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Design and Installation of an Archimedes Screw Turbine for Footbridge Illumination in Bacolor, Pampanga

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ABSTRACT

To supply footbridge illumination in Cabalantian, Bacolor, Pampanga, this project focuses on the design and installation of an Archimedes Screw Turbine (AST) as a sustainable energy source. The project uses the kinetic energy of flowing water from a local weir to address the issues of inadequate lighting and restricted access to electricity in rural areas. The AST was chosen after a thorough analysis of current micro-hydropower technologies because of its high efficiency, fish-friendly design, and capacity to function in extremely low head situations. The system, which includes a permanent magnet generator, buck converter, and inverter to assure stable energy conversion, was constructed and tested by the researchers using theoretical calculations, structural modeling, and practical engineering techniques. Field testing over three days proved that the system was capable of electricity generation with a mechanical maximum of 33.00 watts, and an electrical output of 17.96 watts at a head of 0.07 meters with a flow rate of 0.09379 m³/s, attaining a peak efficiency of 80.88%. These results verify the ASTs' applicability for decentralized energy AST-based power generation in resource-constrained environments, showcasing their usefulness for enhanced public safety, energy autonomy, and sustainable infrastructure development in rural regions.

Keywords: Archimedes Screw Turbine, Renewable Energy, Rural Electrification, Ultra-Low-head Hydropower Bacolor Pampanga

I. Introduction

Hydropower generates electricity from flowing or falling water and accountsfor about 17% of global electricity. It is cost-effective and reduces greenhouse gas emissions, but it can harm local ecosystems [1]. Hydropower, one of the oldest sources of power generation, powers some of the world's most extensive power facilities. Despite the rapid development of new renewable energy technologies, hydropower accounts for a sizable share of global renewable electricity generation. The various types of hydropower—run-of-river, hydro storage, and pumped storage—have distinct advantages and disadvantages, and understanding them is critical for determining hydropower's future position in modern energy systems [2]. One of the earliest methods of producing electricity is hydropower, which still generates most of the world's renewable electricity, regardless of the explosive growth of new renewable generation methods. Run-of-river, hydro storage, and pumped storage systems are only a few of the variants of this technology, each with distinct operational traits and financial ramifications [6]. Each turbine type serves a unique purpose, but the Archimedes Screw Turbine stands out for its simplicity, low maintenance, environmental compatibility, and consistent efficiency under variable load, making it the most efficient choice for low-head, small-scale hydropower projects. [8]. The Archimedes Screw Turbine (AST) is a highly effective solution for small-scale, low-head hydropower projects due to its ability to operate efficiently in head ranges as low as 0.1 to 10 meters and with flow rates from 0.01 to 6 m³/s. Unlike conventional turbines such as Kaplan, Francis, or Pelton, which often require complex infrastructure and clean water, the AST performs well in simple settings and maintains up to 90% efficiency, even under fluctuating loads. This makes it particularly suitable for rural or remote installations like small rivers, irrigation canals, and wastewater systems. Its robust design allows it to operate with untreated water, minimizing the need for filtration or intensive maintenance, thereby lowering long-term operational costs. Beyond performance and practicality, the AST excels in ease of installation and environmental sustainability. Overall, the AST offers a reliable, low-maintenance, and environmentally conscious alternative to traditional turbines, especially in locations where conventional technology is either too costly or unsuitable.

