroelectric power, for illustration, can supply extra energy and eventually serve as the primary source in the future [5].

One of the most common types of renewable energy is hydropower. There are a few categories of hydropower such as mini hydro. Mini hydro is a hydropower station that produces 100 standard units of electricity in one hour and has a power rating of 1MW or less. Mini hydropower is a small-scale energy generation method that converts kinetic energy into electric energy from falling water, such as steep mountain rivers. The mini hydropower system's concept is to use a turbine to generate mechanical power from water pressure, which is subsequently converted to electrical power. Consequently, rather than being discharged straight into a stream or the ocean, cleaned wastewater can be converted into valuable energy resources by using this method. Water falling from a height has been used as a source of energy for a long time; it is possibly one of the oldest renewable energy systems for mechanical energy conversion and electricity generation known to humanity [6].

J. Kennedy and R. C. Eberhart created Particle Swarm Optimization (PSO), a revolutionary evolutionary algorithm [7]. The PSO algorithm is an evolutionary algorithm that has garnered academic interest because of its benefits of ease of implementation, high precision, and rapid convergence [8]. In general, optimization problems are concerned with the process of maximization or minimization to discover a solution to an engineering challenge [9]. In this project, the PSO algorithm will be used to optimize renewable energy which is a mini-hydropower plant.

Malaysia is situated in a tropical climatic zone with high rainfall and dry days that occurs annually throughout the local wet tropical season. This means that the production of mini hydropower will vary according to the weather and must be forecast. However, developing an effective system needs considerable effort, including development, design, distributed generation, and, most significantly, mathematical modeling of the mini hydro-power plant. Mathematical modeling is the most effective technique for improving the performance of the system. The mathematical models abstract the natural world into a comprehensible collection of numbers. If just a few factors in the mathematical model are ignored that have a minimal effect on the abstract natural world, the model accurately captures the actual world [10]. Thus, the Particle Swarm Optimization (PSO) algorithm will be used to design the output power, penstock, and turbine for a mini hydro power plant.

2. Materials and Methods

This Particle Swarm Optimization (PSO) algorithm was created using MATLAB Software with coding windows. After the manual computations were completed, work on the PSO started. This process is crucial to the development of PSO since that ensures the algorithm produces accurate results.

2.1 Mini Hydro Power Generation

Hydro energy is known as a traditional renewable energy resource and is based on the flow of naturally circulating water and its drop from a higher to a lower land surface. This constitutes its potential energy. To convert potential energy into applicable electric energy, the water flow must enter and drive a hydraulic turbine, transforming the hydro energy into mechanical energy. The latter again drives a connected generator, transforming the mechanical energy into electric energy [11]. Mini hydro is described as the generation of electricity harnessing the power of flowing water from bodies of water such as lakes, rivers, and streams. Mini hydro is built on simple principles. It all begins with running water turning a turbine, which then spins a generator, resulting in the generation of power.

Figure 1 shows a block diagram for a mini hydro power plant. When doing a design study of a mini hydroelectric power plant, we must consider various essential factors such as the distance of the waterfalls and the speed of water flowing in the river. This is because a mini hydroelectric power plant will produce efficiently if the speed of water flowing is steady and the volume of water and river flow is substantial. Figure 1 [6] is a simplified diagram of a basic hydroelectric power plant configuration. Fundamental components of a typical hydroelectric power plant with an acceptable head acquisition approach are the reservoir, penstock, turbine, generator, and controls [7], [9].

