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Implementation of Pico Hydro Turbine (PHT) System Integrated with IoT Technology in Oman's Falaj Channel

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ABSTRACT:

The increasing need for sustainable energy solutions has paved the way for innovative approaches to harness renewable energy sources. This research work focuses on the implementation of a Pico Hydro Turbine (PHT) system integrated with Internet of Things (IoT) technology within the traditional Falaj irrigation channels of Oman. The PHT system utilizes a 500W/24V AC generator to convert the potential energy of flowing water into electrical energy, which can be monitored and analysed remotely. The project aims to demonstrate the feasibility of utilizing small-scale hydroelectric systems in regions with limited water flow, leveraging IoT technology to enhance efficiency and operational transparency. The AC voltage generated by the turbine is measured using an Arduino R4 Wi-Fi equipped with an AC voltage sensor module. Then this generated voltage is converted into DC regulated voltage using AC-DC regulator. Data is transmitted in real-time to a cloud platform, ThingSpeak, enabling remote monitoring and data visualization. The study addresses key aspects such as system design, sensor calibration, data acquisition, and IoT integration. Emphasis is placed on ensuring reliability and safety in voltage measurement, especially given the variable nature of water flow in Falaj channels. The solution provides insights into the operational performance of the PHT system while promoting sustainable energy practices within local communities. The results highlight the potential of PHT systems as a cost-effective and eco-friendly energy solution in similar settings worldwide.

***Keywords**:* Oman's Falaj Channels, PHT System, Sensors, Arduino R4 Wi-Fi, ThingSpeak

I. INTRODUCTION

Owing to a combination of population growth, a desire for higher living standards, and government policy, green energy sources are more common than ever. For the lives of people in rural and metropolitan areas to improve, for health care and education to advance, and for local economies to expand, dependable access to electricity is a basic prerequisite. About 80% of the population, who comprise most of this group, lives in rural areas and has little chance of soon having access to electricity. Despite population growth, the International Energy Agency (IEA) projects that by 2030, the number of people without electricity will stay unchanged [1]. In 2050, renewable energy use will be at its peak, according to an IEA study is shown in Figure 1.

Oman also continues to use public-private partnerships (PPPs) to develop power projects and is expected to add around 2,200 MW of additional renewable capacity by 2027, reaching a total of 3.4 GW of renewable energy[2].The world tends to increase the requirement of renewable sources. Solar energy, wind energy, and hydropower clarify as a sustainable and alternative solution.

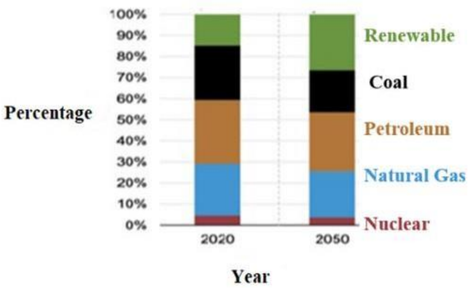

Figure 1: Primary Energy Consumption by Sources (Source: IEA)

Hydraulic energy plays a wide role to cover energy demand and 16% of word energy is done by hydropower [3], [4]. Water potential energy can be produced on the mountain, where springs are found and where raindrops fall from the heavens. Oman has a wealth of natural resources that can be used as sources of energy to sustain life because it is an archipelago and a mountainous region [2]. However, because it is environmentally friendly, New and Renewable Energy (NRE) emerges as the best alternative solution as natural resources become less abundant over time and must plan for this one [3].

As per the Quran explanation around the cycle of water which communicates for renewable (Quran 13:17), "*He sends rain from the sky, and valleys stream in understanding with their capacity. A rising froth is carried by the deluge. A foam comparable to it is created from the [ore] that they warm within the fire in arrange to create enhancements and devices. Allah hence gives an outline of what is genuine and unfaithful. The foam is disposed of and vanishes, though the things that offer assistance individuals remain on the planet. Allah gives occurrences in this manner*".

