Design and Implementation of a Hydro-Energetic System in Water Distribution Networks

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Abstract This thesis details the design and implementation of a prototype for hydro-energetic use in water distribution networks. The prototype is composed of two main systems. On one hand, the generation system, which is in charge of transforming the kinetic energy of water into electrical energy using microturbines, charge regulators and batteries. The second one is the drive and telemetry system. It controls whether the generation units turn on or off as well as allowing remote monitoring of electrical parameters such as power, voltage and current of each unit. The device that monitors the generation units is connected to the charge controller through an RS232 interface and enables acquiring the desired electrical parameters to later store them in an Internet of Things platform to visualize them through the Internet.

Keywords Drive and telemetry system · Electrical energy · IoT · Microturbines

1 Introduction

Nowadays, wireless sensor networks (WSNs) with a large number of sensor nodes allow interaction with the physical world, which is why they are widely used in industrial applications and also in monitoring physical and environmental variables

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[1]. Like many technological advances, the WSNs had their origin in military applications. The Sound Surveillance System (SOSUS) was the first WSN application developed by the United States Militia in 1950 to detect and track Soviet submarines [2].

In the WSNs, the sensor nodes are responsible for capturing data and transmitting it over the network. A large amount of captured data and the process of transmission implies a continuous operation of each of the sensors [3]. These are powered by batteries that hardly provide long-term operation and need to be replaced periodically, making constant maintenance of the network nodes necessary [4].

Researchers have explored multiple alternative forms of energy acquisition to power wireless sensor networks such as solar panels, electromagnetic radiation, water or wind flows [5]. That is why the energy harvesting has emerged as a technique that allows extending the lifetime of the sensors by making use of the available energy in the environment to keep the nodes in constant operation within the network [1]. Among many sources of energy, water flow has been used to power WSN nodes [6] using small hydro-generators placed in irrigation systems or water pipes [7, 8].

The use of a TRD microturbine, whose operation depends on a control system, has been proposed to take advantage of water flow energy. The amount of energy that microturbines can contribute is directly related to the pressure of the circulating water [9].

The control system associated with the microturbine allows its continuous status observation, this being of great importance to determine if it is supplying enough energy and if its operation is optimal. So, it is convenient to store this information in an Internet of Things (IoT) platform to remotely monitor the system.

In this context, an energy generation system designed and built to power telemetry systems, as well as the control and monitoring system previously mentioned.

2 Methodology

This work aims to develop an autonomous system that uses TRD microturbines in hydraulic installations to power a node of a wireless sensor network that monitors water distribution network variables.

First, the TRD microturbine performance was characterized using a hydraulic bench and a pressure-break tank (generation system) to contrast with the parameters established in the manufacturer's datasheet. From this, it was determined what is the amount of energy generated by the microturbine as a function of the flow rate and the pressure that passes through the pipe.

Then, the energy consumption of the central node of the "SMART WATER NETWORK" project was obtained in each of the processes that it performs (active, reception and transmission of data) to determine the battery that will be used to keep the node active 24 h/day.

Next, the telemetry and drive system of the generation units was designed and built. This system obtains electrical parameters (voltage, current, power) of the microturbines and sends this information to an IoT platform. First, the design was carried out at hardware level, establishing the necessary components to obtain the electrical parameters of the generation units and then the algorithm to be used was developed.

Finally, the generation system and the telemetry and drive system were integrated into the UTPL Hydraulics Laboratory to observe the operation of these two systems as a whole.

3 The Electrical Energy Generation System

3.1 TRD Microturbines Energy Efficiency

Table 1 shows the materials and equipment used in the project:

To characterize the microturbines, it was necessary to use a hydraulic bench. The hydraulic bench was built in the UTPL Hydraulics Laboratory. A diagram of the arrangement of the materials used for characterization within the hydraulic bench is shown in Fig. 1.

In Fig. 1, two instruments for measuring hydraulic parameters are identified: flow sensor and pressure gauge, which are used in order to know the pressure and flow that reaches the turbine. There is also a pump that is responsible for sucking the water located in a tank to push it toward the hydraulic circuit. In addition to this, a load is connected to the turbine generator's output.