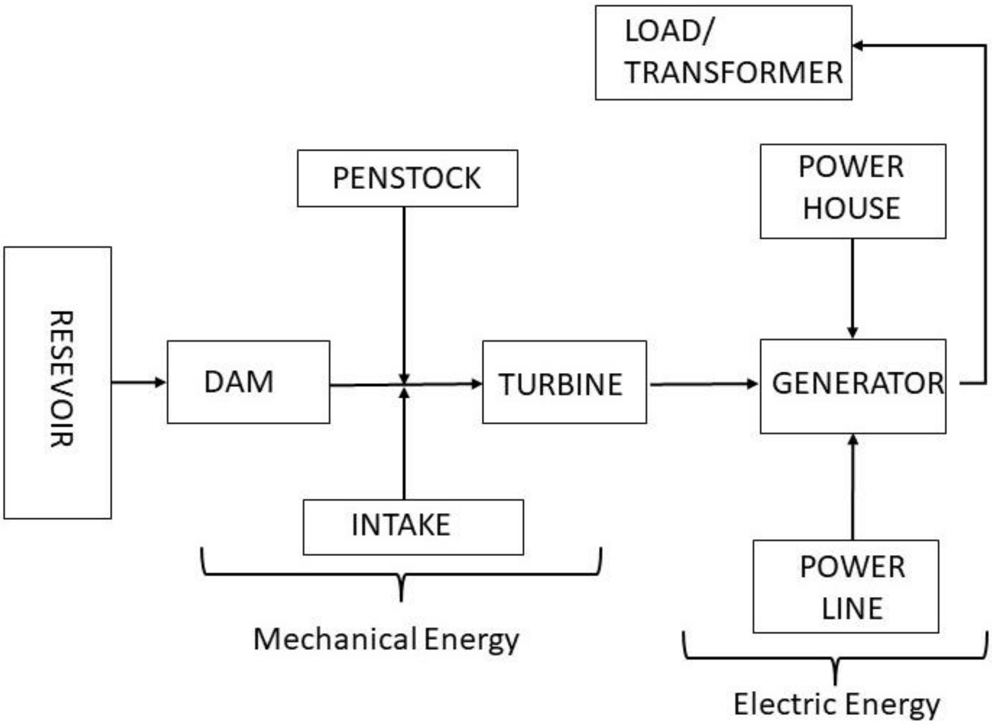


Figure 1: Block Diagram of Mini Hydro Power Plant

2.2 PSO Development

PSO is made from a solution of particles. Following that, by executing updates on the power generators, this procedure looks for the best state. Each particle aims for the best or superior values during each iteration of the updating process. The best solution is fitness, which is the initial value. The fitness value is then saved and given the designation "p-best." After either of the particles inside the population has obtained the particle swarm optimizer, the other best value is removed. The best value is referred to as "g-best" because it is a global best. Every particle in the population participates in this operation because it lives near or beside the operation's location. The particle updates its velocity (vi) and locations (xi) when two of the best values are discovered, as shown mathematically in equation (1 and 2 [11].

$$v_i^{t+1} = wv_i^t + c_1 \times rand \times \left(pbest_i - x_i^t\right) + c_2 \times rand \times \left(gbest - x_i^t\right) \qquad \text{Eq. 1}$$

$$x_i^{t+1} = x_i^t + V_i^{t+1} \qquad \text{Eq. 2}$$

$$V_{min} \leq V_i \leq V_{max} \qquad \text{Eq. 3}$$

The current location of particle I at iteration t is x_i^t. Meanwhile, pbest denotes p-best in proxy I at iteration t, while gbest denotes the best solution under this constraint. The weight (w) of inertia is usually fixed using the formula in equation below.

$$W = W_{max} - \left[\frac{W_{max} - W_{min}}{ITER_{max}}\right] \qquad \text{Eq. 4}$$

The weight factor of inertia is w, according to the formula above. Wmax is the largest weighting factor, while Wmin is the lowest. ITERmax is the largest number of iterations, while ITER is the current number [11].

