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LOW POWER HYDROELECTRIC SYSTEMS (LPHS) TO ENERGIZE IoT DEVICES: A REVIEW

SISTEMAS HIDROELÉCTRICOS DE BAJA POTENCIA (SHBP) PARA ENERGIZAR DISPOSITIVOS IoT: UNA REVISIÓN

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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.

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 world population lives in places where energy depends on fossil fuels; thus, 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 know in detail the structure of Low Power Hydroelectric Systems (LPHS) and establish a perspective for future Colombian context research aswell.

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: Papers related to Hydroelectric Energy Generation review was made, in which 30% research, advantages and disadvantages of LPHS using; 35% enlightened about generators, batteries and converters that complements and strengths this kind of systems; and, finally, IoT devices application record 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, thought of designing and implementing sensors and devices feeding systems by clean energies is an advantage over other generation ways with resources that, although exhaustible, are easily found in national geography and therefore viable for Its implementation in electric system non-interconnected zones.

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.

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

TEXT SHAPE

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 same way: transform nature's available energies into usable electrical energy, [1].

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

On the other hand, in all countries exists renewable energy sources which potential has not been totally exploited. The International Renewable Energy Agency (IRENA) has calculated that 90% of world electricity can and should have Its nature in renewable energies for year 2050, [2].

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

It's so, on 2021, due mostly to pandemic, energy producing increased a 5,7%; then it normalized back onto 2.5%; but since, it has been increased again annually. This generation increasing 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 at other Asian countries (especially south Korea, Malaysia, Thailand, and Japan); and on Latin America (+4,9%) (including +1,9% Brazil and +2,6% in México); Canada (+2%) and Australia (+1,9%); while it remained in África given that increasing in Argelia and Egypt was compensated by a drop in South Africa production. Meanwhile, energy generation contracted a 2,8% in Europe (including -3,6% at EU) due to a dropping of 15% in France, which was partially compensated by a greatest energy generation in Spain and the United Kingdom (around +6% each one), in line with lowest electrical consume. It dropped also more than 27% in Ukraine due to OTAN war; while Russian energy generation remained paradoxically stable, [3].

Technically, to implement a necessary characterization, electric energy is called that results of the existence of a difference of power between two points which allows establishing an electric stream between them getting a work from a renewable energy source; in that sense, It's obtained by the electric charge movement produced inside conductive materials and can turns into many energy types, like luminous, mechanic or thermal, [4].

Said the above, electric energy mostly generated by fossil fuels and/or nuclear energy sources consumers, represents risks and damages to the environment. To this, is added the international oil increasing costs, Its inevitable depletion, the demand of large amounts of energy and the aging of current electrical networks. This has made that, in the last third of te XX century and XXI beginnings, the contamination, climate change and fossil sources shortage concerning has forced to redirect the efforts towards renewable energies production (solar, wind, biomass, hydraulic, among other).

In that perspective, on 2022 occurred an important impulse and development to electricity generation based on renewable energy sources, reflected on exponential increase of Its worldwide contribution: near of 29 % of electricity comes currently from processed energy sources at great plants or stations: Thermoelectric, Thermonuclear, Thermal, Solar, Photovoltaic, Hydraulic, Wind, among other, [4-5]; but where centered on renewability have less environmental impact than conventional, besides of a high energetic efficiency understood as the optimization of energy consumption to reach high comfort and service levels, [6].

As indicated, is an energy type that harnesses water sources in wide range from large scale (oceans, rivers, dams and waterfalls) to microscales, [7]. This is how hydroelectric station model not only has represented a significant progress as a technological solution to provide energy to developing countries; but also, is maybe the best solution in industrialized countries, [8]. In Colombia, for example, it is estimated an average annual demand growth near to a 2.9%; added to the fact that it represents around 70% of the whole generation, [9].

Globally, on the other hand, the installed capacity for hydraulic power generation on 2019 amounts 1,4 of GW, 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.

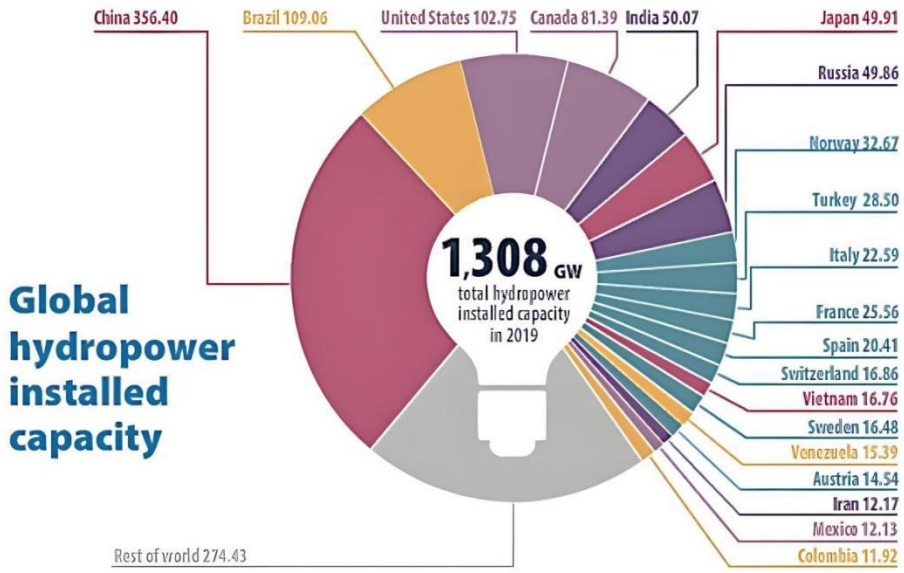


Figure 1. Installed capacity of global hydroelectric production, [3].