Table 1 Equipment and materials

Detail	Quantity
TDR microturbine	5
Smart charger	5
Electrovalve	5
Phoenix inverter	5
12 V Bosch battery	5

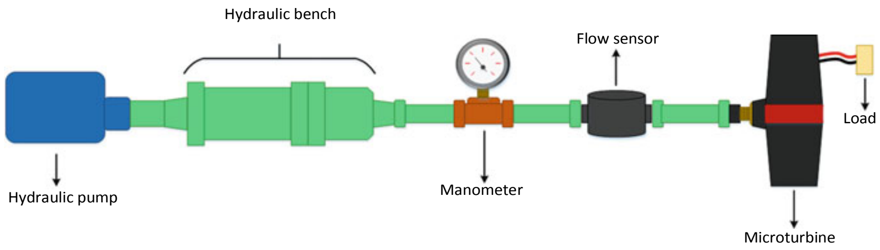

Fig. 1 Microturbines characterization scheme

Table 2 Obtained pressure and flow rate values

Pressure (bar)	Flow (l/min)	Hydraulic power (W)
1	6.98	11.63
1.5	8.23	20.49
2	9.3	30.88
2.5	10.26	42.58
3	11.11	55.33
3.5	12	69.72
4	12.72	84.46
4.5	13.38	99.95
5	14.08	116.86

Considering the characterization made by the manufacturer of microturbines, certain pressure values are taken as a reference to measure: voltage, current and flow rate. Tables 2 and 3 show the results obtained regarding the variables of pressure, flow rate, and power generated by each of the microturbines, respectively.

From the previous results, the performance curve of each microturbine is obtained. Now we contrast the performance curve of each microturbine with the information specified by the manufacturer in the datasheet. The performance curves obtained for the five turbines and the one specified in datasheets from the manufacturer are shown in Fig. 2.

The performance or efficiency of a turbine is defined by the relationship between the input power (Pin) and the output power (Pout). In this case, they are hydraulic power (Pin) and electric power (Pout). Knowing these values from previous results, we have the turbine efficiency at an average of 15.15%; although it exceeds what is specified by the manufacturer that is 10.41%, it is still low determined that the efficiency of a DC generator is between 45 and 50%.

Table 3 Energy generated by the microturbines

Pressure (bar)	Electric Power (W)				
	Turbine #1	Turbine #2	Turbine #3	Turbine #4	Turbine #5
1	1.05	1.13	1.43	1.35	1.18
1.5	2.63	2.38	2.93	3.20	2.66
2	4.42	4.18	5.05	5.30	4.51
2.5	5.64	6.44	7.02	7.93	6.61
3	8.04	8.91	9.32	9.98	8.77
3.5	9.97	10.95	11.70	12.87	11.54
4	12.12	13.61	14.88	15.31	14.02
4.5	14.40	15.57	17.30	17.76	16.37
5	18.03	17.95	17.86	19.89	18.72

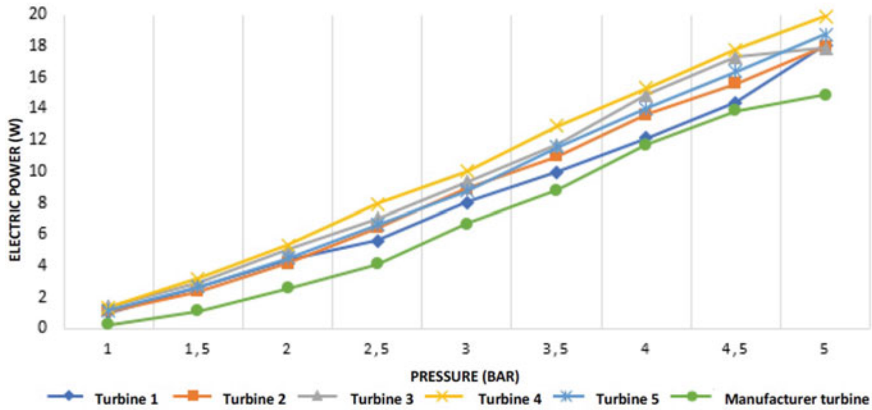

Fig. 2 Microturbines performance curve

3.2 *Integration of Generation Units and Components in the Pressure-Break Tank*

This section describes the implementation of the system, that is, each generation unit (microturbines) is installed, inside a pressure-breaking tank designed. This tank, like the hydraulic bench, is located in the UTPL Hydraulics Laboratory. The materials mentioned in Table 1 are used for the implementation.

The tank is built with galvanized iron sheets 0.9 mm thick. It has a layer of anticorrosive paint that helps it not rust and remain in good condition. The pressure-breaking tank is intended to dissipate energy and decrease hydrostatic pressure [10].