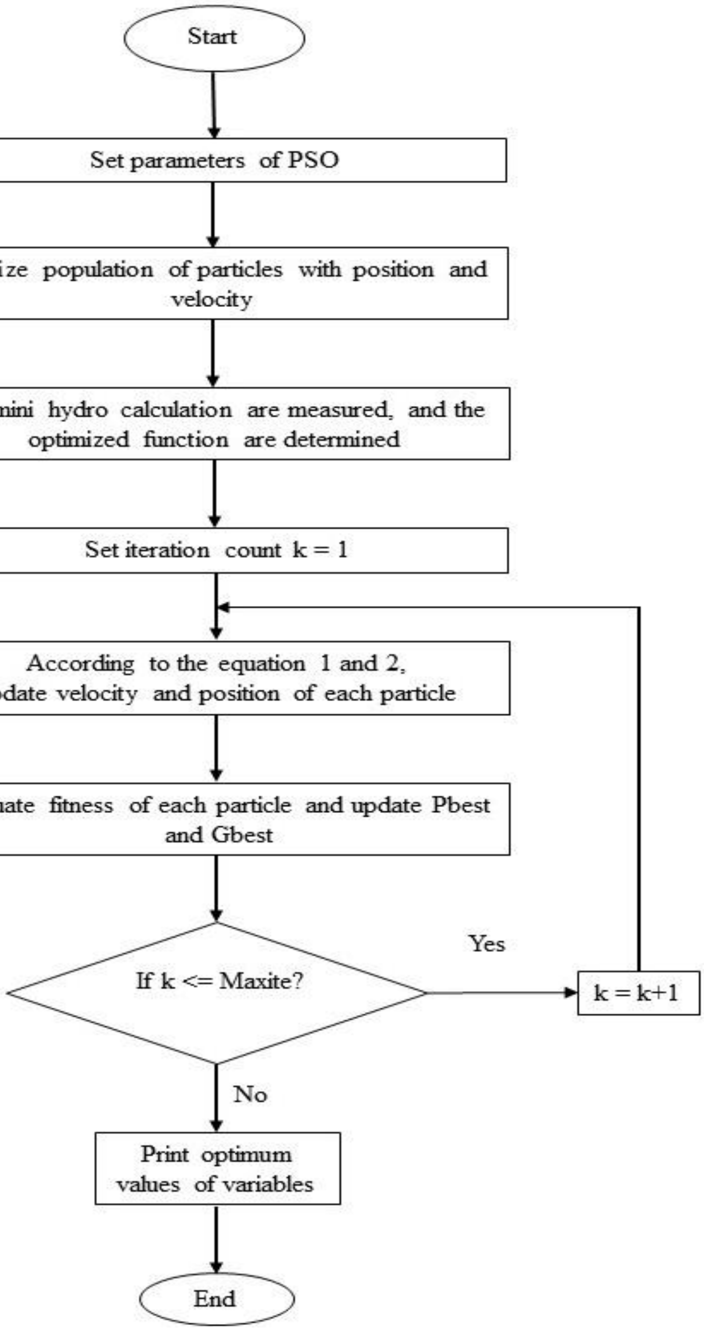
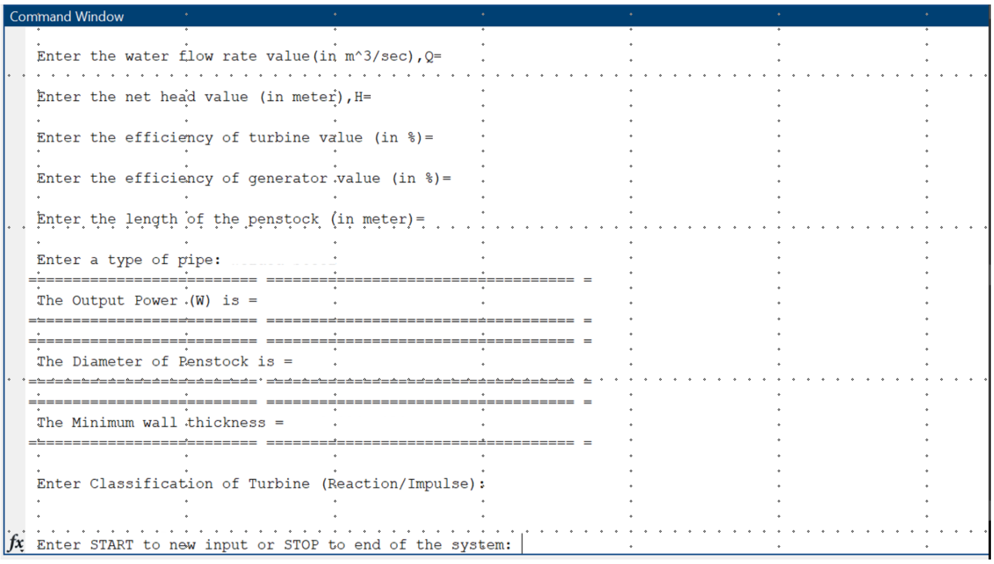