In the middle of this panorama, although has been preferred hydric resources on big scale to build hydroelectric plants, this has implied a high investment in engineering and infrastructure to maximize efficiency of high-altitude hydraulic turbines, [8]. On the contrary, low scale hydric 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 are clean and economical alternatives because minimize environmental damage and reduce projects' management and cost, [7]. Small hydroelectric model considers a power capacity lower than 5 MW and It is generally classified according to chart 1:

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

Chart 1. Hydroelectric station types, according to Its power. Own adaptation of [10].

A Pico, Micro or Mili hydraulic station requires a minimum water reservoir, and Its implementation could be made of Ultra or Very Low Head (ULH) OR (VLH) resources given 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 hydric resources make speed timing unsteady, what avoids continuous electricity generation, [11]. So, Micro and Pico hydraulic designs can provide energy for industry and agricultural application and domestic uses 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 of fitting and design of a low power generation system (which capacity transform lower than 50 KW energy by a primary form to electric energy); transport and distribute it to end consumers and, for practical efficiency reasons, adopts in a generalized way the stream's on an altern form. Here, identifies four fundamental processes: *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 like using and environmental variables monitoring on Monitoring Stations of IoT devices sensor systems, that could be seen as a combination of sensors and actuators capable of provide and/or get information, digitalize it and transmit through bidirectional data network for being used in different users and services.

They 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 nature system, where identifies subsystems of *Source, Capture, Regulation, Storage, Reversal and Sensors*; and to which the corresponding associated devices are added.

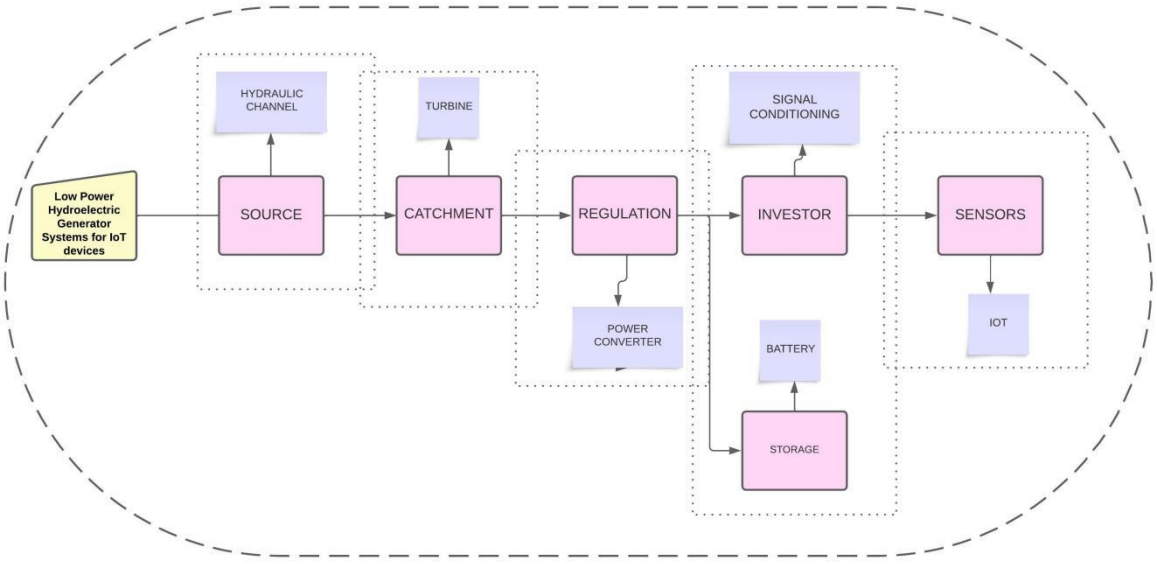


Figure 2. Block diagram of a Low Power Hydroelectric Generation System for IoT devices. Source: own elaboration.

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 in which documents this nature energetic

generation, but micro and Pico scale. In this sense, there are studies in which describe sources located such as in rivers from where power feedings are implemented for cities. In this perspective, have been found some cases in dependence to modernization and known modification of technics for energy generation with less negative impact front of not 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, can't be lost sight of the necessity of re-design the followed stages in the generation given in figure 1, using redesigned plants and tailored to located renewable energies. These have a participation of 17% in whole global energy generation and 45% in world renewable energies generation capacity; in Colombia, somewhat represent more than 60% of energy matrix, [14].