Figure 3 shows the energy generation system which consists of the following parts:

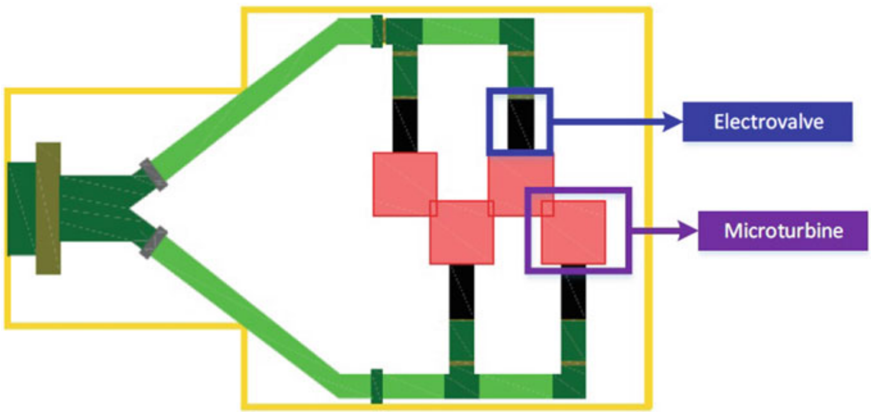

Fig. 3 Arrangement of turbines and components in the pressure-breaking tank

- 4 microturbines,
- 4 electro valves,
- 4 smart chargers,
- 4 batteries and,
- 4 inverters.

The smart chargers are located in a DIN rail that is attached to the side of the tank as well as the batteries. Each battery has an inverter connected to it. Additionally, the tank has iron hooks welded inside to support the weight of the turbines and keep the pipes fixed.

4 Drive and Telemetry System

This section shows the design and implementation of the drive and telemetry system of the generation units (GUs). This system must fulfill two objectives. First, to obtain electrical parameters such as voltage, current and power of each GU automatically and send this data to an IoT platform. And second is to guarantee a 24-hour functional generation system that maintains and adequates rest margin for the GUs.

The electrical parameters are provided by the smart charger through an RS-232 interface and to establish communication with it is necessary to login with user and password credentials. For the automatization, a relay board is used to activate and deactivate the GUs using a microcontroller. A general scheme of the whole system is shown in Fig. 4.

4.1 System Hardware and Connection

The drive and telemetry system is physically integrated by the following devices: Waspmote Pro V1.2 data acquisition board, Atlas Scientific 8:1 UART port multiplexer, RS-232 to TTL converter, a communication module, RJ11 connectors and a 4 relay board.

4.2 PCB Design

Figure 5 shows the PCB design composed on three MAX-232 integrated circuits, a 5 V regulation source, sockets for the connection between the MAX232 and the multiplexer and sockets for the connection between the Waspmote Pro card and the multiplexer.

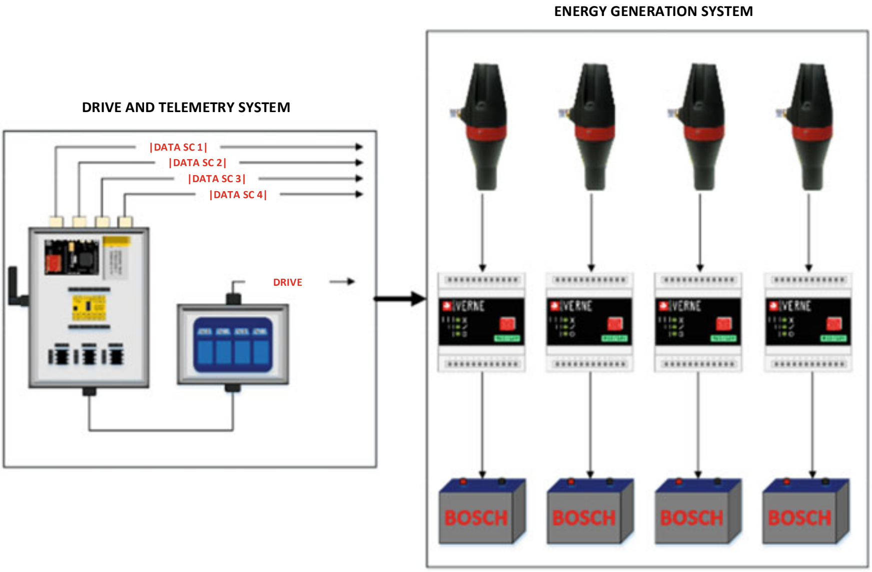

Fig. 4 Complete system general diagram

4.3 System Algorithm

Once the components have been established, an algorithm is developed to make use of this hardware. The proposed algorithm activates the GUs in pairs; this way the pressure in the hydraulic system remains almost constant and guarantees 24 h/day energy generation. Also, it makes the login in each smart charger in order to obtain the electrical parameters and sends this to the cloud.