Figure 2: Flowchart of PSO algorithm

Based on Figure 2, the first step is set parameter value with initialization the parameters such as define the number of populations, lower and upper bound, maximum number of iterations, weight coefficient, velocity, inertia constant and number variable for this algorithm project. The next step is identified mini hydro formula that have been measured. Some important information to design the system are the river mass flow rate, type of hydro-power plant, method of head acquisition, efficiency of generator and turbine and the equations used. After that, evaluate initial fitness of each particle and select Pbest and Gbest for this algorithm to get the best results. Then, set the iteration for this system and update the velocity and position of each particle according to the formula 1 and 2. To get the best results, evaluate the fitness of each particle and adjust the iteration for this system follow by iteration that have been set. The previous step will be repeated until the iteration of the system are finish follow by the number of updates. If iteration have finish, the system will get the optimum values of variables for this system. Finally, the completion of final report writing will be done.

2.3 Develop PSO Algorithm Using MATLAB Software

The Particle Swarm Optimization (PSO) algorithm will be designed using MATLAB software. The PSO is designed to perform calculations of the mini-hydro power generation for the potential location. The command window of the system, the user must enter the data gathered for designing in this display window, which includes the flow rate, net head, turbine efficiency, generator efficiency, and penstock length. The user must choose the type of pipe material to be utilized from this window. The display window of PSO algorithm is shown in Figure 3.



```
Enter the water flow rate value(in m^3/sec),Q=

Enter the net head value (in meter),H=

Enter the efficiency of turbine value (in %)=

Enter the efficiency of generator value (in %)=

Enter the length of the penstock (in meter)=

Enter a type of pipe:
========================== =================================== =
The Output Power (W) is =
========================== =================================== =
========================== =================================== =
The Diameter of Penstock is =
========================== =================================== =
========================== =================================== =
The Minimum wall thickness =
========================== =================================== =

Enter Classification of Turbine (Reaction/Impulse):


Enter START to new input or STOP to end of the system:
```

Figure 3: The Display Window of PSO Algorithm

This page allows the user to obtain design parameters including output power, penstock diameter, and 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 employed in conventional hydropower plants is also can be applied in the mini hydro-powerplants. The output power generated by the mini hydro-power plant is stated in Eq. 4.

$$P_{output} = \rho g H_{net} Q \eta_{turbine} \eta_{generator} \qquad \text{Eq. 4}$$

Where P is the mechanical power produced at the turbine shaft (Watts), η is the efficiency of the hydraulic turbine (in the range 0.8-0.9), ρ is the density of water (kg/m3), g is the acceleration due to gravity (m/s2), Q is the volume flow rate passing through the turbine (m3/s) and H is net pressure head of water across the turbine (m).

The penstock not only transports water to the turbine but also acts as a container for creating head pressure as the vertical drop increases. The penstock funnels all of the water's energy to the turbine at the pipe's bottom. In contrast, an open stream loses energy as it flows downward. The diameter and minimum wall thickness of the penstock are crucial to the design process. The diameter of the penstock is calculated using the formula shown in Eq.5 [12], [13].

$$D_e = 2.69\left(\frac{n^2 Q^2 L}{H_{net}}\right)^{0.1875} \qquad \text{Eq. 5}$$

Where De is penstock diameter, Q is the flow rate, n is Manning Coefficient (n), Hnet is the net head and L is the length of the penstock in meters.

Manning's Roughness Coefficient (n) quantifies the resistance of channels and flood plains to flood flows. The n value is determined by the values of the variables that affect the roughness of channels and flood plains. The typical values of n are as follows [12] [13]:

Table 1: Manning Coefficient n for Several Commercial Pipes [12] [13]

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 (t) of the penstock in millimetres is determined by the pipe material, its tensile strength, the diameter of the pipe, and the operating pressure. The calculated wall thickness should be greater than the penstock's minimum wall thickness (tmin), as specified in Equation 6.

$$t_{min} = \frac{D_e + 500}{400} \qquad \text{Eq. 6}$$

Where De and tmin are in millimeters and 500 and 400 are constants [11] [14].