Hydropower plants come in a variety of sizes, from modest ventures making electricity for a single house or village to massive undertakings. Based on the installation and consumption capacity, hydro power plants can be classified into many types [6]. Generally, the following classifications are the most accepted based on the power generation capacity range (Table1).

Table 1: Hydro Power Plant Types and Capacity

Type	Capacity
Very Large	>100 MW
Large	25 -100 MW
Medium	1 – 25 MW
Small	100 KW – 1 MW
Mini	5 KW – 100 KW
Micro	1 KW – 5 KW
Pico	Less than 1 KW

In Oman, there are more good Falaj units with the best water flow level in all seasons. Figure 2 depicts a few notable and significant Falaj units in Oman, and table 2 lists their specifications [7], [8], [9]. Most of the Falaj channel are located in Ad Dakhliyah region of Oman.

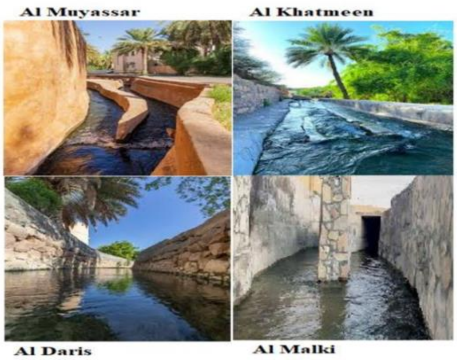

Figure 2: Famous Falaj channels in Oman

Table 2: Falaj Channel's specification

S.No	Name of the Falaj	Governorate	Length (m)
1	Al Muyassar	Al Rustaq	5783
2	Al Malki	Al Dakhiliya	14875
3	Al Khatmeen	Al Dakhiliya	2450
4	Daris	Al Dakhiliya	7990

II. OBJECTIVE AND SCOPE OF THE RESEARCH WORK:

The purpose of this project is to evaluate the viability of installing hydropower in Oman's Falaj channels. The following are the goals of this project work:

- To design and implement Pico Hydro Turbine (PHT) setup in the Falaj channels in order to produce electricity for domestic (Low Power consumption) / streetlights usages.
- To create a sustainable, ecologically sound alternative for producing renewable energy (contribute to a green world).
- To integrate an Arduino based measuring system of Generated voltage (AC), DC voltage, and Turbine speed with IoT Cloud (ThingSpeak) platform.

In the Gulf nations, Oman has just as many good Falaj units that can be used as a source of clean electricity. As a result, Pico and Micro hydropower schemes [10], [11], [12] are suitable to generate the power in Oman. The following subjects will be listed as having the greatest importance to Oman if the PHPP scheme would be used.

- From an economic perspective, it is a dependable utility that brings in money to protect other water flows. It encourages and energizes regional growth.
- In accordance with social factors, to enhance access to the region's resources and living circumstances.

III. METHODOLOGY AND COMPONENTS:

In this research proposal, electrical electricity is being used intelligently (sensors) and to be integrated with IoT platform [13]. The amount of electrical power that can be produced and saved depends on the canal's water flow. In order to increase electrical output, the PHT system is intended to take into account the depth of the canal and the water flow rate. The generated voltage, water flow rate and turbine speed can be measured with the help of Arduino R4 Wi-Fi unit and data can be analyzed through Thingspeak platform.

The following steps can outlined for this research work's methodology:

- System Design and Architecture
- Sensor Selection and Calibration
- Arduino Programming and Data Acquisition
- IoT Integration (ThingSpeak)
- Testing and Validation
- Data Analysis and Optimization

a. PHT Design:

For this project work, a turbine with spiral blade set up is the primary component. This one was designed from steel material for the turbine in order to produce more output power with strong mechanical support [14]. Using Galvanized Iron (GI) for spiral blades in a water turbine can be a practical choice due to its corrosion resistance, strength, and cost-effectiveness.