Said this, local necessities have made Small Hydroelectric Stations a priority in the country due the favorability in Its implementation, considering the isolated geographic, 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 heat wave phenomena which cause the energy supply to decrease as well as precipitation and warm winds proliferation. This situation, added to governments lack of foresight and electrical sector planning Colombian companies in charge, led 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 and with it assure an improvement in energy supplies delivery, [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' that provides public electric energy distribution and supply service in Colombia, [17].

Due to it, even attention over low scale hydroelectric stations front proliferation of Non-Interconnected Zones have increased, there is a documentation absence, particularly over hydraulic micro and Pico generation systems.

That is, hydraulic generation systems have been historically identified with hydroelectric with high altitude dams and small stations that doesn't have a reservoir. Low scale hydroelectric generation, in so far as contributes more at sustainability promotion given that it develops over a renewable natural resource prone developing without affecting ecological wadi flow and offers the possibility of non-blocking fish passage 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].

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

2. MATERIALS AND METHODS

Throughout last decade has been profusely investigated about IoT devices and Its relationship with internet and remote but intelligent and appropriate communication. Above encouraged by infinite possibilities that exist to integrate it or make it converge. In that sense, investigating task for better ways to this communication arrives to places where access is too difficult, needs energization, by clean power generation, and besides allows to reach it in a right implementation regarding territorial needs.

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

In the previous perspective, were focused databases like Google Scholar, Elsevier; digital repositories, specifically, Francisco Jose de Caldas Distrital University and scientific journals of electronics, control, and telecommunications. For documentary identification were used descriptors like *renewable and nonrenewable energies, IoT, Turbines, Batteries, IoT sensors.* Product of the analysis, last 5 years Colombian context was selected. Most Spanish language sources were prioritized to make the critical, bibliographic and knowledge review more accessible for national academic community. Following to 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 being has been evolving by the hand of extractive economy; and renewable energies, which are found in nature –apparently inexhaustible-, less polluting and less aggressive for 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 taxonomy is provided, exploratory nature of the research emphasizes those in flow or at rest, and starting there is established jump criterion, in other words, flow’s height or inclination: high, medium, or low, depending on the storage capacity that can be measured in Kilowatts of power.

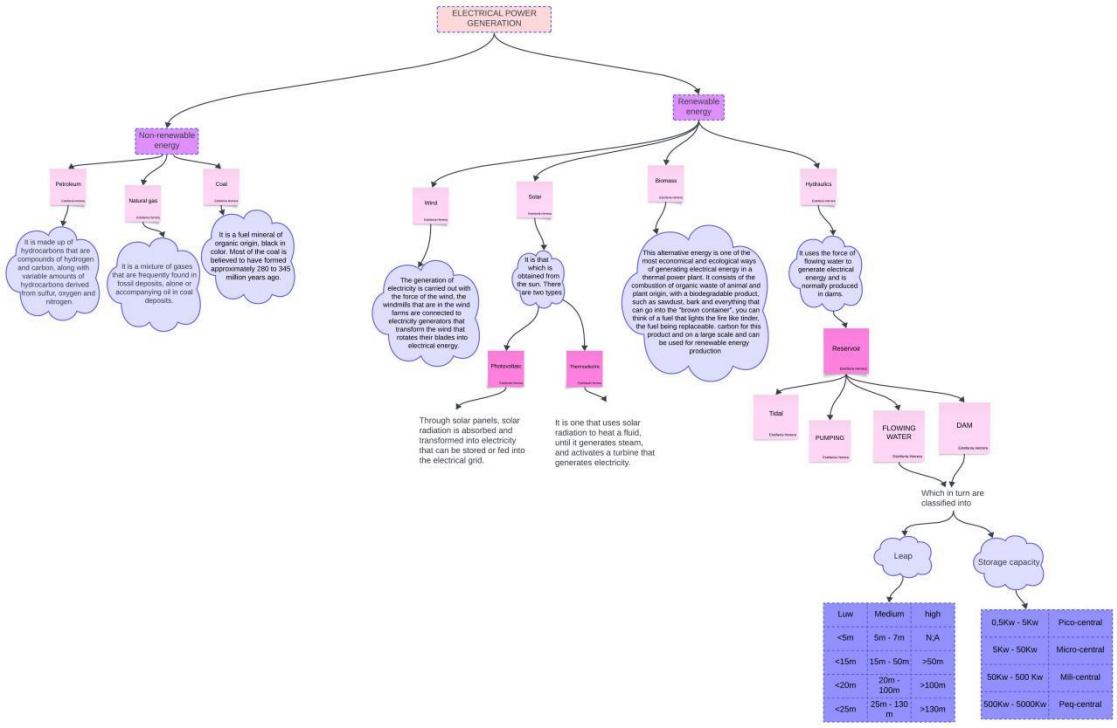


Figure 3. Categorization corresponding to electric energy generation. Source: own elaboration.

