Low Power Hydroelectric Systems (Lphs) To Energize Iot Devices: A Review

Sistemas hidroeléctricos de baja potencia (SHBP) para energizar dispositivos IOT: una revisión

Sistemas hidrelétricos de baixa potência (SHBP) para alimentar dispositivos IOT: uma revisão

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Abstract

Introduction: This paper describes the results of the exploratory research developed by the SciBas investigation group of Francisco José de Caldas Distrital University within the low power-Pico hydraulic Hydroelectric Generation Systems (0,5 Kw to 5Kw) framework, that uses the minimum water reservoirs or Ultra Low Head (ULH) or Very Low Head (VLH) - such as drainage channels – and provides energy to IoT devices or its applications.

Problem: About 80% of the world's population lives in places where energy depends on fossil fuels; thus, it is necessary to generate electric power with renewable sources. Nevertheless, Low Power Generation Systems are an under-researched field, so the applied experiences have not been categorized and documented enough.

Objective: Formulate a baseline to provide a detailed understanding of the structure of Low Power Hydroelectric Systems (LPHS) and establish a perspective for future Colombian context research.

Methodology: Construct conceptualizations, categorizations and sub-categorizations based on vertebrate diagrams oriented to conceptual maps that show documentary references included between the years 2019 and 2023.

Results: A review of papers related to Hydroelectric Energy Generation was made, of which 30% consisted of research about LPHS and its advantages and disadvantages; 35% about the generators, batteries and converters that complement this kind of system; and, finally, IoT device applications and sensor networks comprise 35% of the investigation.

Conclusion: It was established that, in addition to the fact that LPHS generation is propitious for IoT devices and its applications, the idea of designing and implementing systems that power sensors and devices through clean energy is an advantage over other forms of generation with resources that, although exhaustible, are easily found within the national geography and are therefore viable for their implementation in non-interconnected zones of the electric system.

Originality: This research is made in drainage channels terms, confirming its unprecedented nature; as well as considering energizing of IoT sensors and sensors networks by LPHS.

Limitations: The review is limited to academic records; therefore, a deepening fieldwork is required for local, regional and national experience documentation in order to expand the applied research baseline.

Keywords: Hydroelectricity, Drainage channels, Generators, Turbines, Power, Driving force, Water speed, Stream, Flow.

Resumen

Introducción: el presente artículo describe los resultados de la investigación de tipo exploratorio desarrollada por el grupo de investigación SciBas de la Universidad Distrital Francisco José de Caldas, en el marco de los Sistemas de Generación Hidroeléctrica de baja potencia o Picohidráulicas (de 0,5 Kw a 5Kw) que usan mínimos reservorios de agua o de Ultra o Muy Bajo Cabezal (ULH) o (VLH) - como canales de desagüe- y proporcionan energía para dispositivos IoT o sus aplicaciones.

Problema: cerca del 80% de la población mundial vive en lugares donde dependen energéticamente de combustibles fósiles; por ello, se requiere generar energía eléctrica con fuentes renovables. No obstante, particularmente los sistemas de Generación de Baja Potencia son un campo poco investigado por lo que las experiencias aplicadas no han sido suficientemente categorizadas y documentadas.

Objetivo: formular una línea de base para, además de conocer detalladamente la estructura de los Sistemas Hidroeléctricos de Baja Potencia (SHBP), establecer una perspectiva para investigaciones futuras en el contexto colombiano.

Metodología: construir conceptualizaciones, categorizaciones y sub-categorizaciones desde diagramas vertebrados orientados a mapas conceptuales que arrojan referencias documentales comprendidos entre los años 2019 a 2023.

Resultados: se realizó la revisión de artículos relacionados con Generación de Energía Hidroeléctrica, de los cuales el 30% de ellos mostraron investigaciones, ventajas y desventajas del uso de SHBP; un 35% ilustró sobre generadores, baterías y convertidores que complementan y robustecen un sistema de este tipo; y, finalmente, los antecedentes de aplicación de dispositivos IoT y las redes de sensores ocuparon un 35% de la investigación.

Conclusión: pudo establecerse que, además de que la generación dada por los SHBP es propicia para dispositivos IoT y sus aplicaciones, la idea de diseñar e implementar sistemas que alimenten sensores y dispositivos por medio de energías limpias es una ventaja frente a otras formas de generación con recursos que, aunque agotables, se encuentran con mayor facilidad en la geografía nacional y por tanto viables para implementarlos en zonas no interconectadas del sistema eléctrico.

Originalidad: esta investigación está realizada en términos de canales de desagüe, confirmándose el carácter inédito; así como considerar la energización de sensores y redes de sensores de tipo IoT a través de SHBP.

Limitantes: la revisión se limita a los antecedentes académicos, por lo que se requiere Profundización de trabajos de campo para documentar experiencias locales, regionales y nacionales relacionadas y con ello ampliar la línea de base de investigación aplicada.

Palabras clave: hidroelectricidad, canales de desagüe, generadores, turbinas, potencia, fuerza motriz, velocidad del Agua, corriente, flujo.

Resumo

Introdução: este artigo descreve os resultados da pesquisa exploratória desenvolvida pelo grupo de pesquisa SciBas da Universidade Distrital Francisco José de Caldas, no âmbito de Sistemas de Geração Hidrelétrica de baixa potência ou Pico-hidráulicos (0,5 Kw a 5Kw) que utilizam reservatórios mínimos de água ou Ultra ou Very Low Head (ULH) ou (VLH) - como canais de drenagem - e fornecem energia para dispositivos IoT ou suas aplicações.

Problema: cerca de 80% da população mundial vive em locais onde dependem de combustíveis fósseis para obter energia; Portanto, é necessário gerar energia elétrica com fontes renováveis. No entanto, particularmente os sistemas de baixa geração de energia são um campo pouco investigado, pelo que as experiências aplicadas não foram suficientemente categorizadas e documentadas.

Objetivo: formular uma linha de base para, além de conhecer detalhadamente a estrutura dos Sistemas Hidrelétricos de Baixa Potência (PCH), estabelecer uma perspectiva para pesquisas futuras no contexto colombiano.

Metodologia: construir conceituações, categorizações e subcategorizações a partir de diagramas de vertebrados orientados a mapas conceituais que forneçam referências documentais entre os anos de 2019 a 2023.

Resultados: foi realizada uma revisão de artigos relacionados à Geração Hidrelétrica, dos quais 30% deles apresentaram pesquisas, vantagens e desvantagens do uso de PCH; 35% ilustraram geradores, baterias e conversores que complementam e fortalecem um sistema deste tipo; e, por fim, o histórico de aplicação de dispositivos IoT e redes de sensores ocupou 35% da pesquisa.

Conclusão: constatou-se que, além da geração dada pelas PCHs ser propícia a dispositivos IoT e suas aplicações, a ideia de projetar e implementar sistemas que alimentem sensores e dispositivos por meio de energia limpa é uma vantagem em relação a outras formas de geração. com recursos que, embora esgotáveis, São mais facilmente encontrados na geografia nacional e portanto viáveis para serem implementados em áreas não interligadas do sistema elétrico.

Originalidade: esta investigação é realizada ao nível dos canais de drenagem, confirmando o seu carácter inédito; bem como considerar a energização de sensores e redes de sensores do tipo IoT por meio de SHBP.

Limitações: a revisão é limitada à formação académica, pelo que é necessário um trabalho de campo aprofundado para documentar experiências locais, regionais e nacionais relacionadas e, assim, expandir a base de investigação aplicada.

Palavras-chave: hidroeletricidade, canais de drenagem, geradores, turbinas, potência, força motriz, velocidade da água, corrente, vazão.

1. INTRODUCTION

As humanity has evolved, it has decided to look for different ways to generate electrical energy. This kind of electric generation encompasses a set of differentiated processes by which electricity is produced, or in other words: transform nature's available energies into usable electrical energy, [1].

Compared to the above, it is worth recognizing that around 80% of world's population lives in net importer fossil fuel countries, which involves near to 6.000 million people depending on fossil fuels of other countries' origin, making them vulnerable to energy crises, [1].

On the other hand, all countries have access to as-of-yet unexploited renewable energy sources. The International Renewable Energy Agency (IRENA) has calculated that 90% of the world´s electricity can and should have its origin in renewable energies for year 2050, [2].

As indicated before, the ability to produce electricity is one of most important current concerns of humanity due to high energy consumption and normalizing it to the point of becoming essential in daily home life, industry, and even personal items; however, it depends on a constant and stable electrical energy supply, [1].

And so, in 2021, due mostly to the pandemic, energy production increased by 5,7%; this then normalized back to 2,5%. However, since then it has been increasing again annually. This generation increase was driven by China (+3,7%), India (+9,7%) and United States (+3,2%); with significant increases in Indonesia (+7,9%) and Saudi Arabia (+5,9%). Energy generation increase has been seen in other Asian countries (especially South Korea, Malaysia, Thailand, and Japan); and in Latin America (+4,9%) (including +1,9% Brazil and +2,6% in México); Canada (+2%) and Australia (+1,9%); while it remained steady in Africa given that increases in Argelia and Egypt were compensated by a drop in South African production. Meanwhile, energy generation contracted by 2,8% in Europe (including -3,6% at EU) due to a drop of 15% in France, which was partially compensated by the greatest energy generation in Spain and the United Kingdom (around +6% each), in line with lowest electrical consumption. It dropped also more than 27% in Ukraine due to the NATO war; while Russian energy generation remained paradoxically stable, [3].

Technically, to implement the necessary characterization, electrical energy is the existence of a difference of power between two points which allows for establishing an electric stream between them; in that sense, it is obtained by the movement of electric charge through conductive materials and can be turned into many energy types, such as light, mechanical or thermal, [4].

Regarding the above, electrical energy generated by fossil fuels and/or nuclear energy represents a risk to the environment. Additionally, there is the increase in international oil costs, its inevitable depletion, the demand of large amounts of energy and the aging of current electrical networks. In the last third of the XX century and beginnings of the XXI century, contamination, climate change and fossil fuel source shortages have forced efforts to be redirected towards renewable energy production (solar, wind, biomass, hydraulic, among others).