A turbine converts water pressure to mechanical shaft power, which can be used to power a generator or other electrically powered machinery. The conversion process is divided into two major stages, fluid dynamic power is converted to mechanical power after it has been extracted from the water and the mechanical energy that is available is then converted to electrical energy. The turbine type selection for mini hydropower is based on the net head length as shown in Table 2 [15].

Table 2: Different Classification of Turbine Based on Head for mini hydropower [15]

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

2.4 Guidelines Using PSO Algorithm

In MATLAB software, the system function according to the flowchart in Figure 4. At the beginning of the program, the user needs to enter the value of water flow, net head, the efficiency of the turbine and generator, length of the penstock, and type of pipe. For the type of pipe, the system determines the type of pipe by applying an if-else comment according to Table 1. Next, the system will calculate and display the output power of appliances running simultaneously and the diameter and thickness of penstock value by using equations (4), (5) and (6). If the PSO value meets the expected value in this case, equal to the computational design method result, then the next step can be continued. However, if the value were not meet the expected value, parameters in PSO need to be adjusted. In the next step, user is requiring entering the classification of turbines by applying if-else comment according to Table 2. Then PSO algorithm will determine and display the suitable type of turbines based on Table 2. Finally, the user needs to enter the character ‘START’ or ‘STOP’ to restart or stop the system. If the user enter character ‘START’, the system will restart with enter all the input value, if the user enters character ‘STOP’, the system will end.

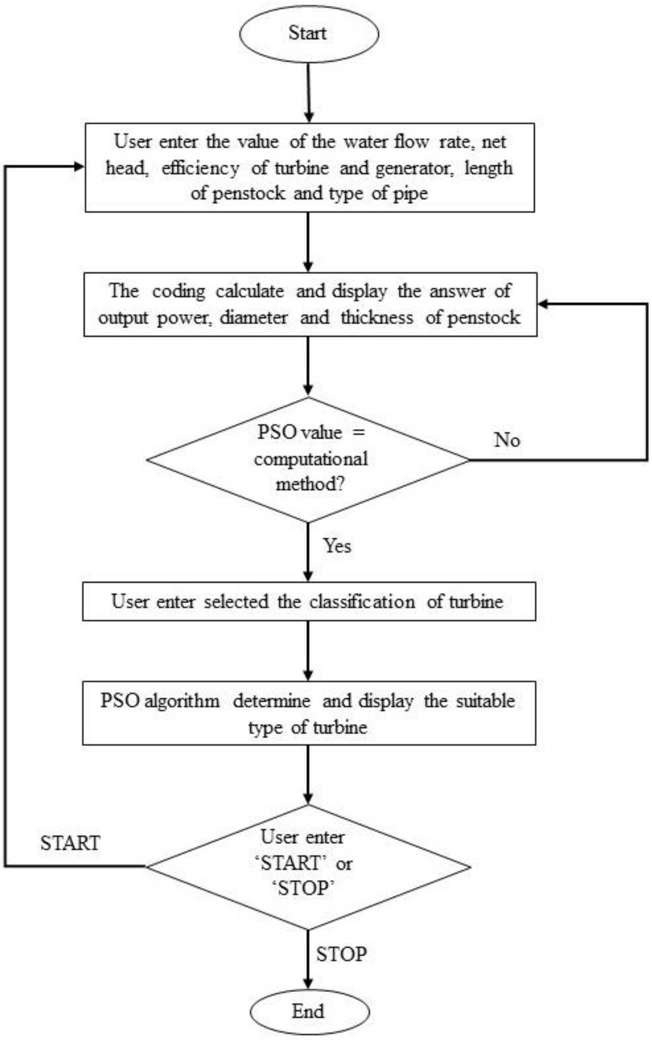


Figure 4: Guidelines Using PSO Algorithm

To summaries, all the procedures and stages involved in data collection for the purpose of building a mini hydropower plant are largely dependent on the flow rate of the waterway. The data collected will be used as a reference in the future for developing and improving Particle Swarm Optimization (PSO). The use of this mini hydroelectric plant will provide long-term energy generation while also benefiting the environment. These types of initiatives or innovations represent a significant improvement in energy consumption processes, which is critical for the global community.