As mentioned before, the GUs work in pairs, but the operation time is limited to 30 min for each pair. This allows a great rest margin for the GUs (required by the smart charger). When a transition is going to occur, the algorithm establishes a 15-second delay which is considered fundamental from the hydraulic point of view to avoid any damage to the turbines or pipeline. This means that the hydraulic system will not suffer pressure transients that at some point can lead to its collapse.

5 Results

5.1 Energy Generation System Implementation

Once the generation units are placed together with their components in the tank, the wiring is carried out, based on the user manual provided by the manufacturer [11]. As showed in Fig. 6 and 7, the microturbines are arranged inside the tank. PVC gutters

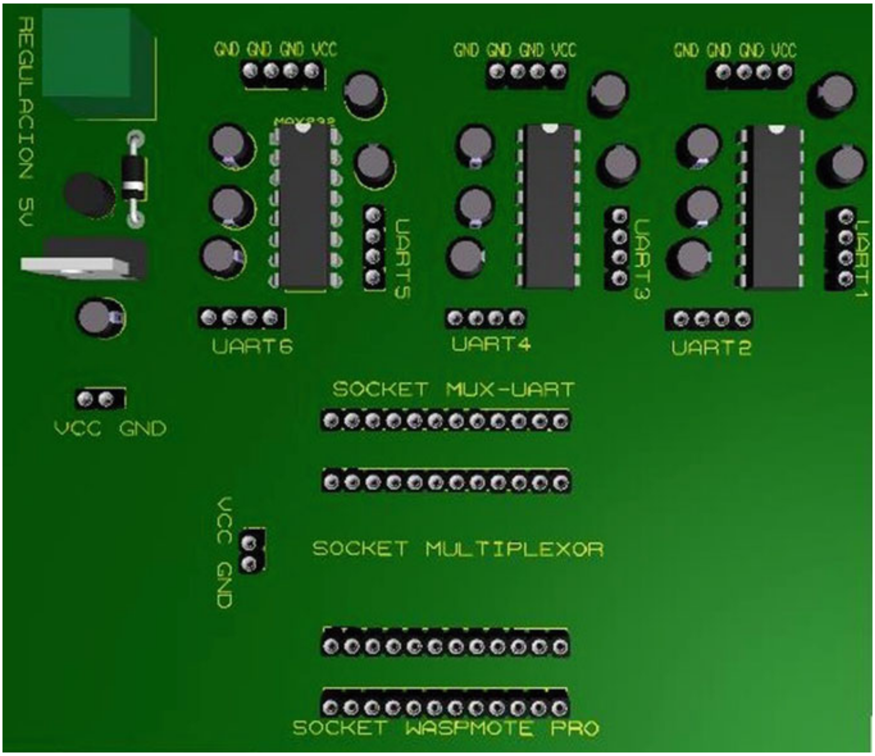

Fig. 5 PCB design for hardware connection

are used in order to properly organize wiring and improve aesthetics. Switches are also used to turn and off the smart chargers.

5.2 Power of the Installed System

For this analysis, the data obtained in Table 3 are used. It is worth mentioning that the data taken into consideration are those corresponding to 3 and 3.6 bar pressure has given that the smart charger works in that range. Table 4 shows the average power generated by the turbines that are part of the generation system.

The installed power of the system is obtained by adding the power generated by each of the turbines; therefore, an installed power of 42.51 W. is obtained. Each of the generation units operates 12 h a day and in groups of two, therefore, the entire system works 24 h a day. Taking this information into account, the energy generated by the entire system is 510.12 Wh/day.

Fig. 6 Generation system installed in the pressure-breaking tank at UTPL Hydraulics Laboratory, top view

5.3 Hardware Integration and Software Implementation

Figure 8 shows the designed PCB, the multiplexer and the Waspmote Pro card together with its battery. These devices are grouped inside an airtight box protected from water and dust.

On the other hand, the algorithm was implemented through the Waspmote IDE version 06.04. It consists of several functions that allow fulfilling everything previously stated in the algorithm.