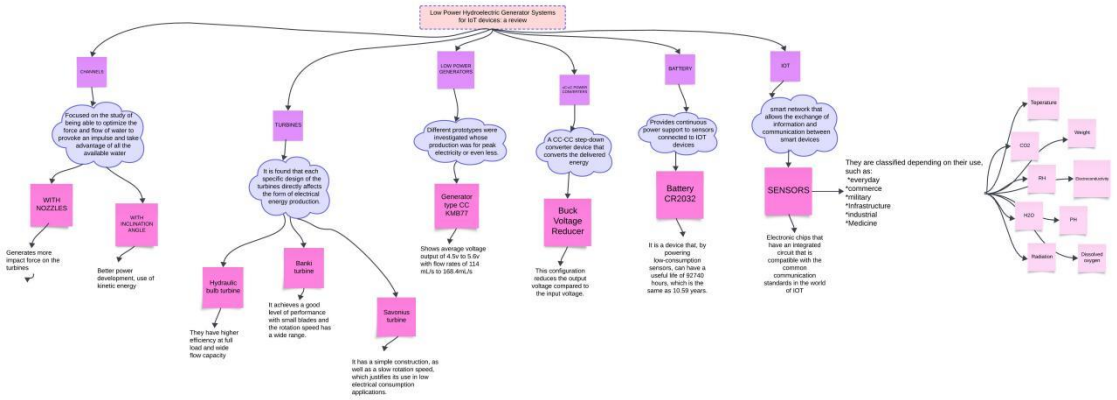


Figure 4. Subcategorization of low Power Hydroelectric generators for IoT devices. Source: authors.

In Figure 4, otherwise, step by step description of low power hydraulic generation system is observed. First is observed as source drainage channels that allows water passing -with or without inclination-, and according to these turbine type 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; and complementing the system, there is a voltage reducer that allows an output voltage lower than input one. Is established an external battery used as IoT sensor backup, which are classified in different types depending on their use and necessities, according to requested requirements.

3. DEVELOPMENT

3.1 **Drainage channels**

Initially, research focus in drainage channels, irrigation, rainwater reception, among other; so that according to basic principles of hydroelectricity, 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.

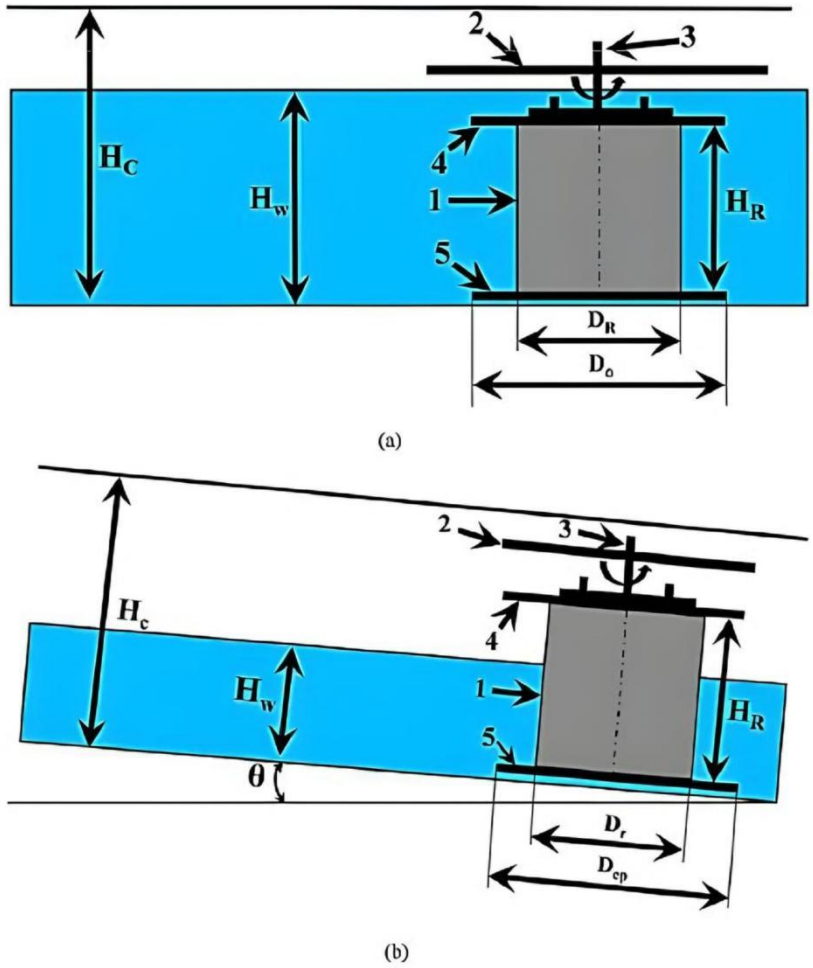


Figure 5. Experimental installation diagram into a horizontal channel (a) and an inclined channel (b). 1. Savonius Rotor, 2. Top Plate, 3. Rotor axis, 4. Rotor Top End Plate, 5. Rotor Inferior Part, Ending Plate, [21].

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

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

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 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, is determined that through channels, with 20 m length dimensions whole channel; 0,6 m width and 1,2 m channel depth (figure 5), with speeds of 0,6 m/s, 1m/s y 2 m/s, obtains efficiencies of 0,517 and 0,55 respectively.

