VOL. 15, NO. 6, MARCH 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
©2006-2020 Asian Research Publishing Network (ARPN). All rights reserved.

www.arpnjournals.com

PICO-HYDROPOWER PLANT FOR THE ECOLOGICAL BOARDWALK ON THE RIVERSIDE OF THE LAS CEIBAS RIVER IN THE CITY OF NEIVA

Jesús D. Quintero P, Diego F. Sendoya-Losada and Josede Jesus Salgado Patrón
Department of Electronic Engineering, Faculty of Engineering, Surcolombiana University, Neiva, Huila, Colombia
E-Mail: jdavid@usco.edu.co

ABSTRACT

The primary object of the study was to design an electricity generation system based on pico power plants aimed at energy consumption in lighting of the 'Malecón Ecológico' park in the city of Neiva, to contribute with the offer of spaces for recreation in harmony with the natural environment. A study of the energy consumption of the park is carried out to define the design parameters of the generation system. Then, the necessary parameters for the installation of the power plant are evaluated in order to recognize the technology that best adapts to the conditions of the land and the needs of the users. It ends with the design of the protection and distribution system of the power plant in order to obtain an efficient use of the led lighting system. The representative values of the sampling made for the average speed were 1.70432681 m/ with the technique of digital pinwheel and 1.69715616 m/s with the floating body technique. This shows a difference of 0.007 m/s which is negligible when establishing the average speed of the river by any technique that is used. The average levels of the river are of 2.1245 m/s for the high level and 1.7505 m/s for the low level. It is recommended to dredge the site where it is planned to install the pico-hydro power plant to keep the water level constant under critical flow conditions in order to avoid efficient operation.

Keywords: distribution, energy, las Ceibas River, pico-hydro power plant, photometric study.

1. INTRODUCTION

Electric power has become a necessity for human beings. Obtaining ways to generate it at low cost and in a sustainable manner with the environment is a challenge. The present article contains the information related to the study and design for the installation and operation of a system of pico-electric power stations that serve for the energy supply, for the light system and other uses, in the ecological boardwalk of the river 'Las Ceibas' in the city of Neiva. All of the above is done with a social, environmental, cultural and technological projection that gives the population of this city a perspective of the different ways of obtaining electric power.

The article also details a financial and technical study on the transport and distribution of electricity from the point of generation to the point of consumption. This study also reports on the amortization of the cost of the turbine. It is informed about the necessary instrumentation to adapt the electrical signal coming from the generator system and adequate to the levels of voltage, voltage, current, frequency, etc., that the luminaire circuit and its extended uses require.

The pico power plant technology represents an independence of the public network, everything leads to conceptualize these generators and their distribution systems under the term of 'off grid' systems. These suppose a solution of first necessity in remote areas where are hydric effluents that fulfill characteristics to install the turbines or in their defect to adapt the spaces.

It should be noted that the study and design are subject to the regulation stipulated in the RETIE and RETILAP, and other regulations concerning the legal issue on the installation and energy efficiency.

2. MATERIALS AND METHODS

2.1 Preliminary stage

In this stage, the place is inspected, "ecological boardwalk", where it is planned to install the electric power generation and distribution system. Essential design parameters are obtained for the construction company of the park. They emphasize the smallest civil work and the working hours of the luminaries (6:00 p.m. - 5:00 a.m.). In addition, the characterization of the latter must comply with the harmony of the architecture of the park and in turn the technical regulations to be installed in a site characterized as 'park', 'pedestrian path', 'alameda', etc., in the section 5 of the RETILAP.

Additionally, in this stage the plans of 'plant and details' of what is proposed to be built are obtained, this is provided by the mayor of Neiva. It is clarified that the place is also inspected in order to recognize the technology of generators of better adaptation to the terrain, either pico power plant of fall or hydrokinetic, having as election the latter.

Figure-1. Geo-referenced location of the "ecological boardwalk" park.

ARPN Journal of Engineering and Applied Sciences
©2006-2020 Asian Research Publishing Network (ARPN). All rights reserved.
www.arpnjournals.com

2.2 Field work

This stage involves the measurement of variables that are required for the design of the distribution network and for the choice of the hydrokinetic turbine of different manufacturers existing in the market. The variables measured are speed and level.

2.2.1 Speed measurement

This measurement refers to the determination of the velocity index of the water tributary where the installation of the hydrokinetic turbines is projected, it should be noted that the affluent here is the 'Magdalena River'. This speed measurement is done under two techniques, floating body and reel.