3. Results and Discussion

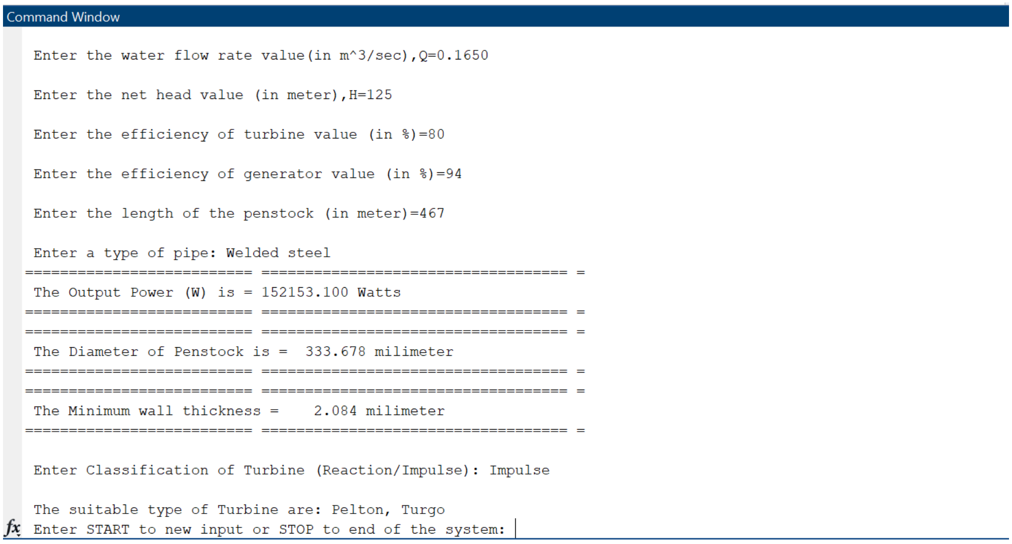
This will describe the manual calculations used to design the mini hydroelectric plant on the Tebing Tinggi River. All gathered data from a variety of trustworthy sources were utilized in the design computation. Some values, such as the net head and penstock length, had to be calculated for the mini hydropower plant assuming a constant output power of 152kW. Table 3 details the data collected for calculating the mini hydropower plant's design parameters.

Table 3: Design parameters of the Mini hydro-power plant for Tebing Tinggi River at Selama Perak

No.	Hydropower	Unit	Value
1	Run-of-river type	-	-
2	Rated (net) Head	m	125
3	Rated Discharge	m^3/s	0.1650
4	Output Power	kW	152

No.	Turbine	Description
1	Classification	Impulse
2	Type	Turgo
No.	Penstock	Description
1	Material	Steel
2	Length	467m
3	Diameter	334 mm
4	Minimum wall thickness	2.085 mm
No.	Generator	Description
1	Phase	3

Basically, the PSO algorithm was combined with a standard coding method to get the value of each component using MATLAB. This is due to some functions that can be calculated easily using simple coding. Thus, PSO is only used in finding the value output power, diameter and thickness of penstock. Results for the design method were obtained using PSO in MATLAB software. Overall results include output power, diameter and thickness of penstock, classification and type of turbine required had to be shown in Figure 5.



```
 Enter the water flow rate value(in m^3/sec),Q=0.1650

 Enter the net head value (in meter),H=125

 Enter the efficiency of turbine value (in %)=80

 Enter the efficiency of generator value (in %)=94

 Enter the length of the penstock (in meter)=467

 Enter a type of pipe: Welded steel
========================== =================================== =
 The Output Power (W) is = 152153.100 Watts
========================== =================================== =
========================== =================================== =
 The Diameter of Penstock is =  333.678 milimeter
========================== =================================== =
========================== =================================== =
 The Minimum wall thickness =    2.084 milimeter
========================== =================================== =

 Enter Classification of Turbine (Reaction/Impulse): Impulse

 The suitable type of Turbine are: Pelton, Turgo
fx Enter START to new input or STOP to end of the system:
```