For Micro or Pico level turbine system, the following calculation will be considered [15], [16].

- Shaft Diameter: 1.5 inches (50.8 mm)
- Shaft Length: 0.7 meters (700 mm)
- Blade Length (Radial Extent): 1.5 to 2.5 times the shaft diameter (3 to 5 inches or 76.2 to 127 mm)
- Blade Width (Chord Length): 0.2 to 0.4 times the blade length (15.2 to 40.6 mm)

For this research work, the PHT system has designed as follows:

- Turbine length : 0.7 m
- Turbine Diameter: 1.5 inches (0.04 m)
- Spiral blade width : 2 inches
- Spiral blade length : 5 inches
- No. of blades : 6 (Based on the length of the shaft and water flow level)

The power can be calculated by,

$$P = \eta \cdot \rho \cdot g \cdot Q \cdot H \quad \text{------------------------------(1)}$$

Where:

η = Efficiency (0.5 to 0.9)

ρ = Density of water (approximately 1000 kg/m³)

g = Gravitational acceleration (9.81 m/s²)

Q = Flow rate (m³/s)

H = Head (m)

Figure 3 shows the proposed design structure of entire PHT system. As per the design structure, the total weight of the entire PHT unit will be 12 Kg (Approximately).

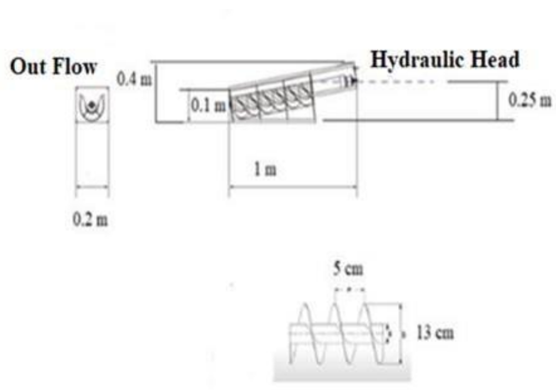

Figure 3: Turbine and Blade Design

b. Generator

In our project, 500 W/24V AC Generator has been taken for electrical power output. The entire PHT system is shown in Figure 4. Generally, low speed Generator can be used for renewable energy projects. This Generator also has low speed capacity (500 rpm).

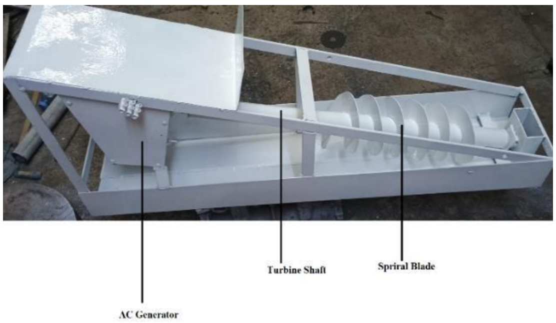

Figure 4: PHT Model Set up

c. Sensors and other devices:

For measuring and analysing the PHT system parameters, the AC Voltage sensor (0-30V), DC Voltage sensor (0-25V), and Optocoupler RPM sensor are used in this research work. In AC load side, the lamp(s) can be controlled by photocell arrangement in this project work. A 10V AC to 12V DC regulator is used for the charge controller. From the charge controller, the 12V DC is given to the battery and is connected to the inverter (12V DC – 240V AC). The AC and DC loads can be used in this system. Arduino R4 Wi-Fi unit is used for IoT integration. Figure 5 shows the sensors and the few important devices which are used in this project work.