The floating body technique was advised by the water quality laboratory, who made a series of recommendations: no presence of tailings and palisades; to the obtained data apply a correction factor of 0.8 for the depth of the river and its surface velocity component of the water and the wind that performs a friction on the floating object. The technique consists of determining two points on the riverbank and measuring the distance in which they are separated. Then, two observers are placed at each point and the floating objects are thrown into the river to record the time it takes to get from one point to another. With this, the speed is calculated, and the mentioned correction factor is applied and its result is the speed of the river.

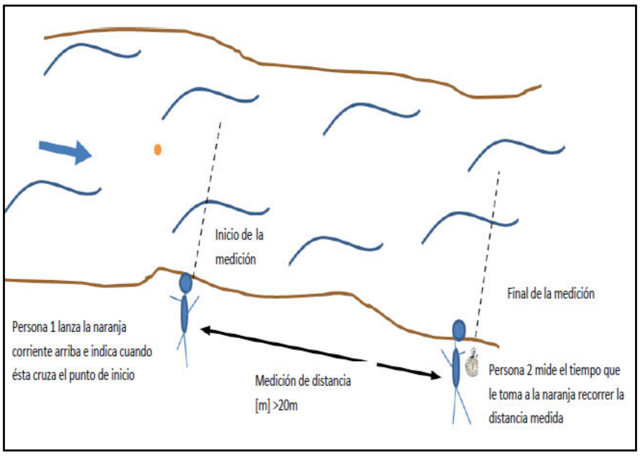

Figure-2. Speed measurement with floating body technique.

The pinwheel technique consists of a device, analog or digital, which contains a vane that according to the angular speed with which its blades rotate, will mark the speed or at least allow it to be calculated according to the device that is available. In this case, a digital device provided by the 'SENA - Techno park Angostura' of the Lab Quest brand is used.

Figure-3. Speed measurement.

The two techniques were used at the same time. The means of the techniques present an error of 0.007 m/s.

Table-1. Results with floating body technique.

Trial	Distance (m)	Time (s)	Speed (m/s)	Corrected Speed (x0.8)
1	20	9.62	2.08	1.66
2	20	9.46	2.11	1.69
3	20	8.84	2.26	1.81
4	20	9.16	2.18	1.75
5	20	9.87	2.03	1.62
6	20	9.25	2.16	1.73
7	20	9.72	2.06	1.65
8	20	9.47	2.11	1.69
9	20	9.81	2.04	1.63
10	20	9.18	2.18	1.74

Table-2. Results with pinwheel technique.

Time (s)	Speed (m/s)
0	1.350326538
1	1.415252686
2	1.442718506
3	1.478881836
4	1.502609253
5	1.54006958
6	1.545028687
7	1.575012207
8	1.613693237
9	1.647415161
10	1.682357788
11	1.671016846
12	1.697311401
13	1.713562012
14	1.738510132
15	1.758499146
16	1.743469238
17	1.743469238
18	1.722259521
19	1.727294922
20	1.738510132
21	1.738510132

VOL. 15, NO. 6, MARCH 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
©2006-2020 Asian Research Publishing Network (ARPN). All rights reserved.

Four measurements were made, two when the river had a high level and two in the opposite state, establishing a work point 'Q' equal to 1.7505 m/s. taking into account an extrapolation process made with historical data of levels provided by the IDEAM, taken by its station located on the Santander bridge of the city of Neiva.

2.2.2 Level measurement

The level measurement consists in determining the depth of the river in the place projected for the installation of the picocentral. The measurement is carried out by means of a rigid rod that is submerged, the section indicated by the humidity of the contact with the water is measured, and the length of the depth is determined.

The level measurement is essential for the election of the picocentral because some manufacturers demand a minimum level to be able to install the generating device in the tributary.

Figure-4. Level measurement.

2.2.3 Resistivity measurement

This measurement is a fundamental data to perform the design of the grounding system (SPT) of the circuit as a whole (generator system - distribution system), which supposes a protection to static and atmospheric discharges. The measurement is taken with a 4-wire tellurometer equipment using the Werner technique.

The measurements result in the premise that the soil is not homogeneous, because it is formed by debris and other materials that give this characteristic; therefore, it is necessary to make an SPT of the circuit and do not use this ground directly.

2.3.4 Selection of the pico-hydro power plant

After reviewing the conditions of the terrain and obtaining the variables of speed and level of the river, manufacturers were consulted that offer hydrokinetic turbines. Maneuverability, cost, generation, maintenance, etc., are taken into account for the choice. The manufacturer houses were Smart Hydro Power, Hydrosol's, JetPro, New Energy, and Smart Hydro Stream.