II. Materials and Methods

A. Waterfall Method

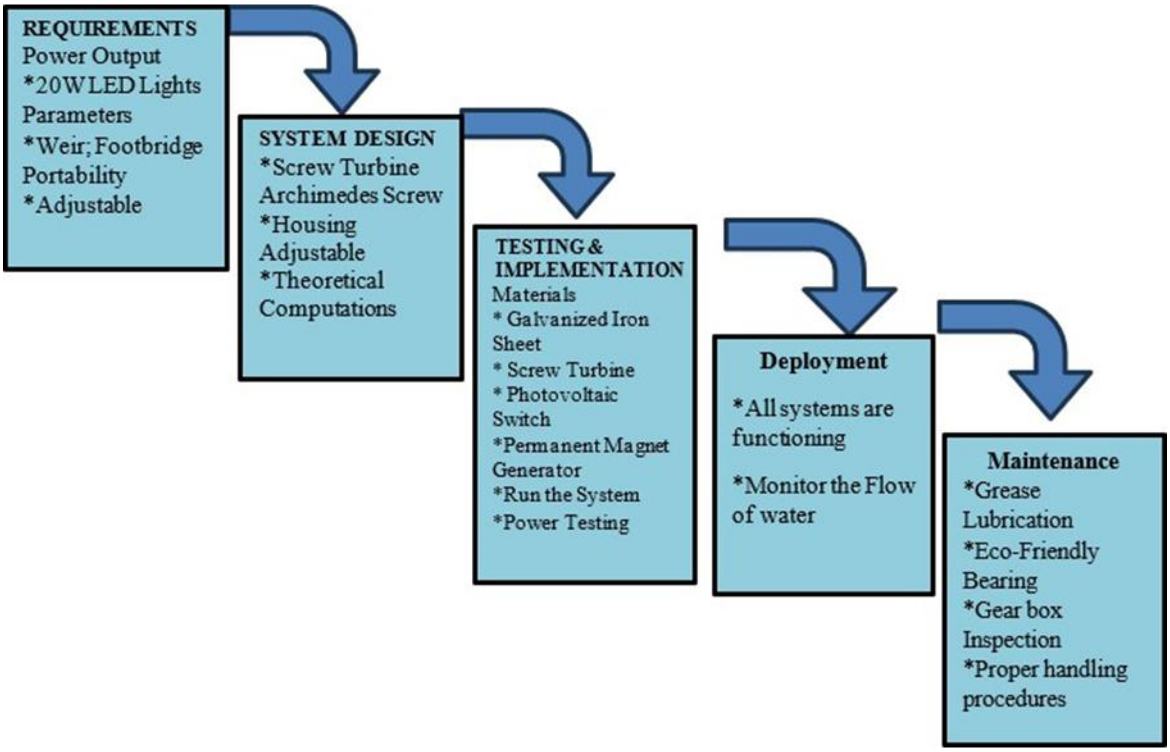

Fig 1. Waterfall Method

In the construction phase, materials such as galvanized iron sheets were selected for their durability, while the turbine was custom-fabricated to meet specific performance needs. A photovoltaic switch was included for power regulation, alongside the use of eco-friendly 16 | P a g e bearings to promote environmental sustainability. To validate the system's performance, theoretical computations were conducted to determine the appropriate dimensions, torque, and power output required to meet the lighting demand. Following construction, the implementation stage involved deploying the system in a controlled water flow environment, where power output testing and functional checks of all components were performed. Continuous monitoring of water flow and system performance ensured the setup's operational efficiency and reliability. Lastly, a maintenance plan was established, including grease lubrication, gearbox inspection, and adherence to proper handling procedures, ensuring the long- term durability and effectiveness of the micro-hydropower system.