Also have to consider that for better production and efficiency energy increase is needed more shock impact of water in turbines [22]; consequently, nozzles for turbine exert pre sure are designed, so there is more channels flown flow; this leads to the possibility of using two turbines, top one and inferior one to take advantage of the generated flow [6]. Another aspect to consider is the inclination angle of the channel, where to an elevation between 0° and 2 ° and while inclinations increase there is a tip speed rising (TSR), but power rates and performance decrease, this can be seen in figure 6, [22]:

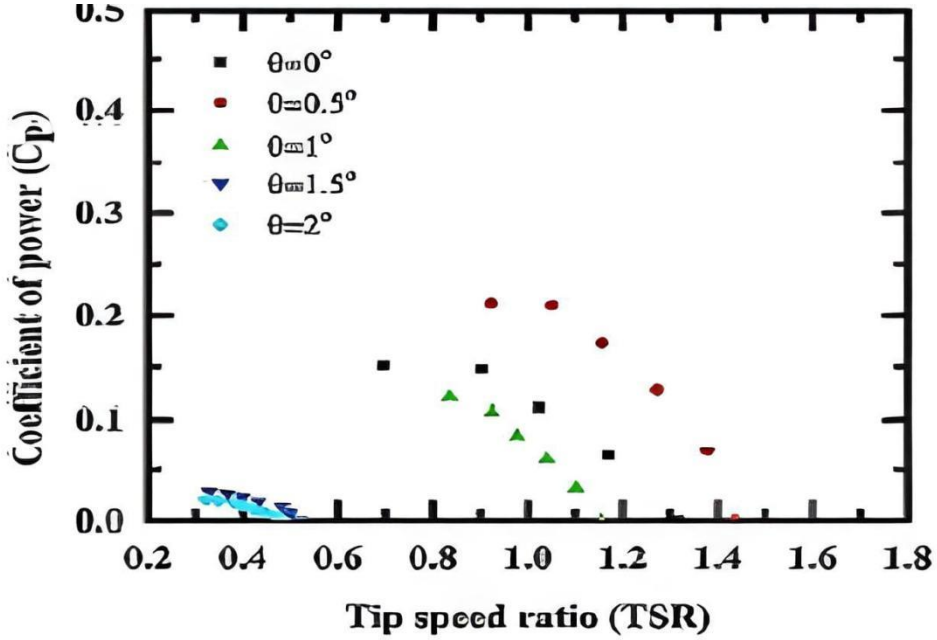


Figure 6. Powe rate variation regarding to tip speed for q= 0º to q= 2º channel inclination, [23].

3.2 Mini turbines

Is found in literature that turbines used to energy generation in macro hydroelectricity, with changes, manage to be totally appropriate and functional for low power production. Among these stands out Savonius turbine, figure 7, which is an eolic turbine type with vertical axe 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
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

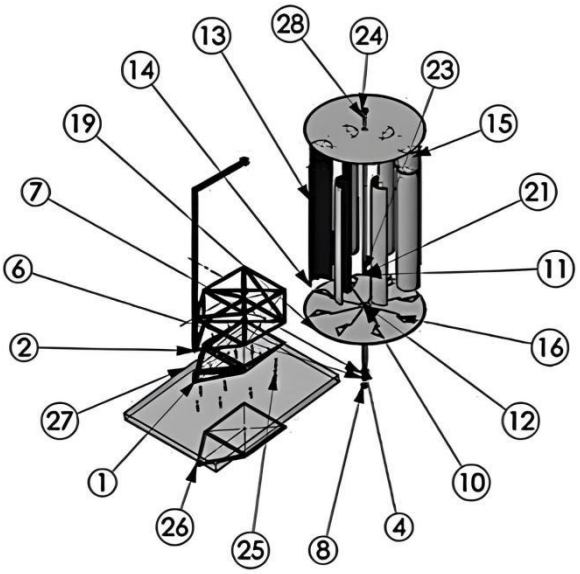


Figure 7. Savonius turbine and its parts, [23].

Another turbine that meets the low power generation functionalities is Banki turbine, figure 8. Is wide 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].

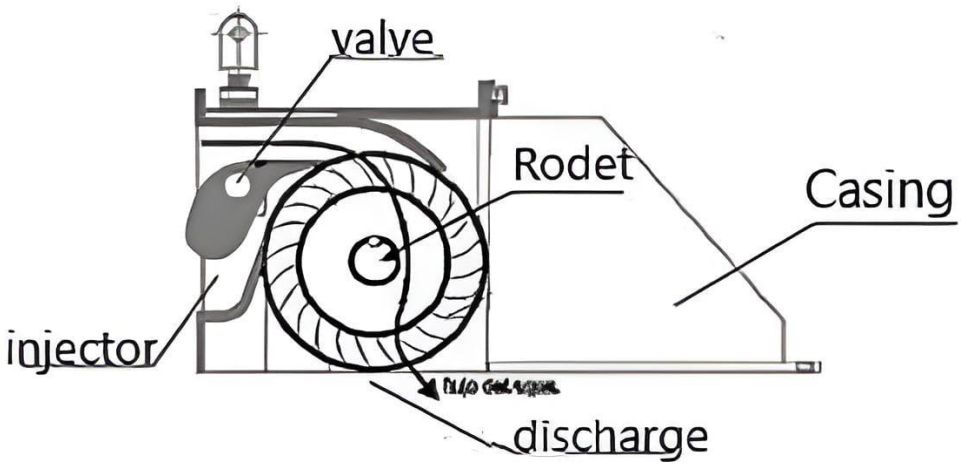


Figure 8. Banki turbine and its parts, [26].