In that perspective, in 2022 an important impulse and development to electricity generation based on renewable energy sources occurred, reflected by the exponential increase of tts worldwide contribution: nearly 29% of electricity currently comes from processed energy sources at large plants or stations: Thermoelectric, Thermonuclear, Thermal, Solar, Photovoltaic, Hydraulic, Wind, among other, [4-5]; however, where renewable means have less of an environmental impact, offering a high energetic efficiency resulting from the optimization of energy consumption to reach high comfort and service levels, [6].

As indicated above, there are many renewable energy types that harness a wide range of water sources, from large scale (oceans, rivers, dams and waterfalls) to microscales, [7]. Hydroelectric stations have not only demonstrated significant progress as a technological solution to providing energy to developing countries; but also, is possibly the best solution in industrialized countries, [8]. In Colombia, for example, it is estimated that average annual demand growth is near to 2,9%; Hydroelectric sources here represent around 70% of the country's electricity generation, [9].

Globally, on the other hand, the installed capacity for hydroelectric power generation in 2019 amounts to 1,4 GW, for which China, Brazil, United States, Canada, India, Japan and Russia represent about 70%; in so far as Colombia with 0,9% of that capacity, see Figure 1.

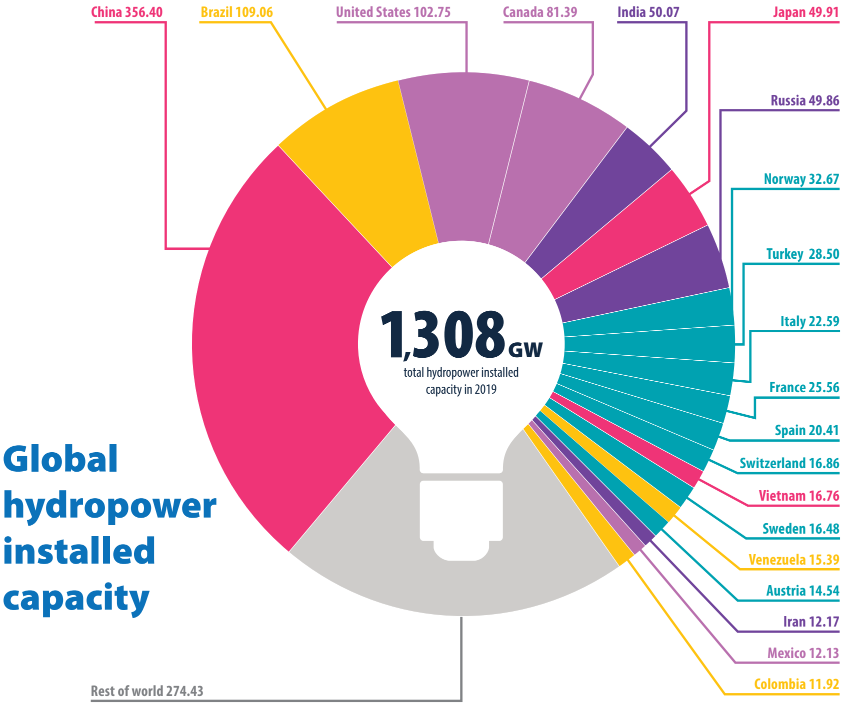

Figure 1. Installed capacity of global hydroelectric production
Source: [3].

In the middle of this panorama, although there has been a preference towards building large scale hydroelectric plants, this has required a high investment in engineering and infrastructure to maximize efficiency of high-altitude hydraulic turbines, [8]. On the contrary, low scale water resources haven't been attractive to this purpose because low charge turbines don't maximize power when stronger absorption is applied to fluid in order to convert it into electricity.

Nowadays, nevertheless, low scale hydroelectric solutions are clean and economical alternatives because they minimize environmental damage and reduce a project's management and cost, [7]. Small hydroelectric models consider a power capacity lower than 5 MW and they are generally classified according to Chart 1:

Chart 1. Hydroelectric station types, according to power rating.

Pico hydraulic	0.5 kW to 5kW
Micro hydraulic	5kW to 50kW
Mini hydraulic	50kW to 500kW
Small Hydraulic	500 kW to 5000kW

Source: Own adaptation of [10].

A Pico, Micro or Mili hydraulic station requires a minimum water reservoir, and their implementation could be made of Ultra or Very Low Head (ULH) or (VLH) resources found in rivers, drainage channels and treatment or water transport plants. These resources have flow and height values between 0,5 y 4 $\frac{m^3}{s}$, and 1-4 m, respectively. However, flow variations in these water resources make speed timing unsteady, preventing continuous electricity generation, [11]. So, Micro and Pico hydroelectric designs can provide energy for industry and agricultural applications and domestic use through direct mechanical energy or coupling a turbine to a generator to produce it.

For the above, and based on Pico and Micro hydroelectric generation means [7], this research is oriented to review and provide possibilities for the design and installation of a low power generation system (lower than 50 kW energy by a primary form to electric energy); its transportation and distribution to end consumers and, for practical efficiency reasons, adoption in a generalized way the stream's on an altern form. Here, four fundamental processes are identified: *generation, conditioning, storage and distribution,* in sources or collection of low flow artificial water flows (created for human benefit) for energy supply on different devices used in telecommunications and environmental variables monitoring on Monitoring Stations of IoT device sensor systems, that could be seen as a combination of sensors and actuators capable of providing and/or getting information, digitalizing it and transmitting it through bidirectional data networks for use with different users and services.

IoT devices are characterized as technologies in which near objects form smart links through sensor systems, permitting making automatic decisions with actuators or controlled ones through augmented reality user interfaces, over sensor action and actuators that work simultaneously in direct communication and in real time on 4G and 5G networks, Wi-Fi networks or different Bluetooth protocols, [12]. The application purposes considered are in the field of home automation or agriculture: home appliances, equipment in medium civil constructions, automata or environmental or IoT devices monitoring plants, [6].

Figure 2 represents a block diagram of this kind of system and identifies subsystems of *Source, Capture, Regulation, Storage, Reversal and Sensors*; and to which the corresponding associated devices are added.

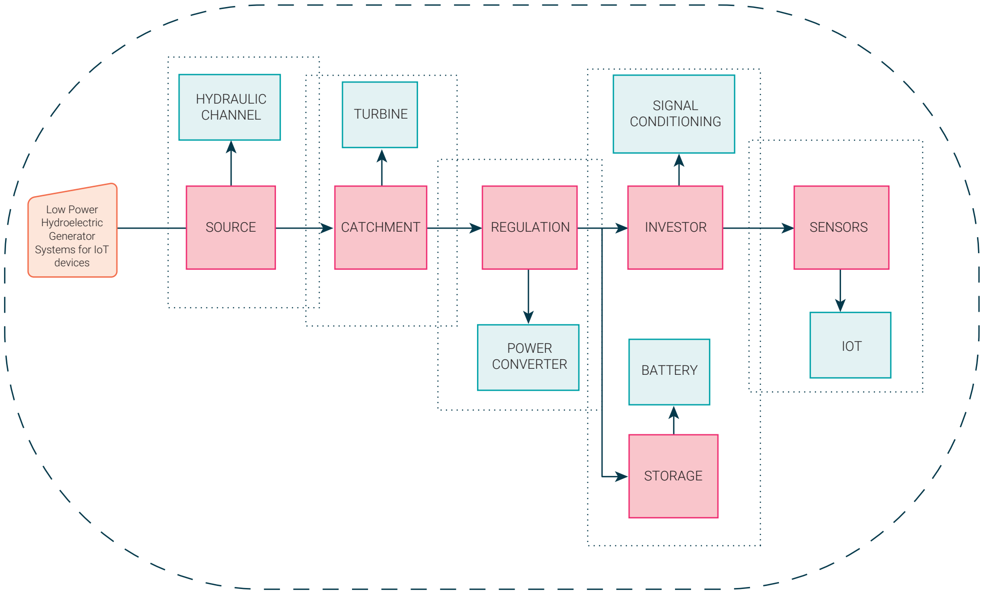

Figure 2. Block diagram of a Low Power Hydroelectric Generation System for IoT devices.
Source: own work.

Background literature that contributes to this research, indicates that, even when Hydroelectric energy Generator Systems have been used in a generalized way for high powers, there are not enough actual studies at the Micro and Pico scale which document this form of energy generation. In this sense, there are studies that describe sources such as in rivers from where power feeds are implemented for cities. In this perspective, some cases have been found with regards to modernization and known modification of techniques for energy generation with less negative impacts than non-renewable energies [13].

On the other hand, together with the low generated powers, an energetic transition process is supported, based in non-conventional renewable energy sources. In this sense, one can't lose sight of the necessity to re-design the subsequent electricity generation stages given in Figure 1, using redesigned plants tailored to renewable energies. These have a participation of 17% in total global energy generation and 45% in world renewable energy generation; in Colombia, this represents more than 60% of energy matrix, [14].

Given the above, local necessities have made Small Hydroelectric Stations a priority in the country due to the favorability in its implementation, considering the abundance of geographically isolated locations, water and topographic conditions, and its high storage and conversion capacity. For this reason, it has been strategically located, now, in the first place of generation in the National Electrical System [15]. In this perspective, it became a necessity the hydroelectric energy generation at different peripheral areas to impact many families that are exposed to the heat wave phenomena, which cause the energy supply to decrease as well as the proliferation of precipitation and warm winds. This situation, added to the government's lack of foresight and electrical sector planning, put Colombian companies in charge, leading to situations that affected the end electrical energy user, due low supply, interruptions or rationing, especially in rural sectors. Therefore, incentives for companies and/or people that embrace established conditions assure an improvement in energy supply, [16].

Otherwise, it can be indicated that energy generated in Colombia is supported, mostly, by hydraulic resources. So, water is the most used resource in electric energy generated in the country and companies provide public electric energy distribution and supply service in Colombia, [17].

Due to this, attention to low scale hydroelectric stations front proliferation of Non-Interconnected Zones has increased, although there is a documentation absence, particularly over hydraulic Micro and Pico generation systems.

Hydraulic generation systems have been historically identified with high altitude dams and small stations that don't have a reservoir. Low scale hydroelectric generation, contribute towards a more sustainable solution given that they do not affect ecological wadi flow and offer the possibility of non-blocking fish passages through civil works, [18]. In addition to what is indicated, it has a great developing potential in the country because the water resources are plenty and topography is privileged by falling recurrence that increase generation potential, [19].