The main result of the implemented code is shown in Fig. 9. Parameters such as voltage, current, power, time of use are considered. All the data obtained is stored within a matrix and it is through the positions that these values occupy in the matrix that the value of each parameter can be obtained.

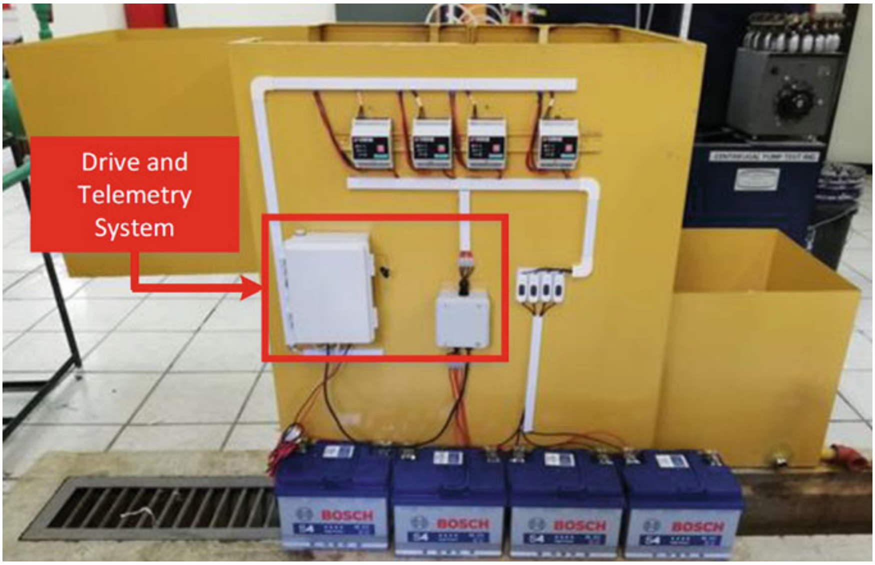

Fig. 7 Generation system installed in the pressure-breaking tank at UTPL Hydraulics Laboratory, side view

Table 4 The average power generated by each GU

Detail	Power (W)
GU #1	10.15
GU #2	10.51
GU #3	10.43
GU #4	11.42

5.4 Pressure Measurement in GU Transition

The generation system consists of 4 GU which work in pairs. That is, once the working units have reached 30 min of operation, they are turned off so that the other pair of GUs starts to work. When a UG is switched on and off, a pressure transient is produced in the hydraulic system. To avoid any damage to the system, the pressure variation in the on and off process must be as small as possible.

In order to quantify the pressure variation at the time one GU started the transition, the system was monitored with an MLH pressure sensor. The experiment consisted of measuring the instantaneous pressure of the system every 5 seconds to obtain the data while a GU was making a transition.

Figure 10 shows that the pressure ranges from 3 to 3.6 bars, with an average pressure of 3.3 bars, which is within the range allowed by the smart charger. As view in Fig. 10, there are two times when transitions occur (described as t1 and t2) where the pressure value decreases to 2.73 and 2.69 bar, resulting in variations of 0.57 and 0.61 bar of the average system pressure. The implemented algorithm forces these variations to be small in order to avoid any damage to the system.

Fig. 8 Hardware implementation

5.5 Data in an IoT Platform

In this work, the ThingSpeak platform is used. After the drive and telemetry systems obtain the electrical parameters, this is upload to the cloud. In the platform, four channels were created for each GU. In each channel, variables of voltage, current, power, time and state are stored. The write “*APIKEYS*” of each channel was added to the algorithm so the code knows where to send the data.