By the other side, 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]. Although tests were done in computer simulations and in air flow platforms that causes variations in net

efficiency due air density is lower than the waters and, in consequence, change applied powers and speeds in a liquid environment, even slightly, [30].



Figure 9. Hydraulic bulb turbine, [31].

3.3 Generators

As for the low power generators oriented to Pico hydroelectricity production, is observed that exists different types that could be implemented. Generally, is worked with generators that show average power between 1W and 1kW, with output tensions of 12 volts, and an efficiency of 95% [33]; this variate depending on RPM which generator is working; Its power and channels flow. From this point of view, was found that a first experience uses the DC generator (type KMB77, figure 10), which average tension production is between 2.5 to 5.6 Volts with flows between 114.0 to 168.4 mL/s [35]; with it follows that voltages in generator terminals are stable and applicable for 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 mechanic power into electric power; [35]. In it, the generator is documented with the proper experimental tests, becoming evident speeds near to 1.000 rpm. The designed generator could reach almost 40kW of power, with efficiencies near to 80%, [36].

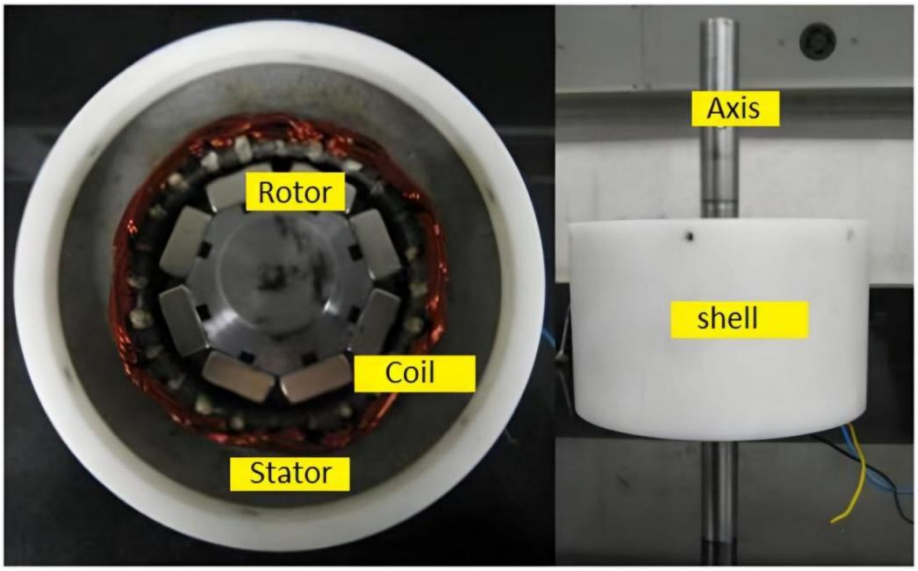


Figure 10. assembled KMB77 generator and Its parts, edited by the authors, [36].

3.4 dc-dc power reductor-converter

Due IoT devices low consume, regarding to power that generators give, is necessary design and implement a conversion stage through a DC-DC reductor-converter device. In found experiences was observed that 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.

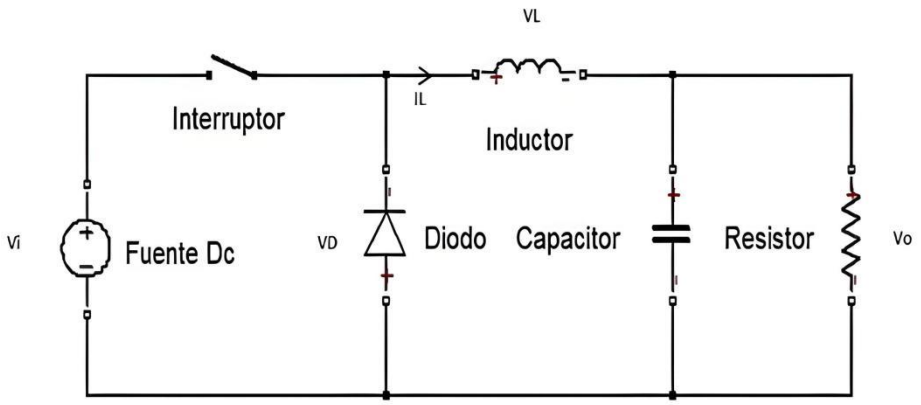


Figure 11. Buck reductor-converter circuit, [38]

Its components and characteristics are shown in chart 2:

ELEMENT	FUNCTION
Diode	Allows current to flow through the circuit when the switch is open
Switch	N type mosfet transistor

Inductance and a capacitor	They do filter the output signal of the circuit
Resistance	Power stage output load

Chart 2. Components of converter circuit. 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 uses whole stored energy before interrupter commutes and passes to closed state, [38]. Based on these criteria, can be designed necessary circuits to carry out the proper power conversions that requires among energy generation and supply stages in the IoT systems.