B. Operational Flow Chart

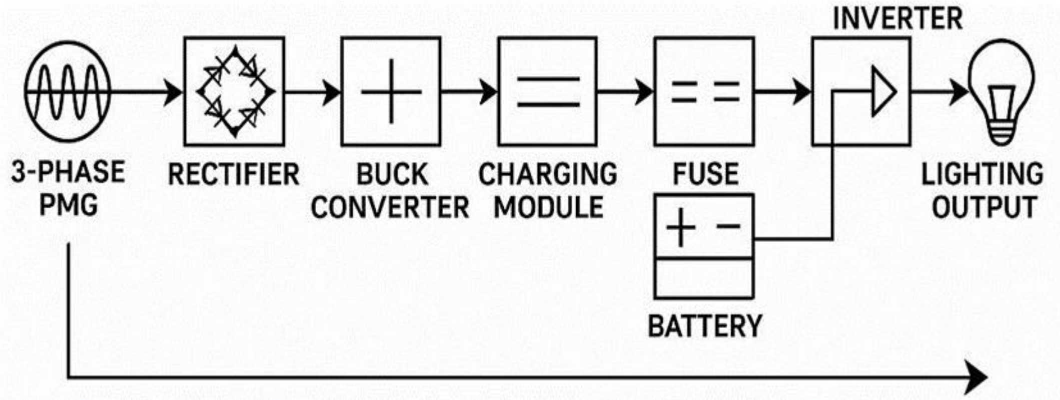

Fig 2. Operational Flow Chart

C. Modeling Analysis

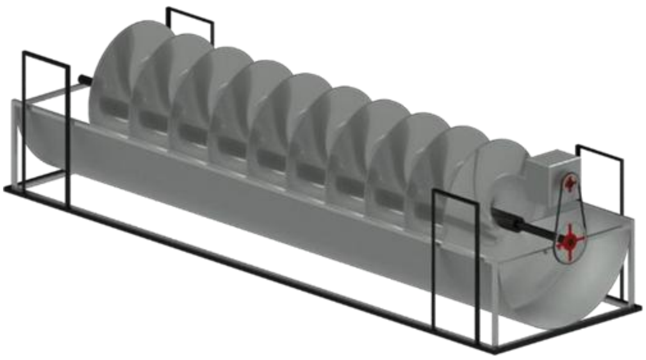

Fig 3. Design of Archimedes Screw Turbine

a. Turbine

Length of screw (L) Generally, the length of the screw is selected according to passing flow rates (Q) and head of water (H) so that maximum available flows can be utilized. But since the Archimedes Screw Turbine can be easily removed for ease of maintenance, the following formula [30] can also be used to find the length of the screw.

$$L = \frac{H}{\sin(\theta)} \tag{1}$$

Using [31] for ASTs, the outer diameter can be approximated:

$$D_o \approx .25Q^{0.4} \tag{2}$$

Wherein (Q) is the average water velocity.

For the shaft diameter, a typical inner/outer diameter ratio is $(Di/Do)ratio$ = .3 − .5. Then safety factor (sf) is considered

$$D_i = (D_i/D_o)_{ratio} \times D_o \times sf \tag{3}$$

The blade is meticulously affixed to the shaft in a helical configuration and secured with a joint. The researcher opts for a single-blade turbine with a diameter of .30 meters. Muysken [32] recommends the maximum rotation rate for a screw pump $nmax$ as a function of the outer diameter is:

$$n_{max} = \frac{50}{\sqrt[3]{D_o^{\,2}}} \tag{4}$$

Note that this is a non-homogenous equation, which means that the units of Do must be in meters, and the units of

$nmax$ will be in rev/min or RPM.

The turbine is 1.3 meters long, with a pitch of 0.13 (the distance between two consecutive threads or flights of the screw) and a gap width between the trough (GI sheet around the perimeter of half the turbine) the turbine of 0.06 m. The approximate rotational speed for a screw pump in revolutions per minute is specified [33].

Archimedes Screw Turbine

The shaft has a diameter of .1 m, resulting in a turbine blade with a .30-meter diameter. The recommended rotational speed is 112 rpm.