The document is structured as follows; initially selected materials and methods adopted for research reference selection; then hermeneutic stage or relevant background description and interpretation; result establishment and finally the conclusions.

2. MATERIALS AND METHODS

Throughout the last decade IoT devices and their relationship with the Internet and remote but intelligent and appropriate communication have been profusely investigated, the above encouraged by infinite possibilities that exist to integrate it or make it converge. In that sense, research tasks to improve this communication focus on locations where access is too difficult, needs energization, by clean power generation, and requires the correct implementation regarding territorial needs.

It is decided then, that a documentary exploration based on scientific papers, Thesis or Degree works that includes thoroughly different topics related to renewable and nonrenewable energies is most appropriate; emphasizing on devices or equipment like turbines, generators, convertors (invertors), batteries, sensors or IoT devices.

In that regard, focused databases were consulted like Google Scholar, Elsevier; digital repositories, specifically, Francisco Jose de Caldas Distrital University and scientific journals of electronics, control, and telecommunications. For documentary identification descriptors were used like *renewable and nonrenewable energies, IoT, Turbines, Batteries, IoT sensors.* For the product of the analysis, the last 5 years within the Colombian context was selected. Most Spanish language sources were prioritized to make the critical, bibliographic and knowledge review more accessible for the national academic community. Following Hernández Sampieri [20], vertebrate diagrams oriented to conceptual maps are made from a General Index in which categories and subcategories (for low power electric generation) shown in Figures 3 and 4.

In Figure 3, the energies generation concept map, relation and renewable criterion is observed; nonrenewable: oil, coal and natural gas, with which human beings have been evolving by the hand of the extractive economy; and renewable energies, which are found in nature –apparently inexhaustible-, less polluting and less aggressive towards the environment. Particularly, it is chosen to work with hydraulic energy; classified depending on the state of the water source: at rest, in flow, pumping or tidal. Once the taxonomy is provided, the exploratory nature of the research emphasizes those in flow or at rest, and from there the jump criterion is established; in other words, the flow's height or inclination: high, medium, or low, depending on the storage capacity that can be measured in kilowatts of power.

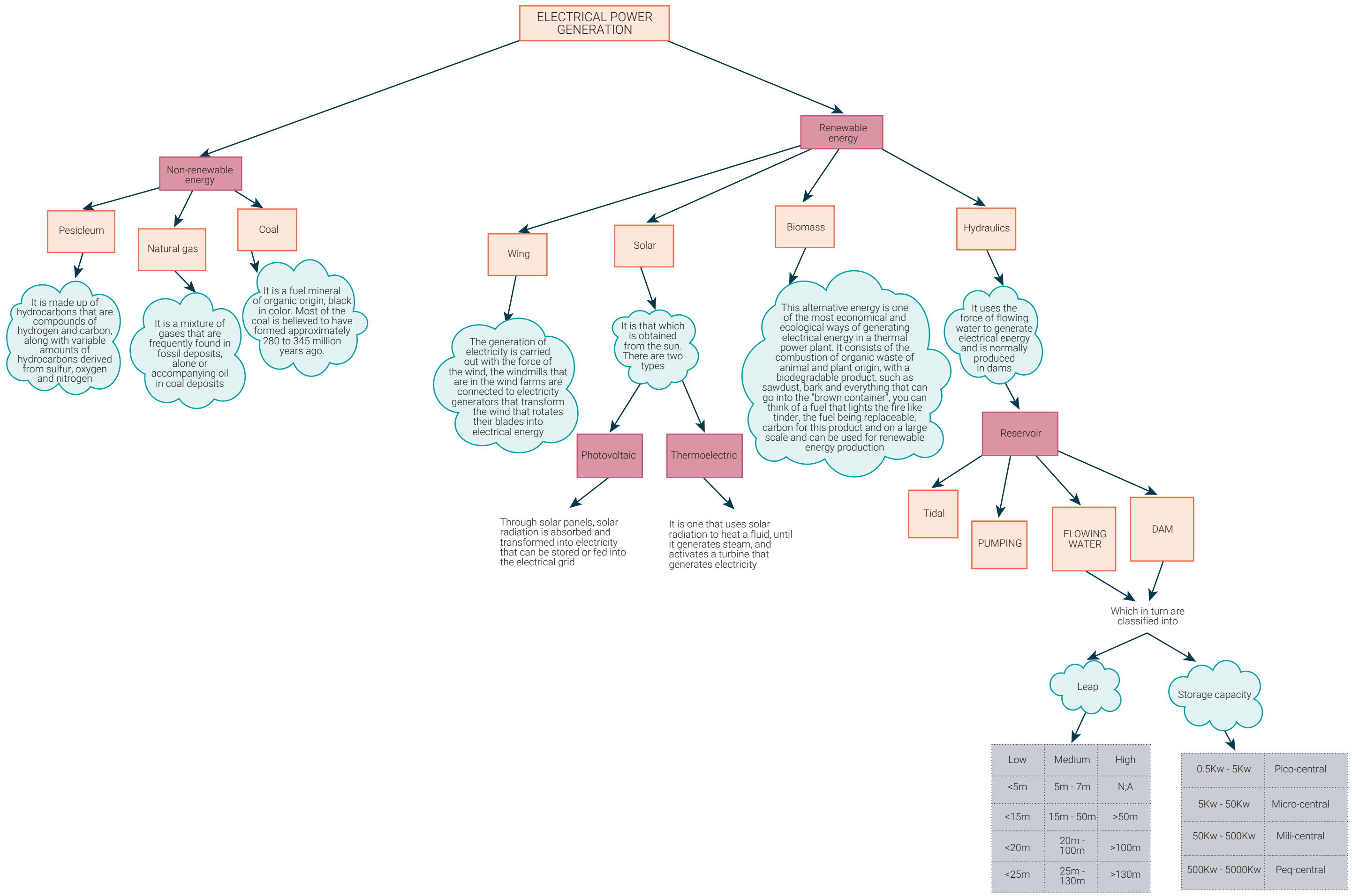

Figure 3. Categorization corresponding to electric energy generation.
Source: own work.

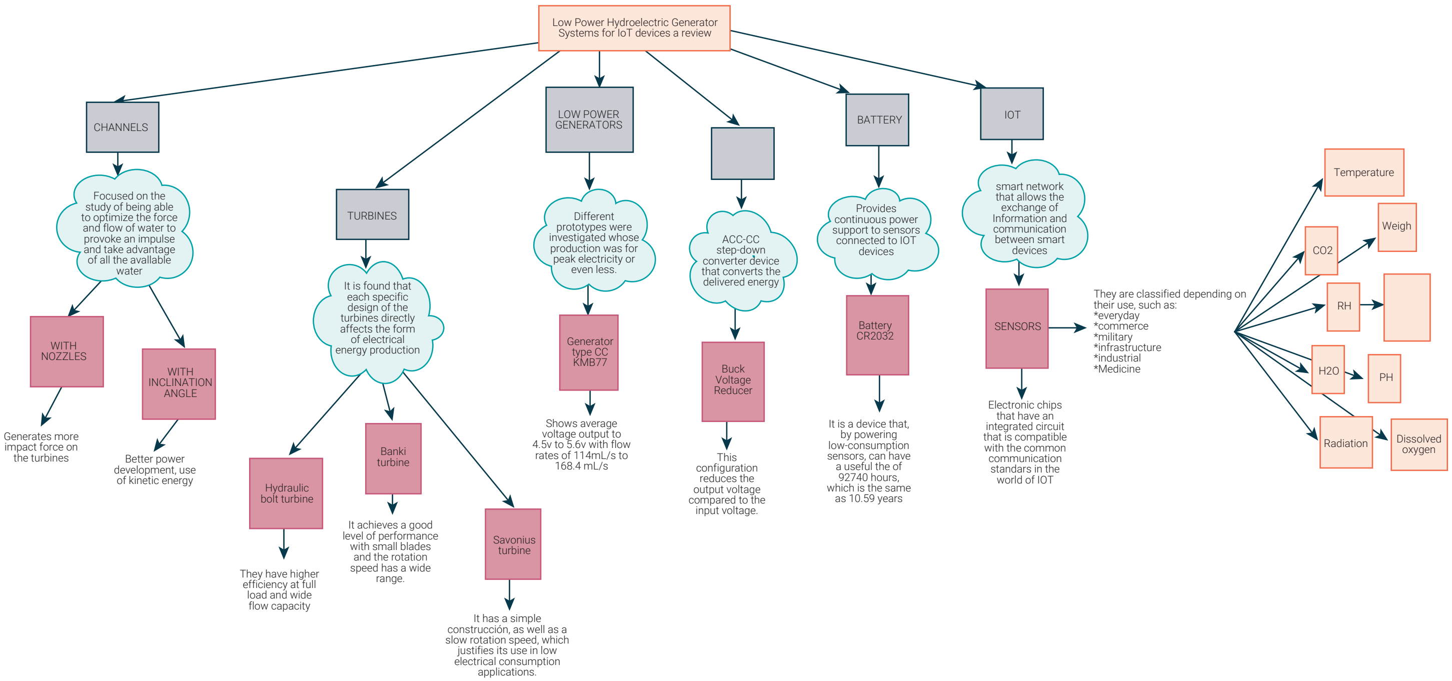

Figure 4. Subcategorization of Low Power Hydroelectric generators for IoT devices.
Source: own work.

In Figure 4, a step by step description of a low power hydraulic generation system is observed. First a source drainage channels that allows for water to pass through is observed -with or without inclination-, and according to these turbine types is established –in reviewed ones there are three: each one provides a different result but it makes them functional within the system-. Then the DC (Direct Current) generator is examined; it regulates the average voltage production. Complementing the system, there is a voltage reducer that produces an output voltage lower than the input one. An external battery is used as the IoT sensor backup, which are classified in different types depending on their use and necessities, according to requirements.

3. DEVELOPMENT

3.1 Drainage channels

Initially, research focused on drainage channels, irrigation, rainwater reception, among other. According to basic principles of hydroelectricity, these respond to parameters like speed, flow angle, efficiency and generated power [21], [22]; fundamentals for a partial mechanism selection, efficiencies and generated powers, as indicated in Figure 5.