3.5 Battery

Taking into account that water flux in studied channels is not continuous, which affects directly the energy production, must consider the battery application so that the same IoT systems are not suspended due to alimentation lack. In this sense is made a review of applicable batteries for those elements. According to facts above, can be attached to the low power IoT devices, small batteries or button batteries; these have voltages around 3V and 220 mAh; among them: CR2032 button battery, figure 12, [35], where is documented that with low consume Bluetooth communication, 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, can be focused energy generation to charge the battery and so extend Its useful life; or directly use the produced energy for feeding IoT devices, and have battery as a reserve when there is no water flux that generate energies.



Figure 12. CR2032 button battery, the authors.

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 population ensures use occasional internet or at least counting with a mobile device, has shown that the more people have access to communication and information infrastructures at global level, proportionally citizens life quality has evolve 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 technologic world, especially in communications. Considers an intelligent network that allows 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 desire tasks through automatic learning, [44]. That is: a powerful platform capable of connecting devices for monitoring topics of daily life, [45]. One of principal contributions of IoT is on increasing of information value thanks to large number of interconnections among things and information, can allow people being connected anywhere or anytime with things or people using ideally any kind of network, route, or server [46].

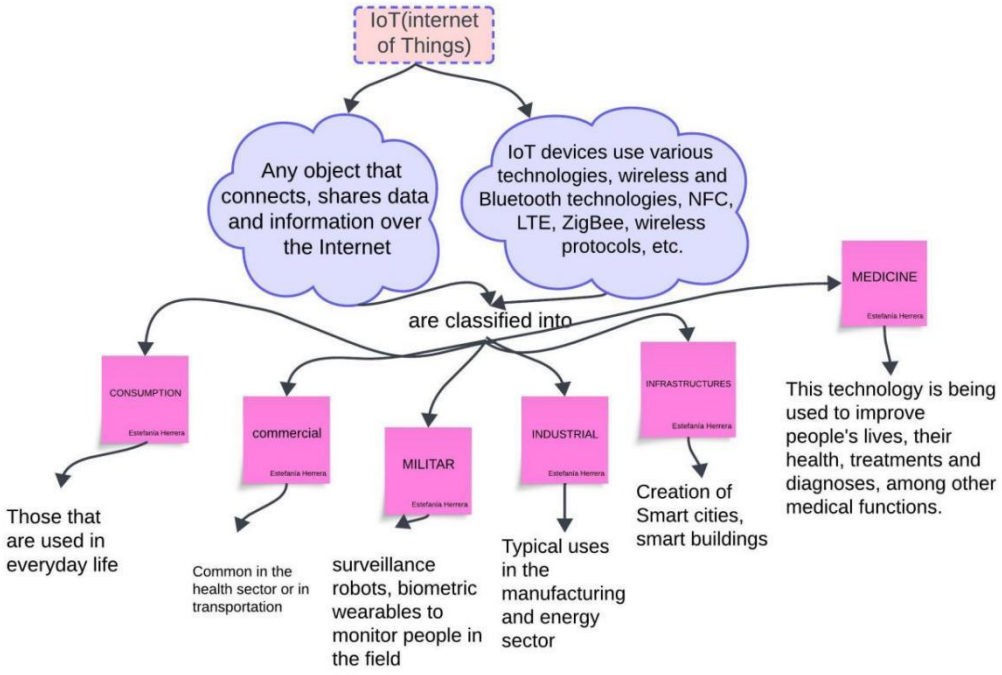


Figure 13. IoT and its branches or levels of enforcement. Source: own elaboration.

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 most important. Are increasingly within the reach of people because has spread base knowledge with facility for designing and programing from zero a project with professional profile.

Among some hardware elements simple and typical 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 connect to a Wi-Fi network and make TCP/IP connections using Hayes type commands; ACS720 current sensors equipped with 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 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 fast response in humidity range of 20%-95%, and temperatures between 0°C-50°C, [47], [48], [49], [50], [51]. Other high sensitivity sensors, more sophisticated, have been developed for example, to detect electromagnetic emissions up to 20 GHz, as so 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.

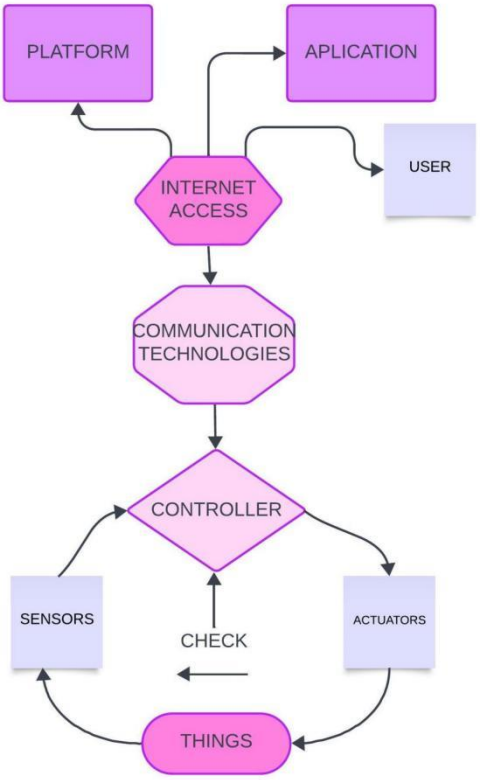


Figure 14. Architecture, elements and operation in IoT. Source: adapted by authors of [46].