The chosen option is the one offered by Smart Hydro Power of Germany in its monofloat version whose generation is at 1.1 kW of power for that nominal river speed that has been established by the fieldwork carried out previously.

Figure-5. Monofloat turbine - Smart Hydro Power.

3. RESULTS AND DISCUSSIONS

3.1 Photometric study

The photometric study is performed by RETILAP, using simulation software certified or with a general public license. The software used for the simulation is Relux® whose algorithms are routed to outdoor environments. To carry out the simulation, the spaces to be illuminated on the plane provided by the construction company are detailed and the work areas are delimited, yielding the following simulation map.

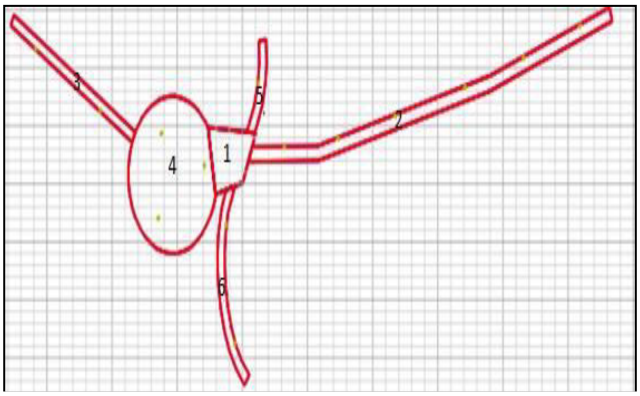

Figure-6. Work areas in the simulation.

The distribution of the lamps is made taking into account the criteria of the lighting regulation. This detail a formation of luminaires according to the height of the post, the projected post has a height of 6 meters therefore

ARPN Journal of Engineering and Applied Sciences
©2006-2020 Asian Research Publishing Network (ARPN). All rights reserved.

the distribution of the lamps is made at the discretion of the designer.

Table-3. Retilap classification of the lamp distribution according to the post height.

Illumination class	Heigth (m)	S/H Ratio	Lamp distribution	
			Criteria	Distribution
M1	12 to 14	3.5 to 4	Two lanes	Unilateral
M2	10 to 12	3.5 to 4	Two lanes	Unilateral
M3	8.5 to 10	3.5 to 4	Minor width lane	Unilateral
M4	7 to 9	3.5 to 4	Unilateral	
M5	6	3.5 to 4	Designer criteria	

The zones delimited in Figure-6 now of being simulated must present a regulation in luminance and uniformity, which are consigned in Table-4, remembering that the lighting class in this case is C3.

Table-4. Retilap classification for public spaces.

Clasification	Illumination class	Mean illumination (lux)	General uniformity
Multiple recreational courts	C0	50	40
Squares	C1	30	33
underground pedestrian crossings	C1	30	33
pedestrian bridges	C2	20	33
Low pedestrian areas and surrounding pedestrian and vehicular bridges	C2	20	33
Platforms, trails, walks and pedestrian malls in parks	C3	15	33
bike paths in parks	C2	20	40

To carry out this simulation, the streetlight zoom lamp with 44 watts of power was chosen. The results of the simulation are:

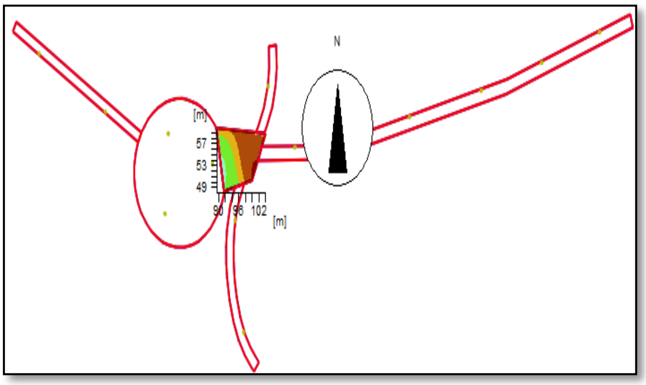

Figure-7. Area 1 simulation render.

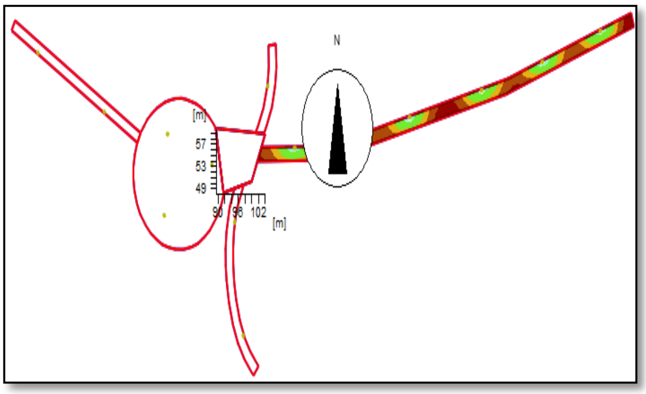

Figure-8. Area 2 simulation render.