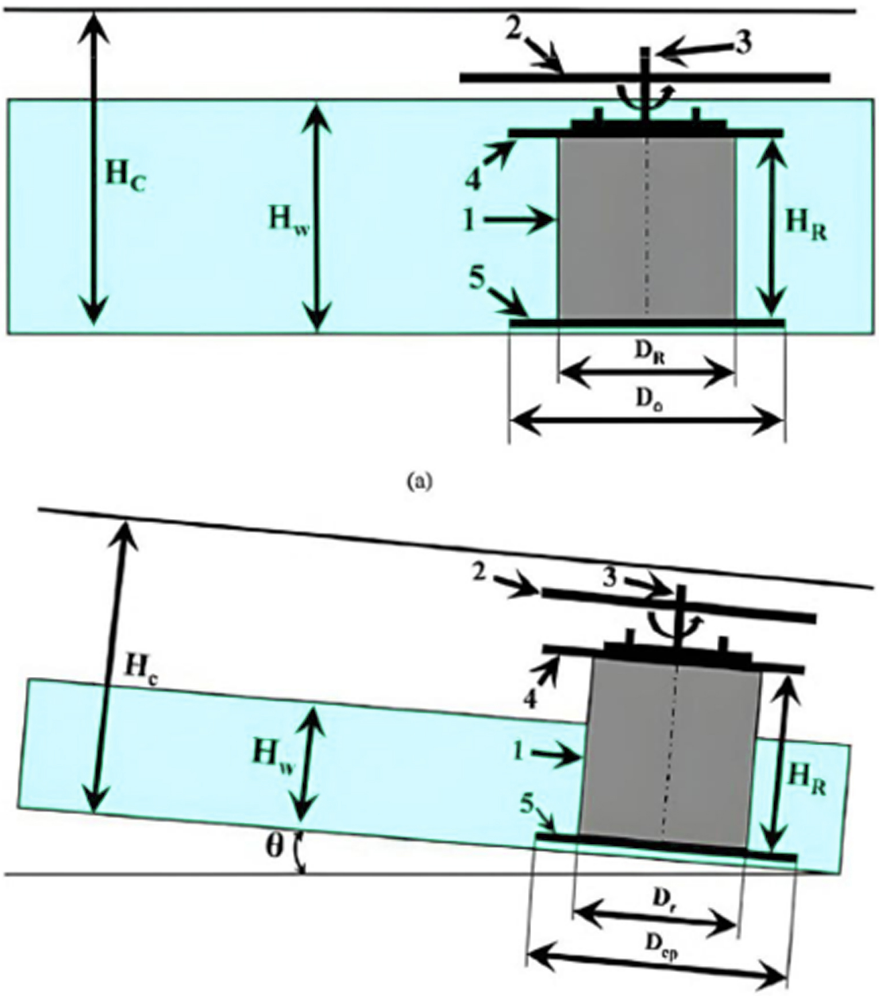

Figure 5. Experimental installation diagram into a horizontal channel (a) and an inclined channel (b). 1. Savonius Rotor, 2. Top Plate, 3. Rotor axis, 4. Rotor Top End Plate, 5. Rotor Inferior Part, Ending Plate

Source: [21].

According to implemented mechanisms in the channel, speeds and generated powers rates are effectively calculated, in this sense, Equations 2 and 3 identifies the water speeds [21] and power rates calculation [22] respectively; water densities and turbulences that affect kinetic energy production are also considered.

$$\text{Watter Velocity}(V_w) = \frac{Q_{actual}}{A_W} = \frac{Q_{actual}}{W_c H_W} = \frac{C_d\left(\frac{2}{3}\right) W_c(\sqrt{2g})(H_w)^{\frac{3}{2}}}{W_c H_W}$$

Equation 2. Calculation to find water speed [22].

Where: Q actual = Actual Discharge, Aw = Wet channel area, Wc = Channel width, Hw = Channel height, Cd = Discharge coefficient, g = Gravity due to acceleration, [22].

$$\text{Power coefficient}\ (C_p) = \frac{P_{rotor}}{P_{disponible}} = \frac{(T_{rotor} \times \omega)}{\left(\frac{1}{2}\rho_w(A_R)V_w^3\right)} = \frac{(T_{rotor} \times \omega)}{\left(\frac{1}{2}\rho_w(H_R D_R)V_w^3\right)}$$

Equation 3. Power rates calculation, [21].

Where: Cp. = Power coefficient, P_{rotor} = Rotor developed power, $P_{disponible}$ = Available power, T_{rotor} = Rotor torque, ω = Angular speed, pw = Water density, Ar = Rotor area, Hr = Rotor height, Dr = Rotor diameter Vw = Water speed.

Given the above, it is determined that through channels 20 m in length, 0,6 m wide and 1,2 m deep (Figure 5), with speeds of 0,6 m/s, 1m/s and 2 m/s, efficiencies of 0,517 and 0,55 can be obtained respectively.

One must also consider that for better production and efficiency energy increase a greater shock impact of water in turbines is needed [22]; consequently, nozzles for turbine exit pressure are designed, so there is greater channel flow; this leads to the possibility of using two turbines, a top one and bottom one to take advantage of the generated flow [6]. Another aspect to consider is the inclination angle of the channel, with elevations between 0° and 2 °; while inclinations increase tip speed rising (TSR), power rates and performance decrease, as can be seen in Figure 6, [22]:

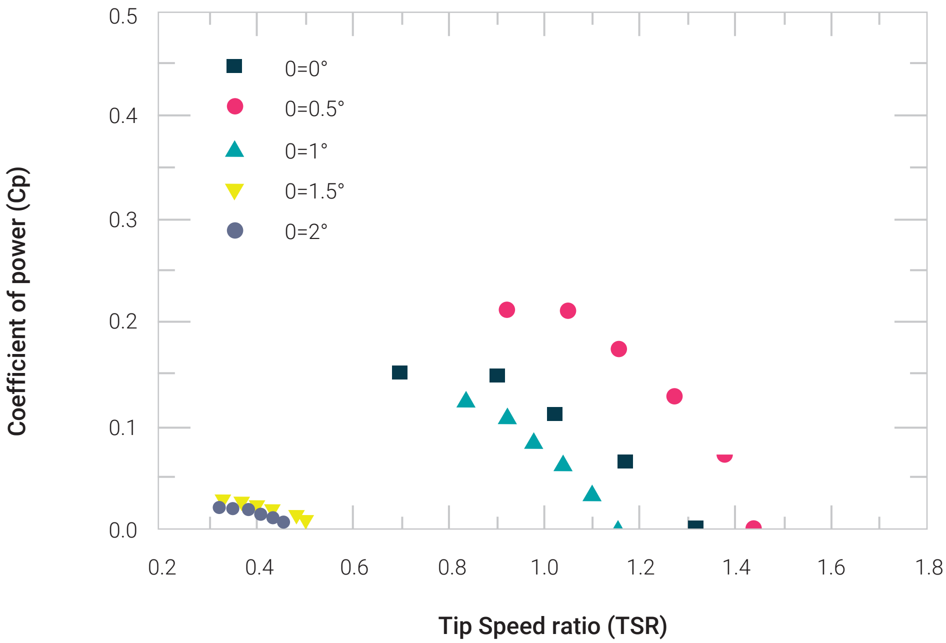

Figure 6. Powe rate variation regarding to tip speed for q= 0° to q= 2° channel inclination
Source: [23].

3.2 Mini turbines

It is found in literature that turbines used for energy generation in macro hydroelectricity, with modifications, manage to be completely appropriate and functional for low power production; among these, the Savonius turbine, Figure 7, which is an eolic turbine type with vertical axis used to transform wind power into torsion over a rotating axis. This design can be useful too in hydroelectric energy generation; for example, in a channels assembly at different angles are obtained power generations of 1,5 W for channels with a 2° inclination angle over the ground, [22].

Item N	Part name	Amount
1	Wedge Structure	1
2	Metalic box	1
3	B18.2.3.2M – Bulon M12x1.75x30	14
4	Lower shaft	1
5	Lower flange	1
6	Conical bearing SKF-T2EE 060	1
7	Conical bearing SKF-T7FC 065	1
8	B18.2.4.6M heavy nut M56x5.5	1

(continúa)

(viene)

Item N	Part name	Amount
9	B18.2.4.1M nut M12x1.75	14
10	Bottom mass_part 1	1
11	Botton mass_part 2	2
12	Reinforcement rod 8 mm	8
13	Praise cover	8
14	Flap foam	8
15	Asparagus M10 x 130	48
16	Blade support plate	8
17	Top mass_part 1	1
18	Reinforcement rod 6 mm	8
19	Inner fiber cap	4
20	B18.2.4.1M nut M10 x 1,5	3
21	Shirt	1
22	Shirt	1
23	Upper shaft	1
24	Ball bearing SKF – 6409	1
25	Threaded rod M20X220	10
26	Counter wedge	1
27	Slab	1
28	Upper shaft	1

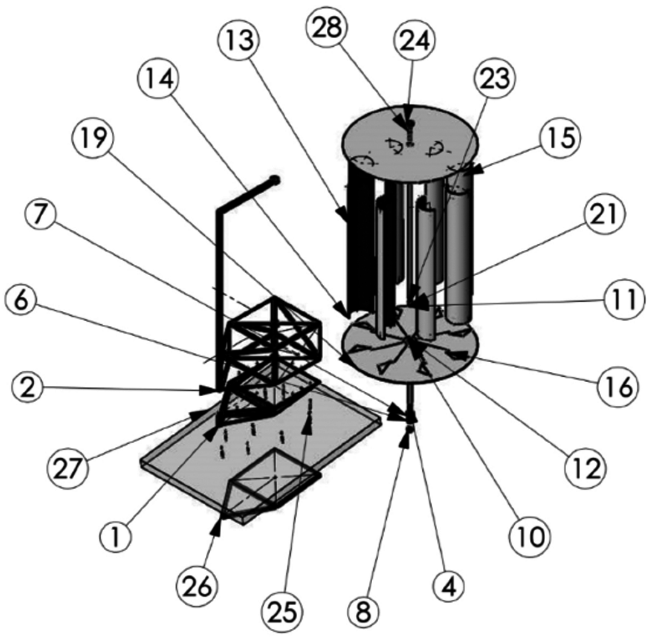

Figure 7. Savonius turbine and its parts
Source: [23].