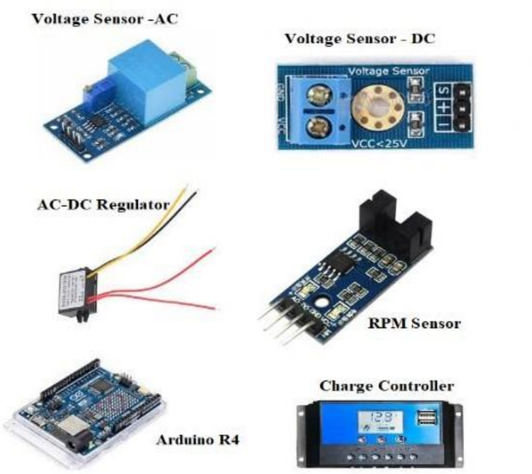

Figure 5: Sensors and Other Devices

The optocoupler speed sensor is connected with Generator shaft point in order to measure the speed of the turbine. The arrangement is shown in Figure 6.

Figure 6: Speed Sensor set up

IV. PROPOSED SYSTEM:

This research work was carried out in Al Khatmeen Falaj Channel-Oman. The water flow rate for this channel (Figure 7) is approximately 370 liters per second during rain fall season [8], [9]. This Falaj is part of a traditional irrigation system and is significant for both its historical and hydrological importance.

It plays a crucial role in providing water for domestic and agricultural use in the area of Birkat Al Mouz (Nizwa), Oman.

Figure 7: Al Khatmeen Falaj Channel

This research work's operation flow can be viewed from the block diagram as shown in Figure 8. The generated power can be utilized for AC load in case of street light or domestic purpose (Low power consumption) and DC load utilization like mobile charging or light work.

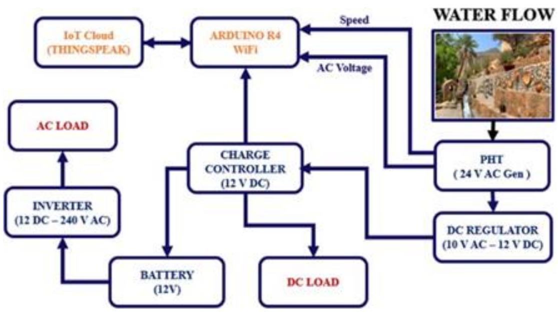

Figure 8: Block Diagram – Proposed System

a. Operation:

According to the block diagram of this research work, the turbine will rotate based on the water flow in the Falaj channel. The generator will be produced AC voltage 10-12V (Approximately). Then this voltage will be rectified into 12V DC with help of regulator and it will connect to the charge controller for safe and stabilized output voltage for the DC load and store to the battery (12V). From the battery output, the inverter will give 240V AC for AC load (Domestic low power utilization) or street lighting system. The battery will give back up for 24 hours for inverter operation with respect to 1 or 2 street light(s) (low power consumption). In this project, 10W Street light could be controlled by photocell set up in order to save energy for 6 Hours. The voltage AC and DC will be measured with help of voltage sensors and the turbine speed also will be measures by Optocoupler RPM sensor. These reading will be interfaced with Arduino R4 Wi-Fi unit and IoT-ThingSpeak platform. The output curves can be analyzed from it easily.

b. Implementation Set up:

As per the design, the prototype model of PHT system is assembled with Arduino – IoT set up as shown in Figure 9.The LCD display also provided for the parameter viewing during the operation time.

Figure 9: PHT Prototype with Arduino – IoT Set up

c. Arduino – IoT Interfacing:

The following steps is carried out for the implementation of PHT set up with Arduino and IoT interface system for this research work as shown in Figure 10.

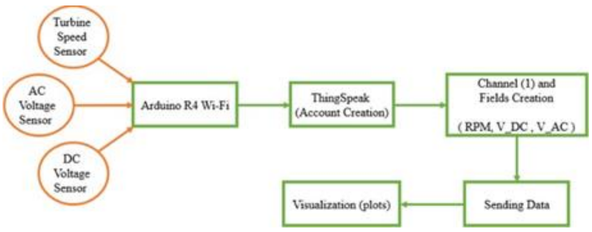

Figure 10: Arduino – ThingSpeak Integration

V.RESULT:

After assembled the PHT system, the entire unit was tested with Al Khatmeen Falaj channel. This is one if the traditional Falaj Channels in Oman. This Falaj is recognized as a UNESCO World Heritage site and plays a crucial role in distributing water for agricultural and domestic purposes.

a. Water Flow Rate:

The water flow rate in Al-Khatmeen Falaj varies seasonally, influenced by factors such as rainfall, groundwater recharge, and agricultural demand. Typically, the flow rate is higher during and after the rainy season. For this research work, the water flow was monitored and measured using Area- Velocity manual method during summer season (July 24), intermediate season (November 24) and winter season (Dec 24) shown in table 3.