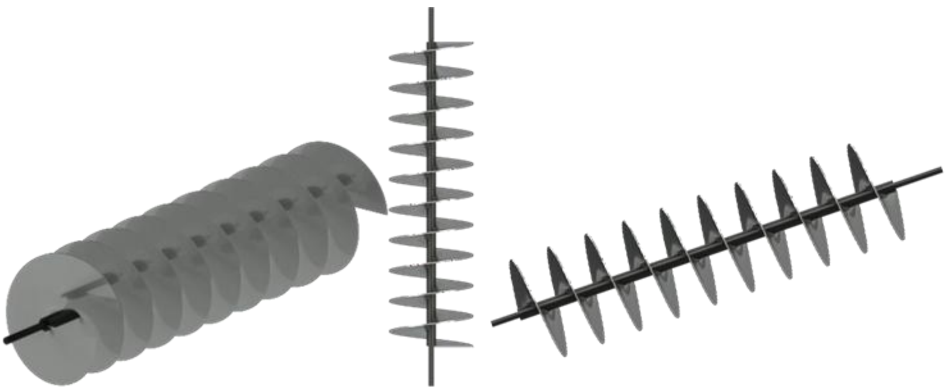

Fig 4: Design of Archimedes Screw Turbine

The estimated hydraulic power output of the Archimedes Screw Turbine will be based on the load it supplies. To allow the screw to rotate freely, there must be a small gap between the outer edge of the rotating screw, and the surface of the circular trough within which the screw rotates. The difference in free surface between consecutive buckets causes a difference in static pressure that drives the water through the gap, causing a steady gap leakage flow down through the screw, which in turn reduces screw efficiency. The width of this gap, in meters, is typically

$$G_w = 0.0045\sqrt{D_o} \tag{5}$$

However, the presence of debris ranging from small rocks to washed up water lilies is occasionally present on the location so a gap (gap) is added

$$G_w = (0.0045\sqrt{D_o}) + gap \tag{6}$$

where Do is the screw diameter in meters (note that neither this or any of the equations that follow are dimensionally consistent, and must only be used with the specified units). Assuming this gap width, [34] also gives an empirical formula for approximating the gap leakage in Archimedes screw pumps. Leakage volume flow rate QL through the screw, in m^3/s, is

$$Q_L = 3.5G_wD_o^{1.5} \tag{7}$$

where Gw is the width of the gap between flight edge and trough in meters.

The loss of work caused by water leaking through the gap between the flights and the walls or leakage loss is given by [34] as another non-homogenous equation:

$$N_{L(hp)} = \frac{Q_LH}{75} \tag{8}$$

$$\boldsymbol{N}_{L(w)} = \boldsymbol{N}_{L(hp)} \times 745.7$$

where $NL(hp)$ is the leakage power loss in horsepower, QL is the leakage flow in (m^3/s) and H is the head in (m). After calculating, we need the $NL(hp)$ to be in w so 745.7 is multiplied to $NL(hp)$.

The Archimedes Screw Turbine (AST) is engineered to transform hydraulic power into mechanical power, operating at a specified rate of turbine rotation and a particular angle of inclination, as depicted in the data below.

LENGTH	$L = \frac{H}{\sin(\theta)}$	1.3	m
BLADE DIAMETER	$D_o \approx .25Q^{0.4}$	0.3	m
SHAFT DIAMETER	$D_i = (D_i/D_o)_{ratio} \times D_o \times sf$	0.18	m
MAXIMUM ROTATION RATE	$n_{max} = \frac{50}{\sqrt[3]{D_o^2}}$	112	rpm
BLADE TO HOUSING GAP	$G_w = (0.0045\sqrt{D_o}) + gap$	0.06	m
LEAKAGE VOLUME FLOW RATE	$Q_L = 3.5G_wD_o^{1.5}$	0.035924	m^3/s
LEAKAGE POWER LOSS	$N_L = \frac{Q_LH}{75}$	0.023217	w

Fig 5: Turbine Design Parameters

b. Housing

The housing will accommodate both the Archimedes Screw Turbine and the generator wherein the housing composes of an angled bar as the exoskeleton with a length of 1.3 meters, a width of .42 meters and a height of .28 meters. The Archimedes screw turbine housing is only halfway enclosed to prevent water backflow and pressure buildup, allow debris to pass through, regulate moisture and temperature, reduce material and construction costs, enable easy maintenance, improve flood resilience, and ensure optimal water flow for maximum efficiency.