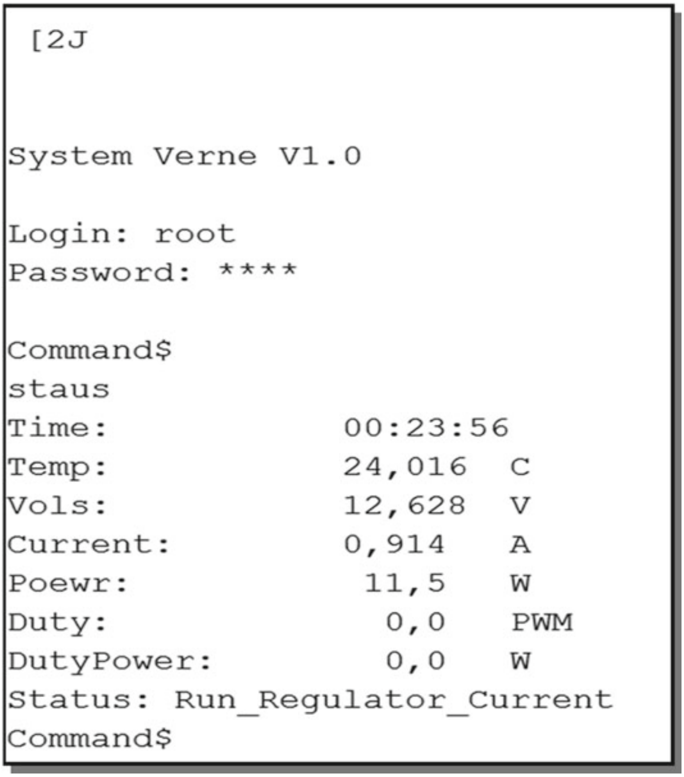

Fig. 9 Smart charger login and electrical parameters

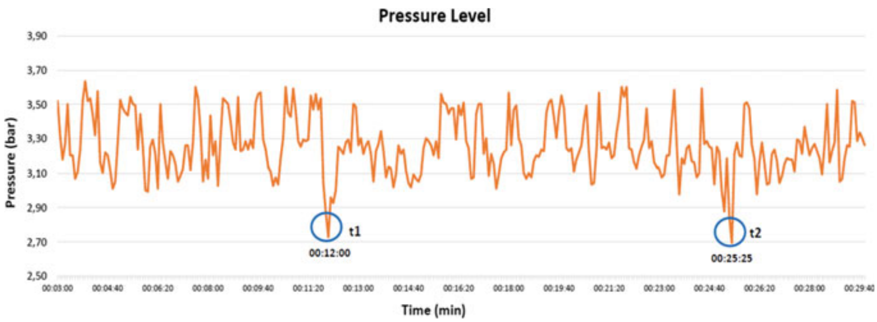

Fig. 10 Pressure variation in GU transitions

6 Conclusions

The implemented system uses the energy accumulated in water distribution lines to generate electricity. The system, which operates twenty-four hours a day, generates 510.12 Wh/day. In addition, the drive and telemetry system allows monitoring the status of the microturbines in real time as well as sending this data to an IoT platform.

In terms of electrical generation, the microturbines generate 10 to 11.5 W in the pressure ranges in which the smart charger works. Although they exceed the generation parameters established by the manufacturer, their energy efficiency, which is 15.15%, is low considering that the efficiency of a DC generator is between 45 and 50%.

The drive and telemetry system implemented allows for a 24-h functional generation system. In addition, thanks to this system, turning on and off the GUs does not produce large pressure variations, thus providing protection to the hydraulic system.

The use of other types of energy in sensor networks and IoT applications, apart from solar energy, makes these systems more robust and independent. For the specific case of the coordinating node, which cannot make use of rest functions due to the role it plays within the network, it is important to guarantee its energy autonomy by using energy generation systems such as the one developed in this paper.

7 Recommendations

VERNE, the manufacturer of the microturbines and smart chargers used in this work, is currently not operating, so there is little availability of information about the devices. It is recommended that for similar developments, the devices used should be from a manufacturer that is active in the market in case of requiring detailed information.

For the energy generation system, it is recommended for field applications to place a bypass to limit the fluid pressure at the system entrance. Also, this is necessary to carry out maintenance on the deployed electronic devices.

The pressure in the system must remain within a set range, and in a laboratory environment, it is easy to monitor and regulate this parameter. However, if deployed, it is recommended to implement an additional control system that constantly measures the pressure in the system to regulate it if necessary. The information obtained may also be available on an IoT platform.

Prior to the construction of the pressure-breaking tank, the design must consider the measures of all the elements to use in the energy generation system. These include microturbines, solenoid valves, pipes, elbows, joints, among others. Otherwise, space, where the generation units are located, will be limited resulting in additional adjustments to the tank.

In the case of deploying the system, protection for batteries and smart chargers must be considered. The batteries should be stored in a place where they are protected from sudden changes in temperature. In addition, this place must have ventilation so that toxic gases are not stored. As for the chargers, they must be protected from rain as recommended by the manufacturer.

If the system is deployed and there is cellular coverage on the deployment area, it is recommended to use the mobile network to send data to the IoT platform. In addition, instead of HTTP, use the MQTT protocol in order to reduce costs.

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