Another turbine that meets the low power generation functionalities is the Banki turbine, Figure 8. It is widely used in micro hydroelectric production; it reaches average performances of 80%, with power generations between 18,36W and 39W using single phase alternating current generators, [22], [24], [25].

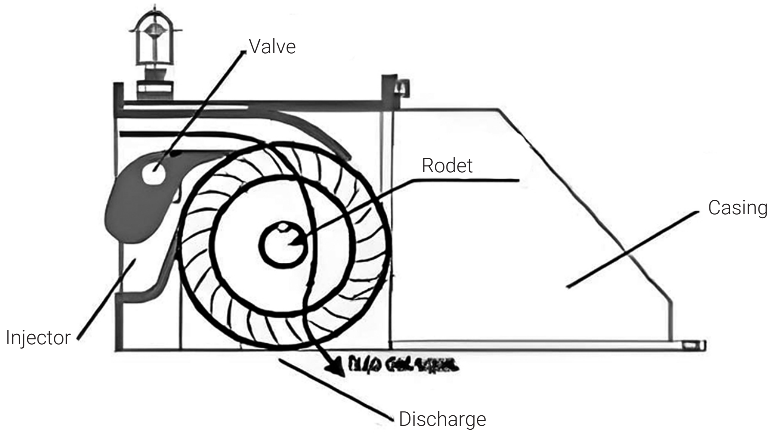

Figure 8. Banki turbine and its parts
Source: [26].

On the other hand, hydraulic bulb turbines, Figure 9, are ideal for eolic uses with efficiencies in a power range between 25W and 30W with single phase alternating current generators [27], [28], [29]. These are totally adaptable too for channel systems for microhydraulic generation, with performances near to 87,7%, [30]. Tests were done in computer simulations and in air flow platforms that caused variations in net efficiency, as air density is lower than that of water, and, in consequence, required slight changes to applied powers and speeds in a liquid environment, [30].

Figure 9. Hydraulic bulb turbine
Source: [31].

3.3 Generators

As for the low power generators oriented to Pico hydroelectricity production, it is observed that various different types could be implemented. Generally, solutions involve generators that show average power between 1W and 1kW, with output tensions of 12 volts, and an efficiency of 95% [33]; which generator is working varies depending on RPM, its power and channel flow. From this point of view, it was found that a first experience uses the DC generator (type KMB77, Figure 10), with average production between 2.5 to 5.6 Volts with flows between 114.0 to 168.4 mL/s [35]; this shows that voltages in generator terminals are stable and applicable for the flow range previously mentioned [34]. An alternative considers assembling the generator, depending on required necessities, of Radial flux synchronous Permanent Magnets (RPMG), which function is transforming rotational mechanical power into electrical power; [35]. The generator is documented with the proper experimental tests, with speeds near to 1000 rpm. The designed generator could reach almost 40kW of power, with efficiencies near to 80%, [36].

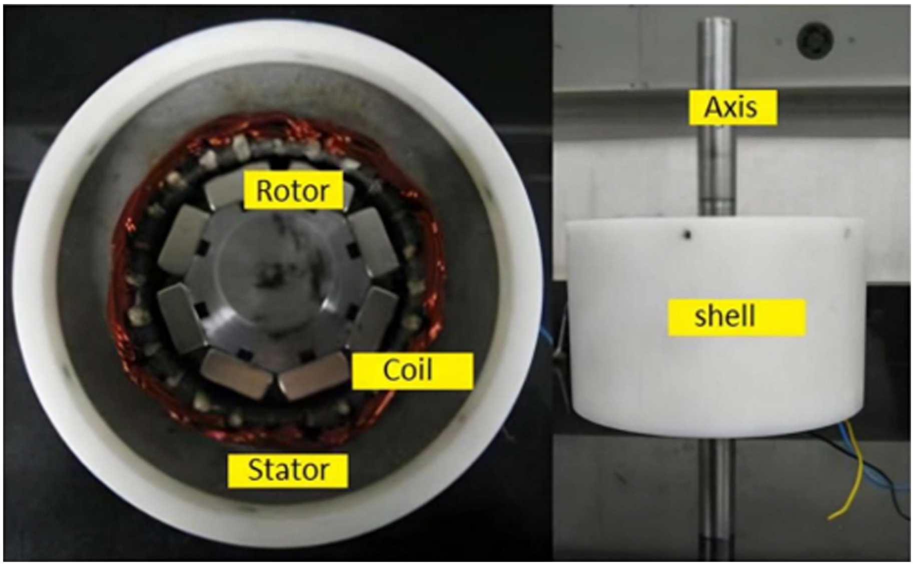

Figure 10. Assembled KMB77 generator and its parts, edited by the authors
Source: [36].

3.4 DC-DC power reductor-converter

Due to an IoT device's low power consumption, relative to the power levels provided by generators, it is necessary to design and implement a conversion stage through a DC-DC reductor-converter device. Historically, experience shows that this works with the voltage reductor (Buck, linked circuit in Figure 11) [38], given that in this configuration, output voltages are superior to input voltage and its efficiency can reach high values.

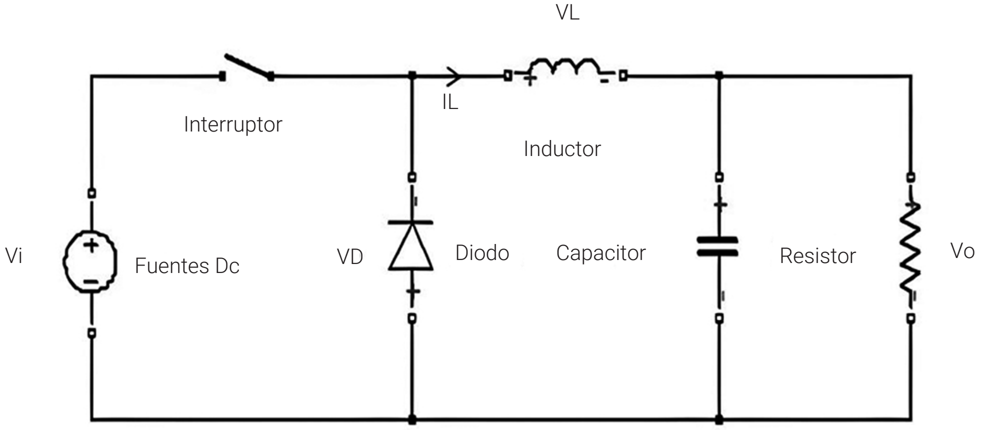

Figure 11. Buck reductor-converter circuit
Source: [38]

Its components and characteristics are shown in Chart 2:

Chart 2. Components of converter circuit.

ELEMENT	FUNCTION
Diode	Allows current to flow through the circuit when the switch is open
Switch	N type mosfet transistor
Inductance and a capacitor	These filter the output signal of the circuit
Resistance	Power stage output load

Adapted by the authors, [38].

The present exploration shows that stored energy in the inductance, at the end of the work cycle, is zero; that is, current in the inductor is zero in a portion of the commutation cycle due to the charge resistance using all stored energy before the interrupter commutes and passes to a closed state, [38]. Based on these criteria, the necessary circuits can be designed to carry out the proper power conversions that are required for energy generation and supply stages in the IoT systems.

3.5 Battery

Taking into account that water flux in the studied channels is not continuous, which directly affects energy production, the battery application must be considered so that the same IoT systems are not suspended due to lack of power. In this sense a review of applicable batteries for those elements has been made. According to the facts above, small batteries or button batteries can be attached to the low power IoT devices; these have voltages around 3V and 220 mAh; among them: CR2032 button battery, Figure 12. [35] documents that with low powered Bluetooth communication, this battery can last up to 92.740 hours or even 10.59 years; this, besides, considering that systems have sleep configurations; that is, just works when are required [39]. With the above, energy generation can be focused on charging the battery and so extend its useful life; or directly use the produced energy for feeding IoT devices, and have the battery as a reserve when there is no water flux to generate energy.

Figure 12. CR2032 button battery
Source: own work

3.6 Internet of Things (IoT)

Information Technologies evolution (TICs), in which are based the added value of developed and resilient societies: Singapore, Malaysia, Brazil or China, where the population ensures occasional internet use or use of a mobile device, has shown that the more people have access to communication and information infrastructures at the global level, proportionally citizens life quality has evolved to the point in which a jump is related so that machines and smart objects communicate and coordinate among them, [43].

Internet of Things (IoT), Figure 13, is considered as a revolutionary paradigm in the technological world, especially in communications. [44] considers an intelligent network that allows for information and communication exchange among smart devices; so IoT is described as an environment where things can talk and its data can be processed to do the desired tasks through automatic learning. That is: a powerful platform capable of connecting devices for monitoring topics of daily life, [45]. One of the principal contributions of IoT is on increasing information value thanks to large numbers of interconnections among things and information, allowing people to be connected anywhere or anytime with things or people using ideally any kind of network, route, or server [46].