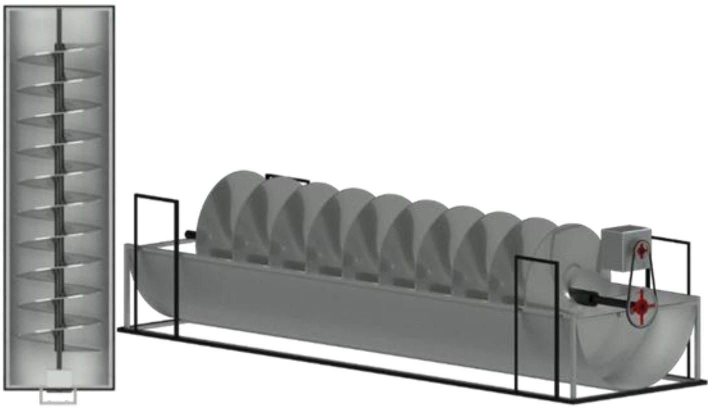

Fig 6. Archimedes Screw Turbine

c. Electric Generator

The electric generator utilized operates at a rotational speed of 800 rpm to 1500 rpm. To align with the mentioned speed, a 1:2 gear ratio is implemented. The generator produces a alternating current; it has a rated voltage of 90 volts and rated speed of 2000 RPM. A Turbine controller will be integrated to produce a 12/24 volts output and a battery as a buffer to stabilize 12-volt supply and smooth outs voltage fluctuations. Additionally, a 12V DC to 220V AC, 500W inverter will be employed to adjust and invert voltage from 12V DC to 220V AC, ensuring stability in the generated electromotive force (emf), particularly during changes in the turbine's rotational speed. The electric generator can generate enough electrical power to supply 5 – 20w LED Spotlight, and charge a Smartphone or any equivalent devices.

Fig 7. Permanent Magnet Generator

Equations

The Archimedes Screw Turbine generates mechanical power, which then transformed into electrical power using a Generator. To determine the specific features of the CFST, it is assessed based on the analysis provided in the reference material. The fundamental principle underlying the velocity-area method is that the flow rate (Q) is equivalent to the product of the mean velocity ($Vave$) and the cross-sectional area (A) [35].

$$Q = AV_{ave} \quad (9)$$

Water velocity can be measured with the "Float method". A series floats, such as a mountain dew bottle that are equally weight at 300 grams, are timed as they travel over a measured length of the stream (7 meters at this case). The outcomes are averaged to determine the flow velocity. By multiplying the cross-sectional area by the average and corrected flow velocity, the volume flow rate can be estimated.

The Degree of inclination can be calculated using:

$$D_{rad} = \arcsin\left(\frac{a}{c}\right) \quad (10)$$

Where:

a = length of the Archimedes Screw Turbine

c = head (represented as c in this case since its trigonometry)

To get the angle we must convert it Radians to Degrees. We can calculate it using:

$$D_{deg} = D_{rad} \times \frac{180}{\pi} \tag{11}$$

The hydraulic potential power supplied by the water is [35]:

$$P_{hyd.pot.} = \rho gQh \left(\frac{kg - m^2}{s^3}\right) \tag{12}$$

Where:

ρ = water density $(1000 \frac{kg}{m^3})$

g = gravitation acceleration $(9.81 \frac{m}{s^2})$

h = height difference between inlet water level and the outlet water level (m)

The hydraulic kinematic power supplied by the water is [35]:

$$P_{hyd.kin.} = \rho g h_c A v \left(\frac{kg - m^2}{s^3}\right) \tag{13}$$

where:

ρ = water density $(1000 \frac{kg}{m^3})$

g = gravitation acceleration $(9.81 \frac{m}{s^2})$

hc = the vertical distance from the fluid surface to the centroid of the area (m)

A = area (m^3) (radius of turbine blade)

v = water velocity (m^3)

The formula for estimating the torque of the screw turbine is provided below [35]:

$$\boldsymbol{T = \rho g h_c A r \ (Nm)} \tag{14}$$

where:

ρ = water density $(1000 \frac{kg}{m^3})$

g = gravitation acceleration $(9.81 \frac{m}{s^2})$

hc = the vertical distance from the fluid surface to the centroid of the area (m)

A = area (m^3) (radius of turbine

r = radius (m)

The mechanical power supplied by the hydraulic power is given below:

$$P_{mech} = \frac{2\pi NT}{60} (W) \tag{15}$$

where:

N = rotational speed at load (RPM)

T = torque (Nm)

The mechanical efficiency of the Archimedes Screw Turbine is calculated by:

$$\eta_{mech} = \left(\frac{P_{out(mech)}}{P_{in(hyd)}}\right)(100\%) \tag{16}$$

The electrical power produced can be calculated by:

$$P_{elec} = VI\ (W) \tag{17}$$

The electrical efficiency of the Archimedes Screw Turbine is calculated by:

$$\eta_{elec} = \left(\frac{P_{out(elec)}}{P_{in(mech)}}\right)(100\%) \tag{18}$$

The overall efficiency of the Archimedes Screw Turbine is calculated by:

$$\eta_{overall} = \left(\frac{P_{out(elec)}}{P_{in(hyd)}}\right)(100\%) \tag{19}$$

D. Vicinity Map

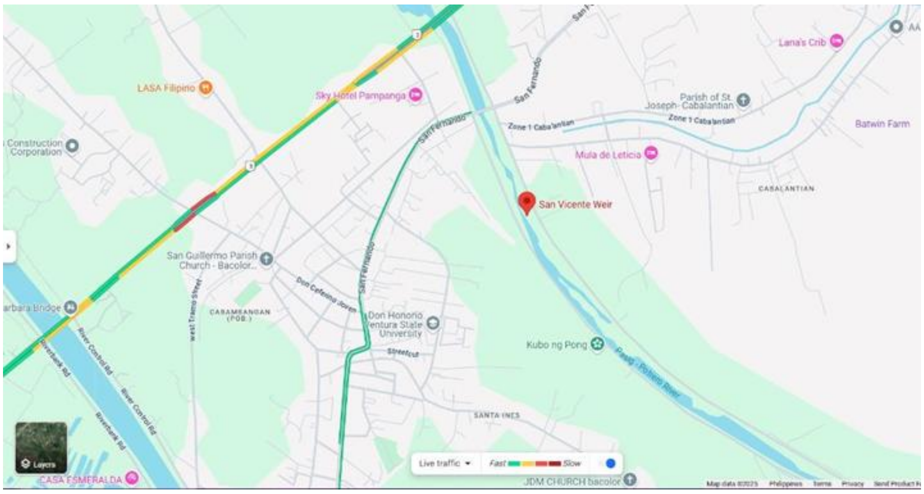

Fig 8. Vicinity Map of Project Area

Figure 8 shows in Barangay Cabalantian, Bacolor, Pampanga, the Cabalantian Weir to San Vicente is an essential piece of infrastructure intended to control water flow for agriculture and flood prevention in the area. Although the exact specifications of the weir's construction and capacity are not made public, its existence highlights the significance of water management in a region that has a history of floods and lahar flows, especially after the 1991 Mount Pinatubo eruption.

IV. Results and Discussion

A. Hydrodynamic and Electrical Performance Parameters of the Archimedes Screw Turbine

PARAMETER	DAY 1	DAY 2	DAY 3
DISTANCE (M)	7 m	7 m	7 m
TIME (S)	12.22, 8.60, 14.25, 11.86, 10.69	11.75, 10.06, 8.46, 8.11, 9.95	5.27, 5.09, 5.03, 4.55, 6.16
WATER VELOCITY (M/S)	0.62463 (avg)	0.73699 (avg)	1.35390 (avg)
AREA (M²)	0.06927	0.06927	0.06927
FLOW RATE (M³/S)	0.04327	0.05105	0.09379
WATER HEAD (M)	0.07	0.07	0.07

POTENTIAL POWER (W)	27.59	32.55	59.80
HYDRAULIC (KINEMATIC) POWER (W)	63.67	75.12	138.01
SPEED (RPM)	40	47	69
TORQUE (NM)	4.57	4.57	4.57
MECHANICAL POWER (W)	19.13	22.48	33.00
MECHANICAL EFFICIENCY (%)	30.04	29.92	23.91
VOLTAGE (V)	11.9	11.92	11.97
CURRENT (A)	1.3	1.33	1.5
ELECTRICAL POWER (W)	15.47	15.85	17.96
ELECTRICAL EFFICIENCY (%)	56.07	48.70	30.02
OVERALL EFFICIENCY (%)	80.87	70.54	54.41