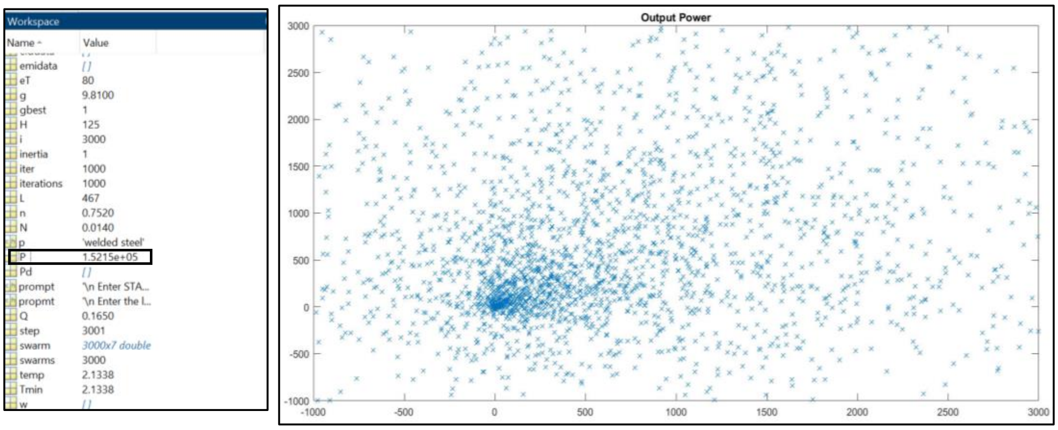
Figure 5: Mini hydro-power plant design parameters calculated by PSO algorithm

Table 4: Result obtained compared to PSO algorithm

	Manual result	**PSO result**
Output Power	152kW	152153.100W
Penstock diameter	334mm	333.678mm
Penstock minimum wall thickness	2.085mm	2.084mm
Turbine classification	Impulse	Impulse
Turbine type	Turgo	Pelton Turgo

Using Equations 4, 5 and 6, the output power, diameter of the penstock, and minimum wall thickness of the penstock were determined. Table 4 compares the computational design and PSO result for the primary estimation of the mini hydropower plant on Tebing Tinggi River. The given result has a very small margin of error, proving that the PSO is operating well.

Figure 6 shows a graph for the output power. The graph shows the movement of 3000 particle swarm in a space which has been set to 1000 iteration and inertia weight to 1.0 with correction factor 2.0. The swarm were primarily scattered on the scale from 0 to 3000 value. This happened because PSO did 1000 possible solutions to find the minimum value for the objective function even though there are few differences between both values, as we round off the PSO value.



Name	Value
emidata	[]
eT	80
g	9.8100
gbest	1
H	125
i	3000
inertia	1
iter	1000
iterations	1000
L	467
n	0.7520
N	0.0140
p	'welded steel'
P	1.5215e+05
Pd	[]
prompt	'\n Enter STA...
propmt	'\n Enter the I...
Q	0.1650
step	3001
swarm	3000x7 double
swarms	3000
temp	2.1338
Tmin	2.1338
w	[]

Figure 6: Graph and Display Value for Output Power

After thorough investigation in Figure 6, the value of output power for mini hydro power plant using PSO is 152153.100W. This value is slightly different from the result of the computational design method, which is 152kW. This happened because PSO did 1000 possible solutions to find the minimum value for the objective function even though there are few differences between both values, as we round off the PSO value. It shows comprehensive data for developing hydropower plants has been obtained from a variety of trustworthy sources. These data were employed in the development and deployment of the particle swarm optimization algorithm. In addition, PSO algorithm have been presented well. Consequently, this demonstrates that hydropower output is largely reliant on the local installation site's geographical characteristics, such as the river's gradient and flow rate. This is one of the key reasons why hydropower production prediction is so essential since it enables us to build the power plant properly.

4. Conclusion

The objective which was to build a PSO that could conduct the designing technique for a mini hydro-power system was accomplished using MATLAB software. As shown in Section 4.3, the PSO is well-designed with user-friendly features and may produce the same outcomes as data collection. Finally, the study's last goal, which was to evaluate the performance of the proposed PSO algorithm by comparing the manual design to the PSO outcome, was effectively accomplished. The produced result has a very little margin of difference, as shown in Section 3, confirming the PSO's appropriate function.