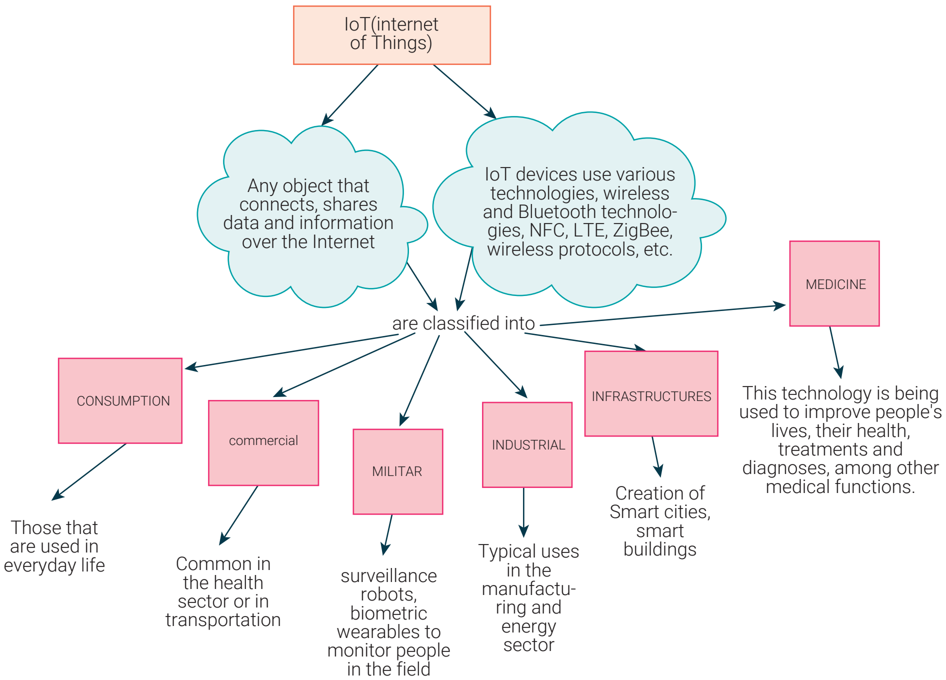

Figure 13. IoT and its branches or levels of enforcement.
Source: own work.

In this smart context, IoT devices imbibe in quality monitoring of food, water and wind, water and gas leak detection, electromagnetic emissions detection, environmental and soil variables detection; among the most important. These are increasingly within the reach of people because base knowledge, with facility for designing and programing a project from zero with a professional profile, has spread.

Among some simple and typical hardware elements are included: Arduino, plates capable of reading sensor inputs and transform it into outputs; Raspberry Pi, reduced board computer or simple board computer (SBC); N portable wireless router capable of sharing a mobile 3G/4G connection, compatible with modem, USB, 3G/4GLTE/HSPA+/UMTS/EVDO; ESP8266 Wi-Fi module that allows microcontrollers to connect to a Wi-Fi network and make TCP/IP connections using Hayes type commands; ACS720 current sensors equipped with a meter through Hall effect sensor for induction magnetic field ; LM393 sound sensor, for controlling lights, alarms and sound following robots through potentiometers that make it possible to configure volume; MQ-135 air quality sensors for buildings/houses which detects presence of NH3, NOx, alcohol, benzene, smoke, CO2; DHT11 sensor for humidity and temperature, constituted by resistive sensors that have a fast response in the humidity range of 20%-95%, and temperatures between 0°C-50°C, [47], [48], [49], [50], [51]. Other more sophisticated high sensitivity sensors have been developed, for example, to detect electromagnetic emissions up to 20 GHz, such as weak environmental signals like FM and AM radio, Wi-Fi, Bluetooth, through spectrum analyzers; this opens up unusual possibilities for controlling multiple variables, even environment temperature, more effectively compared to receptors and analyzers of standard radiofrequency, [44]. In this perspective, investigation, development and innovation has not ceased.

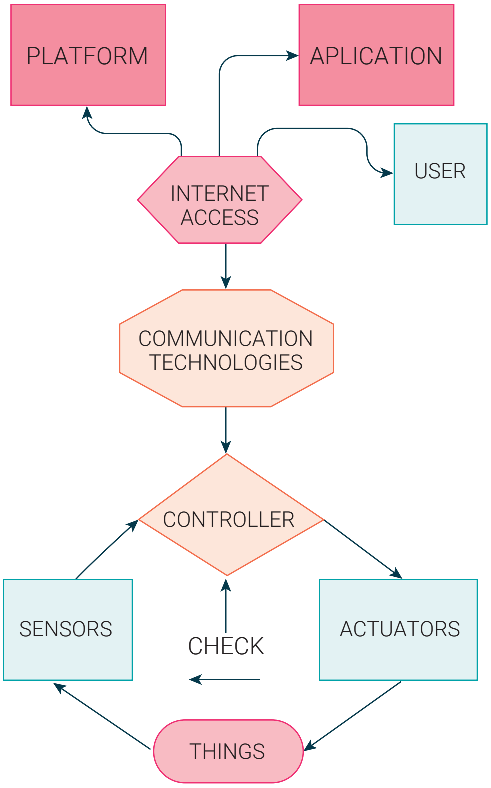

Figure 14. Architecture, elements and operation in IoT.
Source: adapted by authors of [46].

However, and despite of edge computer options and other alleviating information traffic elements, for safe performance in IoT in low power energization terms for devices, it is necessary that users feel safe about data protection and its privacy. In this context, for IoT applications there are multiple layer security architecture series: 3 layers, 4 layers, ending on current 6 protection layers; the last one corresponding to a hierarchical structure on a network, and are described as follows:

A. Codification layer, which oversees object identification.
B. Perception layer, which give physical sense to every object, like sensors (temperature, humidity, speed, etc), RFID labels.
C. Network layer, its purpose is receiving the information as digital signals and transmitting it through communications like Wi-Fi, Bluetooth, Zigbee, among others.
D. Middleware layer, in charge of processing the sensors receipt information.
E. Application layer, it makes the IoT application for industries based on last processed data.
F. Business layer, it manages IoT applications and services, [36].

Among IoT systems exist the necessary elements for their functionality, corresponding to layers:

A. Devices, any object that could connect to the Internet and can communicate with other objects.
B. Communications, in charge of sending and receiving data, are used on various technologies: mobile networks, satellites, Wi-Fi, Bluetooth, Zigbee, among other.
C. Storage, necessary for improving system performance.
D. Services created applications tailored to IoT systems, [53].

IoT devices communication, are made mostly through radio, but protocols exist which must be chosen:

- Wi-Fi, given that have many advantages whenever possible to achieve energy requirements and its complex necessities of processing and provisioning doesn't represent an obstacle. Wi-Fi executes TCP/IP natively, so, once configured, we can escape the difficulties of proper internet.
- Zigbee and Z-wave are popular among home automation networks because they are optimized for low consumption communications and low bandwidth, and both allow home devices to directly communicate with each

other for higher speed and safety. None of them directly admits internet protocol, so communications out local line used to enrout through a bridge.

- Lora-WAN protocol is increasingly popular also for IoT bandwidth. It combines long range with very low bandwidth, supporting a range of miles for devices in line-of-sight that only have small amounts of data to transmit.
- Bluetooth and its low energy sister BLE are very popular for simple IoT devices. None of them can communicate very far, so must use another device -often a mobile phone- to make long distance messaging easier.
- Mobile networks can now easily accommodate IoT devices. New mobile protocols, like Cat-M and NB-IoT, allow devices with batteries to work for months without recharging them, in exchange for a limited bandwidth.
- Other protocols like 4G LTE and 5G require much more power, but also can manage heavier data like digital video.
- There are also many proprietary protocols and from single manufacturers that adapt to unique distance necessities, special bandwidth requirements, difficult radio environments and, of course, cost optimization. There is not a protocol that may rule them all. Each project will have its own solution. [54], [55]

3.6.1 Sensors

Most innovations arise due to the high demand for technological provision in processes and repetitive actions that are susceptible to automation. One of the innovations of this automation lies in sensor networks (biosensors and others of adaptative nature) that facilitate information harvesting of an environment that can be of important monitoring [46]. If there is functionality, these networks have advantages given that transducers are more and more sophisticated or interpret and measure increasingly weak signals; as so a conditioner in charge of transforming those readings into interpretable data by electronic devices [53]; in general, IoT sensors properly energized, serve to:

- **Capture information** in an easier way.
- Improving **reliability and security** in data capture.
- **Automate processes.**
- Reduce interaction and **necessity of technical staff**.
- **Improving data availability** for companies and users.

- **Save time and resources** for companies that implement IoT sensors in their productive processes.
- Improving **compliance with safe measures** of TIC departments of companies in different productive areas.

The functionalities of IoT devices come with many advantages; although, of course, this kind of technology has its own challenges with regards to low power feed in a continuous way; quality data extraction with IoT sensors will be guaranteed by continuous and safe feeds [46].

IoT sensors are electronic chips that have an integrated circuit compatible with usual communication standards in TIC´s world. Thanks to these sensors, it is possible to extract data and take reality to a dimension which can be managed through information. These kinds of sensors can transform an input amount into a measurable and interpretable signal by electronic devices.

The purpose of IoT is to extend internet connectivity beyond standard devices, like computers, smartphones, and tablets, to any kind of physical devices and daily objects not enabled for the Internet. Integrated with technology, these devices can communicate and interact through the Internet, and can be monitored and controlled in remote ways.

Some examples belong to connected devices that make up part of a scenario in which each device talks with other related devices in an environment to automate housework and industries; and to communicate sensor data usable for users, companies, and other interested parts. IoT sensors are designed to work in concert with people at home, industry, or in the office.

Now, some of the main IoT sensor types that exist in the market can be classified in different ways; by their method of detection:

- **Temperature and humidity:** IoT sensors for humidity measure heath level and humidity generated in a determined area. Acts in a fixed range around an objective area.
- **Accelerometer:** Accelerometer sensors enable remote monitoring of a vehicle's speed.
- **PIR sensors:** Monitors movement of people and objects. It can be used for business ships, security control or private homes.
- **Location:** Are often used in warehouses to position objects and help in logistic management of IT.

- **Optical:** Measure light and transform it into electric signals that are legible for other devices and for professionals. It can be used, for example, in environmental control.
- **Water:** In general, this is used to talk about IoT sensors for water quality control.
- **Image:** It transforms optical data into electronic signals that are storable in other devices. It is used in digital cameras, medical image systems, sonar or radar.
- **Pressure:** Detect pressure changes, measure it and transform it into interpretable information by other devices and by own users.
- **Movement:** Help to detect movement in a determined area. It can be used in automatic doors and automatic parking systems.