In the table, the "Time (s)" values listed under Day 1, Day 2, and Day 3 represent the measured times it took for a floating method to travel a known distance, in this case, 7 meters downstream in the water channel. This measurement is part of the float method, which is a simple way to estimate water velocity. Based on the data presented in Table 1.0, the performance of the Archimedes Screw Turbine from Day 1 to Day 3 demonstrates an increase in energy input but a noticeable decline in efficiency. As shown in the table, the water flow rate increased significantly due to heavy rainfall from 0.04327 m^3/s on Day 1 to 0.09379 m^3/s on Day 3 resulting in a rise in hydraulic power from 63.67 W to 138.01 W. While the mechanical power output also improved (from 19.13 W to 33.00 W), the table indicates that mechanical efficiency dropped from 30.04% to 23.91%. This suggests that the system had difficulty converting the increased hydraulic energy into mechanical motion efficiently, likely due to added friction or inefficiencies at higher rotational speeds. The electrical power output, as seen in the table, showed a modest increase, yet electrical efficiency declined sharply from 56.07% on Day 1 to 30.02% on Day 3, possibly due to generator overload or losses in the conversion system. Overall, the table highlights a downward trend in total system efficiency from 80.87% to 54.41%, which suggests that while the turbine benefits from increased water flow in terms of power generation, its design is more suited to low-flow, low-head conditions and becomes less efficient as input energy rises.