Table 3: Water Flow Rate Data From Different Months

Date	Canal Width (cm)	Canal Depth (cm)	Velocity (m/s)	Flow Rate (L/s)
16/09/2024	96	48	0.817	376.47
24/09/2024	96	54	0.702	363.92
16/10/2024	96	35	0.829	278.54
24/10/2024	96	37	0.529	187.90
03/11/2024	96	32	0.488	149.91
20/11/2024	96	35	0.493	165.65
18/12/2024	96	33	0.461	146.05
25/12/2024	96	33	0.42	133.06
04/01/2025	96	33	0.42	133.06

Based on the data, the water flow rate has analysed for this research work from the different season as shown in Figure 11.

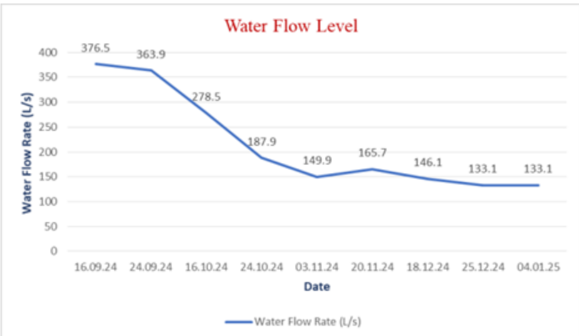

Figure 11: Water Flow Rate during different seasons

b. Generator Output:

Based on the water flow rate, the Ac generator is produced the output voltage. The PHT System has produced 10 - 17 V AC from different months with different water flow rate. The average 12 V AC voltage was observed (Figure 12) during the intermediate season (November - December months) from this Falaj channel.

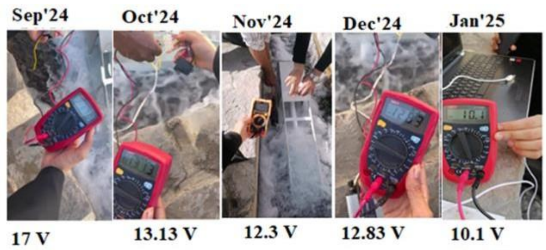

Figure 12: Generator Output Voltage Measurement

c. Overall performance output:

After the design process, the PHT system was tested in Al Khatmeen Falaj channel during winter season (January'25). Many trial tests were conducted and monitored the parameters during morning and evening times during the December month. The following results (Figure 13-a & 13-b) were observed and recorded from the IoT platform at night time (7.00 PM) in the Al Khatmeen Falaj on 4th January 2025 with water flow rate of 133 L /s. The loads (AC and DC) were operated smoothly based on the generated output voltage (Figure 14).