By its output signal or kind of energetic spending, according to Figure 13, in, [56]:

Home automation: a scenery apt to IoT solutions is where lots of devices are already connected to the Internet to make a human beings' life easier. Besides, IoT software has more and more standards that make it accessible to create any kind of device. Other IoT examples and applications for daily life, [57]:

- **Geolocation devices**, that relate among them triangulating the signal of another device to locate it; commercially a clear example is Apple tag.
- **Gas detection sensors** in homes or electronic devices with failures.
- **Home safety**: sensors, lights, alarms, and cameras that can provide continuous and uninterrupted safety.
- **Pet monitors:** It can help with interaction, programing, and food dispensing.
- **Smart locks:** safety during human absence.
- **Activity and health trackers**: sensors that can control and transmit health indicators like blood pressure, appetite, physical movement, and oxygen levels. They could even detect cardiac abnormalities anticipating more serious episodes.
- **Indoor air quality**: Products like Foobot , an IoT device that measures indoor contamination; improvement in air quality or elimination of germs in houses, coffee shops and other indoor spaces.
- **Road safety**: Installation of detection devices of excessive exhaled alcohol inside vehicles can block car starters.

- **Connected appliances:** Based in housework robots or that predict expiry dates of products; or microwave activation to satisfy users when they work or are going home.
- **Smart clothing**: In shoes that count all miles a person runs, smart shirts capable of measuring sweating during a physical activity.
- **Virtual assistants** that control devices and enable comfort tasks: Google Home, Alexa or Siri, [58].

Commercial: Smart Home illumination. Thermostats that regulate temperature at home; dimmable bulbs, smart locks, smoke detectors, pet dispensers with smartphones: alert sending when feeding or when is food enough, [59].

Medicine: medical device ecosystem endowed with connectivity or Internet of Medical Things (IoMT), includes: digital audiometers which enable having data in different systems of health management in real time, tele-audiometry without the need of patient and medical professional in same place, on diabetes presence, controlling sugar blood levels thanks to monitor continuous glucose (MCG), is important about glucose traditional measurers that they only give data of instantaneous reading, smart inhalers for asthma management through smartphones, [59].

Agriculture: There are different types of sensors:

- **Soil condition**, climate conditions or humidity.
- **Nutrients that affect** harvest or garden.
- **Best time to harvest** plants.
- **Custom fertilizers** based on concrete soil chemistry.
- **Pests** or endemic problems.
- **Biometric monitoring** of animals.
- **Geolocation** of animals.
- **Volume and quality of the yields**, optimize water and nutrients supply for each crop and even select yield characters to improve quality.

Or to implementing it on **smart greenhouses**, sensors that provide information about pressure, humidity, temperature, and light levels; and enable an automatic adjustment of conditions of temperature, irrigation, among others, [60].

Military: EO / IR sensors, radars, sonars, movement, or sound detectors have augmented capacities tailored to technology improvement that incorporate; developing in components technology increases capacities of backbone IoT networks. In this sense manufacturers of subsystems stay at the forefront of the market, closing the gap with platform manufacturers, [61].

Smart Cities IoT & Smart Buildings

- **Smart people**: citizens as city sensors network for detection of problems like crowding or breakdowns.
- Monitoring of **air quality.**
- **Smart Environment**: monitoring and optimization of natural resource usage (water, gas, light, etc.).
- **Structural movements detection:** movement sensors can detect vibrations in buildings, bridges, dams, and other big scale structures. These devices can identify anomalies and disturbances in structures that should cause catastrophic failures. It can also be used in areas susceptible to suffering floods, landslides, and earthquakes.
- **Smart roads:** traffic lights that activate depending on the traffic flow or pedestrian crossings that automatically detect people presence, light on, indicate crossing rhythm, among others [60].

On Chart 3 are established other IoT sensors relevant in daily life.

Chart 3. Some IoT sensors that complement daily activities.

Personal	Home automation	Industrial	Automotive	Smart Cities
Watches	Alarms	Production	GPS	Velocity cameras
Glasses	Locks	Inventory	Fuel saving	Building monitors for looking at Its condition
Fit Bands	Cameras	Physical state	Automatic locks	
Rings	Fridges	Staff location	Smart power on	Cameras
Bracelets	TV set	Machine efficiency	Automatic driving and parking	Parking lots
Clothes	Illumination control Temperature			
Belts	Automatic curtains			Traffic congestion
	Plants and garden irrigation			Drone surveillance

Source: adaptation from [62].

4. DISCUSION AND CONCLUSIONS

Lack of infrastructure, poor management or governmental decisions have induced a deficit of generation or energy supply. Given this, the way nonrenewable resources have been used for electric energy generation consider friendly technological solutions with the planet; this renders SHBP a viable solution, providing sufficient energy to IoT devices consistent with TICs permitting monitoring, sensing or measuring different kinds of necessities depending on the context. Sources here determined are drainage channels with a length of 20m; 0,6m wide; and 1,2m deep; endowed with velocities between 0,6 and 2 m/s, reaching energetic efficiencies of about 50% and 60%. Additionally, increased hit impact of water in turbines can be done with nozzles that increase pressure exerted, as well as position more turbines to take advantage of generated flow. On the other hand, artificially increasing the inclination angle of channel, although it increases tip speed (TSR), it decreases performance and power coefficients.

It is concluded that, in the research carried out, conventional electric energy generation methods are no longer the most viable; resources are lacking and the possibility of natural resources energy generation has been studied, in this case hydroelectric energy. This is a favorable option given that it can be found almost everywhere, cities or non-interconnected rural zones. This creates the possibility of taking energy to places where it usually doesn't arrive; in addition with this same energy, installing sensors and IoT devices, that no matter the distance can be energized to monitor different daily life topics or productive or agro-industrial: of a crop, detection and control of humidity or temperature where plants grow.

5. REFERENCES

[1] Generación Eléctrica - Qué es, cómo se produce, renovables. Concepto. [Online]. Available: https://concepto.de/generacion-electrica/

[2] A. Gutierres. "Energías renovables: energías para un futuro más seguro". Organizacion de las Naciones Unidas. [Online]. Available: https://www.un.org/es/climatechange/raising-ambition/renewable-energy

[3] Datos sobre producción eléctrica | Estadísticas mundiales sobre electricidad | Enerdata. Estadísticas energéticas mundiales | Enerdata. [Online]. Available: https://datos.enerdata.net/electricidad/estadisticas-mundiales-produccion-electricidad.html

[4] M. A. Tamayo Rincón, Panorama actual de la generación hidráulica en Colombia y Antioquia ante el crecimiento de la demanda de energía, Univ. Antioquia, Medellín, 2022.

[5] J. Rosero, L. Morales y D. Pozo, "Fuentes de Generación de Energía Eléctrica Convencional y Renovable a Nivel Mundial," *Rev. Politec.*, vol. 32, no. 2, p. 13, 2013.

[6] E. Malagón, La Hidroelectricidad, La Mayor Fuente De Energía Sostenible. ¡Aquí Te Decimos Por Qué! - Energía Para El Futuro. [Online]. Available: <https://blogs.iadb.org/energía/es/la-hidroelectricidad-la-mayor-fuente-de-energia-sostenible-aqui-te-decimos-por-que/> [

[7] A.A. Khan, M.R. Khan, A simple and economical design of micro-hydro power generation system. 2015 Power Generation Systems and Renewable Energy Technologies, PGSRET 2015. doi: https://doi.org/10.1109/PGSRET.2015.7312183

[8] L.M. FerroL.M.C. Gato, A.F.O. Falcão, "Design of the rotor blades of a mini hydraulic bulb-turbine," *Renewable Energy*, vol. 36, no.9, pp. 2395–2403. doi: https://doi.org/10.1016/j.renene.2011.01.037

[9] E. R. Oviedo Ocaña, "Las Hidroeléctricas: efectos en los ecosistemas y en la salud ambiental," *Rev. Univ. Ind. Santander.*, vol. 50, no. 3, 2018.

[10] E. Sierra Vargas, A. F. Sierra Alarcon y C. A. Guerrero Fajardo. "Pequeñas y micro-centrales hidroeléctricas: alternativa real de generación eléctrica. | Informador Técnico," *Revistas SENA*. [Online]. Available: https://revistas.sena.edu.co/index.php/inf_tec/article/view/22/3439#info

[11] J.L.S. Villarreal, P.G. Avalos, S.R. Galvan Gonzalez, F.J. Dominguez Mota, Estimate electrical potential of municipal wastewater through a micro-hydroelectric plant. 2018 IEEE International Autumn Meeting on Power, Electronics and Computing, ROPEC 2018, Ropec. doi: https://doi.org/10.1109/ROPEC.2018.8661411

[12] F. Qusay, Hassan, "An Overview of Enabling Technologies for the Internet of Things," in Internet of Things A to Z: Technologies and Applications, IEEE, 2018, pp.77-112. doi: 10.1002/9781119456735.ch3.

[13] S. Quevedo Osorio, "Generacion de Energía Hidráulica en Colombia", Informe Final de práctica social, empresarial y solidaria, Univ. Cooperativa Colomb., Neiva, 2022.

[14] M. A. Daza Vargas, "Los proyectos hidroeléctricos y su aporte a la matriz de generación de energía en Colombia", Univ. EAFIT, Medellín, 2023.

[15] J. O. Bacca Garcia, "Análisis de la viabilidad de la hidroelectricidad en Colombia", Magíster en Medio Ambiente y Desarrollo, Univ. Nac. Colomb., Bogota, 2019.

[16] E. Lopez Suarez y J. Mera Vega, "Prototipo de generador hidroeléctrico con molino de agua para una granja y su sistema de riego en zona veredal del Departamento de Santander", *Docencia*, vol. 1, no. 1, p. 63, 2019.

[17] C. A. Osorio Rosado, "La Consulta popular ante los impactos ambientales de la construcción de Proyectos Hidroeléctricos en Colombia. Estudio del Caso de la hidroeléctrica El Quimbo", Trabajo de grado, Univ. Catol. Colomb., Bogota, 2020.

[18] D. H. Cristancho Castillo, "Estudio de la Micro Generación Hidráulica de Energía (MGH), como fuente no convencional de generación distribuida", Trabajo de grado, Pontif. Univ. Javer., Bogota, 2021.

[19] P. A. Maya Ruiz, "D. H. Cristancho Castillo, "Estudio de la Micro Generación Hidráulica de Energía (MGH), como fuente no convencional de generación distribuida", Trabajo de grado, Pontif. Univ. Javer., Bogota, 2021

[20] R. Hernandez Sampieri, M.P. Baptista Lucio, C. Fernandez Collado, Metodología de la investigacion (6a ed.). Mcgraw-HILL / Interamericana Editores, S.A. DE C.V.