B. Generator Performance Testing

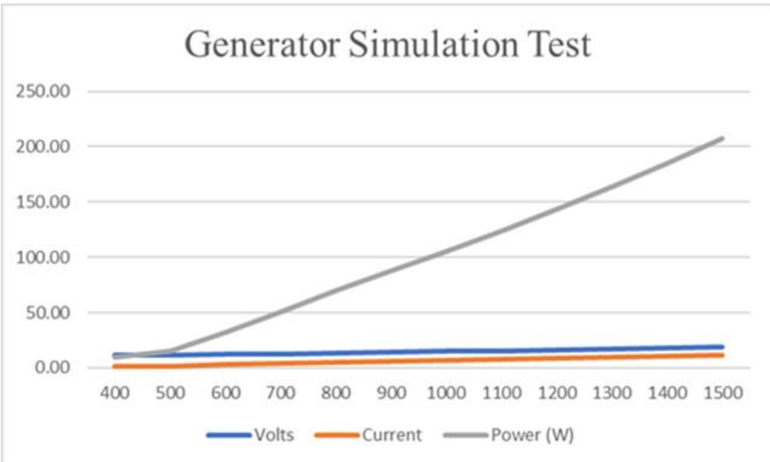

Fig. Generator Simulation Test @ 3 degrees of inclination

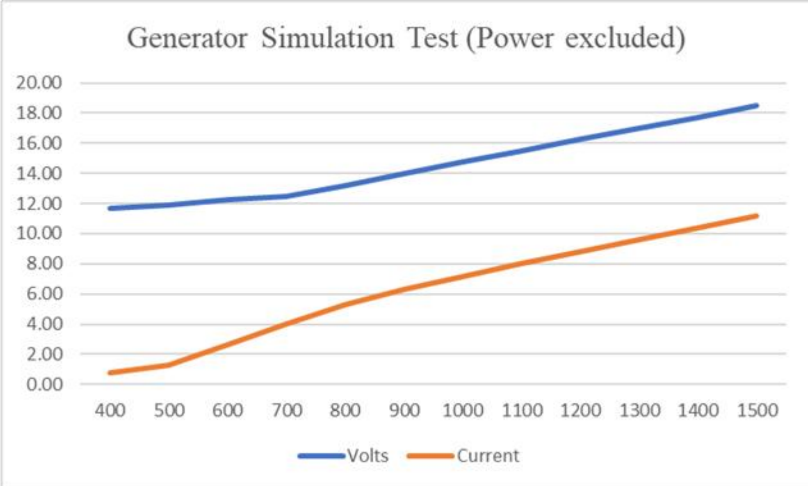

Fig. Generator Simulation Test (Power excluded) @ 3 degrees of inclination

The table above presents the electrical output of the generator across a range of rotational speeds from 400 to 1500 RPM. It demonstrates a clear positive correlation between generator RPM and electrical output in terms of voltage, current, and power. As the RPM increases, both voltage and current rise, resulting in a significant increase in overall power output. At 1200 RPM, the generator produces 16.84 volts and 8.82 amps, delivering 143.24 watts— well above the target—demonstrating its capability to power a broader range of electrical loads with a reliable margin. The highest recorded output occurs at 1500 RPM, where the generator reaches 18.48 volts and 11.20 amps, yielding a total power output of 206.98 watts. This reflects the generator's potential for supplying multiple or higher-wattage devices simultaneously, provided adequate mechanical input.

C. Conclusion

The design and implementation of the Archimedes Screw Turbine (AST) at Cabalantian Weir in Bacolor, Pampanga, have demonstrated the feasibility of utilizing micro-hydropower technology for localized, renewable energy production—specifically for footbridge illumination in a rural setting. Through theoretical modeling, prototype construction, and field testing conducted over three days, the project evaluated the turbine's performance under ultralow-head conditions and varying water flow rates. On Day 1, with an average water velocity of 0.04327 m/s and a water head of 0.07 meters, the system achieved a hydraulic potential power output of 63.67 W. The turbine operated at 40 RPM, generating 19.13 W of mechanical power with a mechanical efficiency of 30.04%. The generator then produced 15.47 W of electrical power at 11.9 V and 1.3 A, resulting in an electrical efficiency of 56.07% and a combined overall efficiency of 80.87%. These values established the baseline performance of the AST in minimal flow conditions. On Day 2, with the same head and velocity but slightly improved flow conditions, the turbine operated at 47 RPM, producing 22.48 W of mechanical power, yet its mechanical efficiency dropped slightly to 29.92%. The generator output reached 15.85 W at 11.92 V and 1.33 A, with an electrical efficiency of 48.70% and a slightly lower overall efficiency of 70.54%. These results suggested energy loss potentially due to mechanical friction, gear misalignment, or turbulence within the screw housing. Day 3 recorded the most significant changes, as the aftermath of heavy rainfall substantially increased the water flow. The water flow rate surged to 0.9379 m³/s, and the 39 | P a g e hydraulic power jumped to 59.80 W (potential) and

138.01 W (kinematic). The turbine operated at 69 RPM, producing 33.00 W of mechanical power, but surprisingly, mechanical efficiency dropped to 23.91%, possibly due to flow instability or over-speeding. Despite that, electrical performance improved with 17.96 W of electrical output at 11.97 V and 1.5 A, achieving an electrical efficiency of 30.02%, but the overall system efficiency dropped to just 54.41%. This sharp decline in efficiency despite higher power input suggests that the system is not yet optimized for handling increased flow rates. In conclusion, this project successfully validates the concept of using an Archimedes Screw Turbine for micro-hydropower generation in the Philippines. While further optimization is needed to meet real-time power demands, the system presents a scalable, cost-effective, and sustainable alternative for rural electrification and infrastructure enhancement. It also provides a valuable framework for future academic, engineering, and community-led energy initiatives focused on renewable energy integration at the grassroots level.

D. Recommendation

Enhancing Mechanical Performance Reduce Friction Losses: Optimized lubrication to decrease mechanical resistance. Regular Inspection and Cleaning Check for debris accumulation: Remove leaves, sediments, or floating objects that may obstruct water flow. Inspect the screw housing: Ensure no foreign materials are trapped within the turbine that could affect rotation. Clean turbine blades and shaft: Prevent algae buildup or sediment deposits that may reduce mechanical efficiency.

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