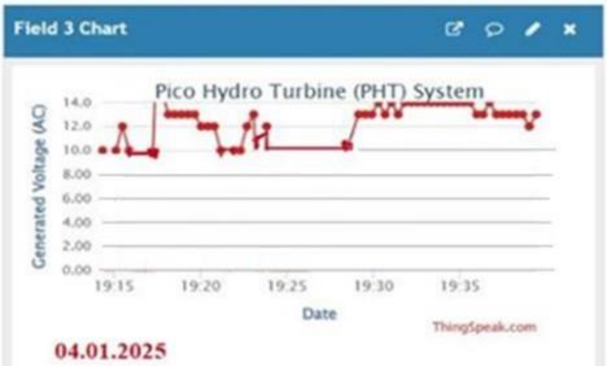

Figure 13-a: Generated AC Voltage

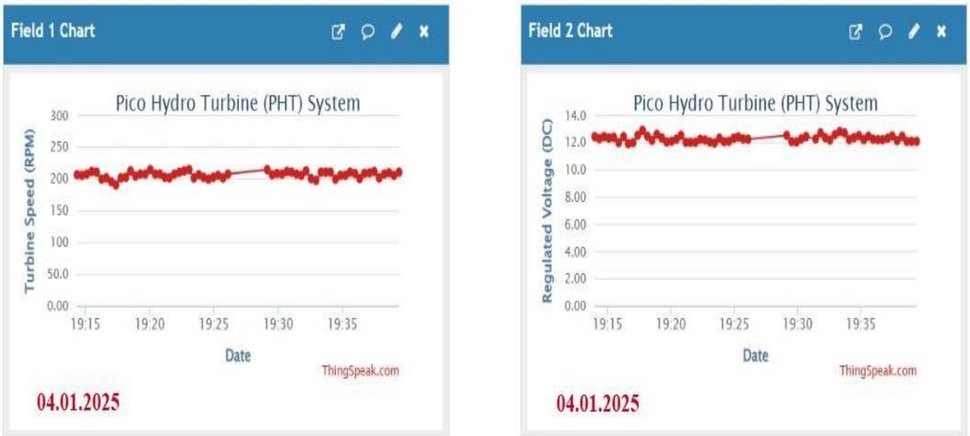

Figure 13-b: Turbine's Speed and DC Voltage Performance Curve

Figure 14: PHT Performance View

VI. CONCLUSION AND FUTURE WORK:

a. Conclusion:

The implementation of a Pico Hydro Turbine (PHT) System integrated with IoT technology in Oman's Falaj channels demonstrates significant potential for generating sustainable energy while preserving traditional irrigation systems. This research work focused on testing the system in an only one Falaj Channel (Al Khatmeen) to evaluate its feasibility, energy generation capacity, and integration with IoT for real-time monitoring. The key conclusions from this work include:

- **Feasibility and Efficiency**: The PHT system was successfully deployed in the selected Falaj channel, highlighting the compatibility of the technology with the existing water flow dynamics.

- **IoT Integration**: The integration of IoT technology allowed real-time monitoring of system performance, including energy output, water flow rate, and operational conditions, ensuring efficient management and maintenance.
- **Sustainability**: The system proved to be an eco-friendly and cost-effective solution for harnessing renewable energy, offering a promising alternative for rural communities dependent on traditional water channels.

b. Future Work

To enhance the applicability and scalability of the system, the following areas are recommended for future research:

- **Testing on Multiple Falaj Channels**: Extend the study to include Falaj channels of varying flow rates, channel sizes, and geographical locations across Oman to evaluate system adaptability and performance under different conditions.
- **Optimization of Turbine Design**: Investigate and develop customized turbine designs to maximize energy generation efficiency while minimizing impact on the Falaj's water flow and traditional usage.
- **Advanced IoT Integration**: Incorporate advanced IoT features such as predictive maintenance algorithms, enhanced data analytics, and integration with renewable energy storage systems to improve reliability and scalability.
- **Increasing Battery and Regulator Current Capacity:** Improving battery and regulator capacity will enhance the system's reliability, efficiency, and scalability for broader applications. Based on these improvement, more output power and number of Lamps can be used in Street light for 8 Hours.

- **Cost-Benefit Analysis**: Perform a comprehensive economic analysis, including the cost of installation, maintenance, and energy savings, to assess the long-term viability of the system for widespread deployment.

- **Hybrid Energy Systems**: Explore the integration of the PHT system with other renewable energy sources, such as solar panels, to create hybrid systems that maximize energy generation in rural areas.

Conflict of Interest:

No Conflict of interest with any organization.

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