[21] C M, S. Honnasiddaiah, R. Hindasageri, V. Madav, "Studies on application of vertical axis hydro turbine for sustainable power generation in irrigation channels with different bed slopes," *Renewable Energy*, vol. 163, pp. 845–857. doi: https://doi.org/10.1016/j.renene.2020.09.015

[22] A.H. Elbatran, O.B. Yaakob, Y.M. Ahmed, M.R. Jalal, "Novel approach of bidirectional diffuser-augmented channels system for enhancing hydrokinetic power generation in channels," *Renewable Energy*, vol. 83, pp. 809–819. doi: https://doi.org/10.1016/j.renene.2015.05.038

[23] D. Lucas, E.A.T. Spies, ·Diseño y Fabricación de una Turbina Eólica de Eje Vertical Impulsada por Dra.," *Revista Tecnología y Ciencia*, pp. 319–328.

[24] L. Acevedo, J. Lopez, S. Sánchez, Diseño de una turbina Banki para la recolección de aguas y generación de energía en una propiedad agrícola. Universidad tecnológica de Pereira. [Online]. Available: http://repositorio.utp.edu.co/dspace/bitstream/handle/11059/5770/62124A174.pdf;jsessionid=5662092429514C805182C7EA731C6F45?sequence=1

[25] Laboratorio de máquinas hidráulicas, Unidad 6 Turbina De Flujo Transversal O Michell Banki.2, 1–25. [Online]. Available: https://luiscalderonf.files.wordpress.com/2012/01/turbina-m-banki.pdf

[26] C. Alfonso, P. Gutiérrez, “La turbina Michell-Banki y su presencia en Colombia,” *Avances En Recursos Hidráulicos*, vol. 17, 33–42.

[27] V.K.T. Bangi, Y. Chaudhary, R.K. Guduru, K.T. Aung, G.N. Reddy, “Preliminary investigation on generation of electricity using micro wind turbines placed on a car,” *International Journal of Renewable Energy Development*, vol. 6, no.1, pp. 75–81. doi: https://doi.org/10.14710/ijred.6.1.75-81

[28] Y. Ochoa, J. Rodríguez, F. Martínez, Sistema de regulación y control de carga para aerogenerador de baja potencia. Universidad Distrital Francisco José de Caldas - Facultad Tecnológica.

[29] L.M.C. Ferro, L.M.C. Gato, A.F.O. Falcão, “Design of the rotor blades of a mini hydraulic bulb-turbine,” *Renewable Energy*, vol. 36, no. 9, pp. 2395–2403. doi: https://doi.org/10.1016/j.renene.2011.01.037

[30] Hidrotu, “La turbina hidráulica del bulbo 0.1MW-10MW/la turbina del agua con descarga grande y el agua baja dirigen”, Hoja técnica turbina de bulbo hidráulico, 2020. [Online]. Available: http://spanish.hydrotu.com/china-

[31] La_turbina_hidr_ulica_del_bulbo_0_1mw_10mw_la_turbina_del_agua_con_descarga_grande_y_el_agua_baja_di-295887.html. [Accessed: 08- Nov- 2020].

[32] Imagen turbina bulbo hidráulico. [Online]. Available: https://equipo2fae.wordpress.com/turbinas-kaplam/

[33] Turbinas Kaplan, Recuperado 28 de diciembre de 2020, de EQUIPO2FAE. [Online]. Available: https://equipo2fae.wordpress.com/turbinas-kaplam/

[34] J.A. Vargas, F.V. Clavijo, C. Torres Gómez, “Desarrollo del prototipo de un hidrogenerador eléctrico como alternativa de generación de energía limpia en zonas rurales,” *Ingeniare*, vol. 12, no. 20, pp. 91–101.

[35] N. Naoe, A. Imazawa, K. Takehisa, S. Nakamura, Bridge structure type micro hydropower-generating system and local region implementation. 2017 International Conference on Electrical, Electronics and System Engineering, ICEESE 2017, 2018-January, 78–83. doi: https://doi.org/10.1109/ICEESE.2017.8298392

[36] A. Plata, Diseño y desarrollo de un pico-generador hidroeléctrico para producción preindustrial. Universidad de Los Andes, 76.

[37] A.F. Delgado Flores, Construcción de un convertidor CC-CC tipo reductor orientado a la enseñanza. Universidad Tecnológica de Pereira, 42.

[38] M. Probe, E. IoT, Power Consumption Measurements for IoT Applications Application Note. Rohde-Schwarz, 1–16.

[39] D.N. Pane, M. Fikri, H.M. Ritonga, "Análisis del consumo de energía promedio en dispositivos IoT de baja potencia con Blockchain como solución de seguridad," *Journal of Chemical Information and Modeling*, vol. 53, no. 9, pp. 1689–1699.

[40] Y. Sun, J. Chen, Y. Tang, Y. Chen, "Energy modeling of IoT mobile terminals on WiFi environmental impacts," *Sensors*, vol. 18, no. 6, pp. 1–15. doi: https://doi.org/10.3390/s18061728

[41] R.K. Eldridge Scott, "La Internet De Las Cosas-Una Breve Reseña," *Internet Society*, vol. 83. doi: https://doi.org/10.1007/978-0-85729-103-5_5

[42] M. Kim, J. Lee, Y. Kim, Y.H. Song, An analysis of energy consumption under various memory mappings for FRAM-based IoT devices. IEEE World Forum on Internet of Things, WF-IoT 2018 - Proceedings, 2018-January, 574–579. doi: https://doi.org/10.1109/WF-IoT.2018.8355212

[43] I. Bonilla-Fabela, A. Tavizon-Salazar, M. Morales-Escobar, L.T. Guajardo Muñoz, C.I. Laines-Alamina, El Internet De Las Cosas Y La Innovación De Sus Aplicaciones, Trabajo de grado, UANL, Mexico, 2016.

[44] S. et. al., "Internet of Things (IoT): A Review," *Turkish J. Comput. Math. Educ. (TURCOMAT)*, vol. 12, no. 2, pp. 521–526. doi: https://doi.org/10.17762/turcomat.v12i2.871

[45] J. Flores Zermeño y E. G. Cosio Franco, "Aplicaciones, Enfoques y Tendencias del Internet de las Cosas (IoT): Revisión Sistemática de la Literatura," *Academia J.*, vol. 13, no. 9, p. 9, 2021.

[46] R. Arturo, A. López, Ciudad inteligente y sostenible: hacia un modelo de innovación inclusiva, 2007–3607.

[47] Consulta sobre el Internet de las Cosas (" IoT &quot). (n.d.). [Online]. Available: https://www.crcom.gov.co/recursos_user/20 16/Actividades_regulatorias/PCA_IoT/com /Verizon.pdf

[48] Innovation Center, B. (n.d.). Innovation-Trends-Internet-de-las-cosas-BBVA-Innovation-Center. [Online]. Available:https://www.bbva.com/wp-content/uploads/2017/10/ebook-ci-bbva-trends-internet-de-las-cosas.pdf.

[49] M.B. Andrés, Internet De Las Cosas. [Online]. Available: https://www.editorialreus.es/static/pdf/primeraspaginas_9788429020380_internetdelas cosas.pdf

[50] [50] Internet De Las Cosas: Retos Para Su Desarrollo. (n.d.).

[51] [Online]. Available: http://www.ift.org.mx/sites/default/files/conocenos/pleno/presentaciones/maria-elena-estavillo-flores/comenoriotmeef160523.pdf.

[52] [51] N. Bernar, et al., "Urban planning and smart city decision management empowered by real-time data processing using big data analytics," *Sensors (Switzerland)*, vol. 18, no. 9, pp. 6–12, 2018.

[53] C. Chuquimarca, "Análisis comparativo entre arquitecturas de sistemas IoT," *RITI J.*, vol. 10, no. 21, p. 16, 2021.

[54] Anónimo, "¿Qué son los sensores IoT y para qué sirven? ¡Descúbrelo! | Tokio". Tokio School. [Online]. Available: https://www.tokioschool.com/noticias/sensores-IoT/

[55] R. Faludi, "¿Cómo se comunican los dispositivos de IoT ?" Dispositivos y servicios IIoT para redes M2M | Digi International. [Online]. Available: https://es.digi.com/blog/post/how-do-iot-devices-communicate.

[56] "No solo Wi-Fi: estándares de comunicación inalámbrica en IoT". Elektronische Teile. Vertriebshändler und Onlineshop - Transfer Multisort Elektronik. [Online]. Available: https://www.tme.com/co/es/news/library-articles/page/53063/no-solo-wi-fi-estandares-de-comunicacion-inalambrica-en-iot/#zastosowanie-urzadzen-internetu-rzeczy.

[57] "¿Qué es? | IoT Devices (Dispositivos IoT) - OnTek". OnTek. [Online]. Available: https://www.ontek.net/que-es-iot-devices/#:~:text=Los%20dispositivos%20IoT%20están%20diseñados,:%20consumidor,%20empresa%20e%20industrial.

[58] "Innovacion y Tecnologia". [Online]. Available: https://innovacion-tecnologia.com/iot/dispositivos-iot/#google_vignette.

[59] "los 13 dispositivos IoT más populares para el hogar y el trabajo". Geekflare. [Online]. Available: https://geekflare.com/es/most-popular-iot-devices/

[60] “5 Ejemplos de Dispositivos del Internet de las Cosas en la vida cotidiana | SEIDOR”. SEIDOR | Consultoría Tecnológica. [Online]. Available: https://www.seidor.com/blog/internet-de-las-cosas-ejemplos

[61] “Megalista: ejemplos de dispositivos Iot 2023”. Open sistem. [Online]. Available: https://open-sistemas.com/dispositivos-iot/.

[62] “IoMT, 5 tendencias del IoT Militar| infoTeknicoo”. infoTeknico. [Online]. Available: https://www.infoteknico.com/cinco-tendencias-de-iot-militar-iomt/

[63] J. M. Martinez Martinez, J. Mejia Miranda, M. A. Muñoz Mata y Y. M. Garcia Molinaes, “Security in the Internet of Things: Information Traffic Analysis for iOS Apps,” *Rev. Electronnica Comput. Informatica, Biomed. Electron.*, vol. 6, no. 1, pp. 77–96, 2017.