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, is necessary that users feel safe about data protection and Its privacy. In this context, for IoT have found multiple layer security architecture series: 3 layers, 4 layers, ending on current 6 protection layers, last one corresponding with hierarchical structure on a network, and are described like this:

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 transmit it through communications like Wi-Fi, Bluetooth, Zigbee, among other.
D. Middleware layer, in charge of processing the sensors receipt information.

E. Application layer, it makes IoT application for industries based on last processed data.
F. Business layer, it manages IoT applications and services, [36].

Among IoT systems exists necessary elements for Its functionality, corresponding to layers:

A. Devices, any object that could connects to 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 exist protocols among which must choose, as so are:

- 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 scape th difficulties of proper internet.
- Zigbee and Z-wave are the greats of home automation networks because are optimized for low consume communications and low bandwidth, and both allow home devices directly communicate 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 miles of range in line vision for devices that only have small things to say.
- Bluetooth and its low energy sister BLE are very popular for simple IoT devices. None of them can communicate very far, so must be used 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 battery to work for months without recharging them, in exchange of a limited bandwidth.
- Other protocols like 4G LTE and 5G requires much more power, but also can manage heavier data like digital video.
- There are also many proprietary protocols and from single manufacturer that adapt to unic 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

Due to high demand of technological provision in processes was identified that there lies most of innovations: repetitive actions and are susceptible to automation (that an integration of tools does work without needing human intervention). One of the innovations of this automation lies in sensor networks (biosensors and others of adaptative nature) that facilitate information harvest 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 signals

increasingly weak; as so a conditioner in charge of transform those readings into interpretable data by electronic devices [53]; in general, IoT sensors properly energized, serve for:

- **Capture information** in an easier way.
- Improving **reliability and security** in data capture.
- **Automated processes.**
- Reduce interaction and **necessity of technical staff** that make right concrete measures in some areas.
- **Improving data availability** for companies and users at every place and moment.
- **Save time and resources** for companies that implement IoT sensors on Its productive processes.
- Improving **compliance with safe measures** of TIC departments of companies in different productive areas.

This functionalities of IoT devices becomes in some of best advantages; although, of course, this kind of technologies demands challenges when is about low power feeding in a continuous way; quality data extraction with IoT sensors will be guaranteed by continuous and safe feedings [46].

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

IoT purpose is to extend internet connectivity beyond standard devices, like computers, smartphones, and tablets, to any kind of physical devices and daily objects none enabled for 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 part of a scenario in which each device talks with other devices related in an environment for automate housework and industries'; and to communicate sensors data usable for users, companies, and other interested parts. IoT sensors are designed to work in concert for people at home, industry, or company.

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

- **Temperature and humidity:** IoT sensors for humidity measure heath level and humidity generated in a determined area. Acts in a concrete range around an objective area.
- **Accelerometer:** accelerometer sensors enable monitoring by a remote way the vehicle speed of any kind.
- **PIR sensors:** Monitories 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, 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, 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 already are lots of devices connected to internet to make easier human beings' life. Besides, IoT software has more and more standards that make it accessible to create any kind of devices. Other IoT examples and applications for daily life, [57]:

- **Geolocation devices**, that relate among them triangulating the signal of another device to localize it. commercially a clear example is Apple tag.
- **Gas lacks detection sensors** in homes or electronic devices with failures.
- **Home safety**: sensors, lights, alarms, and cameras that can provide continuous safety and uninterrupted.
- **Pet monitors:** It can help with interaction, programing, and food dispending.
- **Smart locks:** safety while 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, 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 expired alcohol inside vehicles can block car starters.
- **Connected appliances:** Based in robots in housework's or that predicts 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 measure sweating during a physical activity.
- **Virtual assistants** that control devices and enable do 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. In other sense, 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**, so as Its vulnerability to adverse meteorological conditions, 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 other, [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 forefront of 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 other [60].

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

Personal	**Home automation**	**Industrial**	**Automotive**	**Smart Cities**

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

Chart 3. Some IoT sensors that complement daily activities. Proper adaptation from [62].

4. DISCUSION AND CONCLUSIONS

Lack of infrastructure, wrong managements or governmental decisions have induced deficit of generation or energy supply. Given this, the way nonrenewable resources have been used for electric energy generation consider friendly technological solutions with planet; in that sense make SHBP viable, energize sufficiently IoT devices consistent with TICs permitting monitoring, sensing or measure different kind of necessities depending on context is required to use. Source here determined are drainage channels that with length of 20m; 0,6m width; y 1,2m depth; endowed with velocities between 0,6 and 2 m/s, reach energetic efficiencies of about 50% and 60%; in addition, increase hit impact of water in turbines can be done with nozzles that increase pressure exerted, as well as position more turbines takes advantage of generated flow. On the other hand, artificially increases the inclination angle of channel although increases tip speed (TSR), decreases performance and power coefficients. That is: technologic considerations go by the hand of geography, Hydrography and Colombian urban or rural environment.

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

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