The results show that the Particle Swarm Optimization (PSO) algorithm can be used to implement the design method for mini-hydropower systems. All design methods and formulas have been integrated with the PSO. In furthermore, this PSO can produce a suitable design proposal for any user-entered value, including flow rate, net head, generator & turbine efficiency, and penstock length. In moreover, this PSO algorithm can demonstrate how to utilize formulas in the design process, providing an excellent learning opportunity.

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References

[1] B. Klaus and P. Horn, Robot Vision. Cambridge, MA: MIT Press, 1986

[2] L. Stein, "Random patterns," in Computers and You, J. S. Brake, Ed. New York: Wiley, 1994, pp. 55-70

[3] L. Bass, P. Clements, and R. Kazman, Software Architecture in Practice, 2nd ed. Reading, MA: Addison Wesley, 2003 [E-book] Available: Safari e-book. (Example for e-books)

[4] J. U. Duncombe, "Infrared navigation - Part I: An assessment of feasibility," IEEE Trans. Electron. Devices, vol. ED-11, pp. 34-39, Jan. 1959

[5] T. Brunschwiler et al., “Formulation of percolating thermal underfill using hierarchical self-assembly of microparticles and nanoparticles by centrifugal forces and capillary bridging,” J. Microelectron. Electron. Package., vol. 9, no. 4, pp. 149–159, 2012, doi: 10.4071/imaps.357

[6] H. K. Edwards and V. Sridhar, "Analysis of software requirements engineering exercises in global virtual team setup," Journal of Global Information Management, vol. 13, no. 2, p. 21+, April-June 2005. [Online]. Available: Academic OneFile, http://find.galegroup.com. [Accessed May 31, 2005] (Example for an e-journal article extracted from a database)

[7] A. Altun, "Understanding hypertext in the context of reading on the web: Language learners' experience," Current Issues in Education, vol. 6, no. 12, July 2003. [Online]. Available: http://cie.ed.asu.edu/volume6/number12/. [Accessed Dec. 2, 2004] (Example for an e-journal article extracted from the internet)

[8] L. Liu and H. Miao, "A specification-based approach to testing polymorphic attributes," in Formal Methods and Software Engineering: Proceedings of the 6th International Conference on Formal Engineering Methods, ICFEM 2004, Seattle, WA, USA, November 8-12, 2004, J. Davies, W. Schulte, M. Barnett, Eds. Berlin: Springer, 2004. pp. 306-19 (Example for a conference paper)

[9] T. J. van Weert and R. K. Munro, Eds., Informatics and the Digital Society: Social, ethical and cognitive issues: IFIP TC3/WG3.1&3.2 Open Conference on Social, Ethical and Cognitive Issues of Informatics and ICT, July 22-26, 2002, Dortmund, Germany. Boston: Kluwer Academic, 2003 (Example for conference proceedings)

[10] A. A. a. N. K. H. Sachdev, "Analysis and evaluation of small hydropower plants: A bibliographical survey," Renewable and Sustainable Energy Reviews, vol. 51, pp. 1013-1022, 2015.

[11] S. M. K, "Optimum Design of Penstock for Hydro Projects," International Journal of Energy and Power Engineering, vol. 4, no. 4, p. 216, 2015.

[12] I. Adejumobi and O. Adebisi, "Equipment Selection for a Sustainable Small Hydro Power Scheme," Top Research Group Conference, Lome, Togo, 2011.

[13] I. A. Adejumobi and O. I. Adebisi, "Exploring Small Hydropower Potentials for Domestic and Information Communication Technology Infrastructural Application in Rural Communities in Nigeria," Proceeding of the 12th Biennial International Conference of Botswana Institution of Engineers, Gaborone, Botswana, pp. 19-26, 2011.

[14] N. B, "Design Considerations of Micro-hydro-electric Power Plant," Energy Procedia, vol. 50, pp. 19-29, 2014.

[15] J. Bratley, "Advantages & Disadvantages of Wind Energy," Clean Energy Ideas, February 4, 2021.