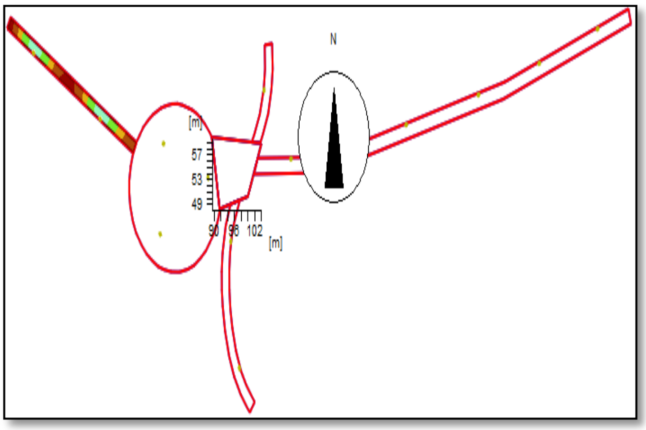

Figure-9. Area 3 simulation render.

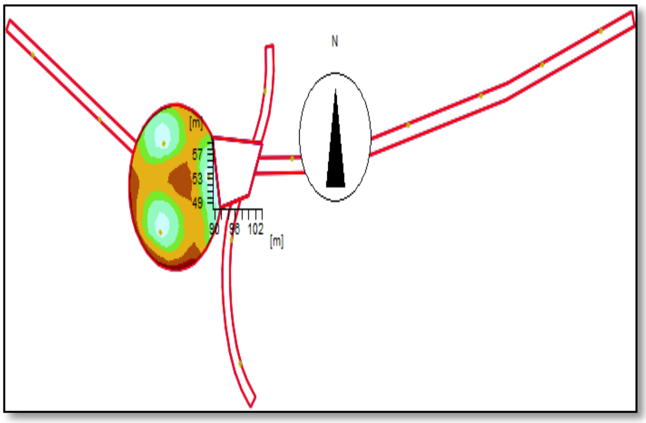

Figure-10. Area 4 simulation render.

VOL. 15, NO. 6, MARCH 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
©2006-2020 Asian Research Publishing Network (ARPN). All rights reserved.

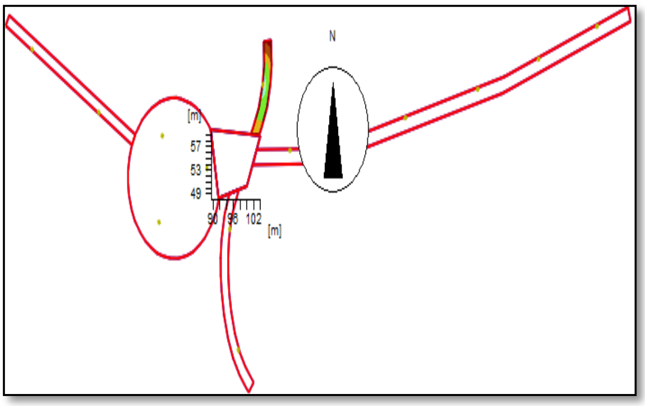

Figure-11. Area 5 simulation render.

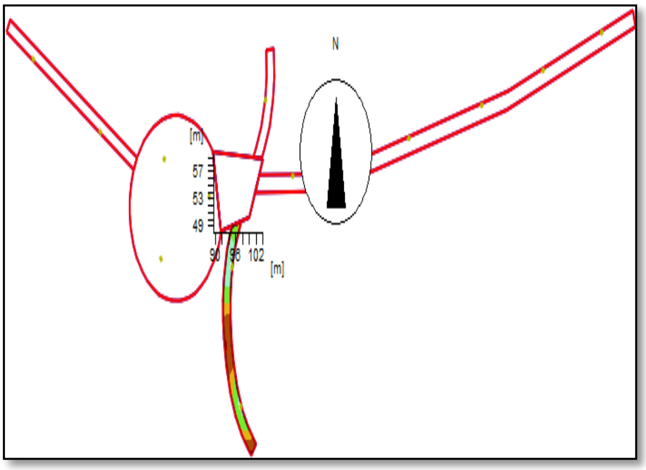

Figure-12. Area 6 simulation render.

Table-5. Simulation results.

Area	1	2	3	4	5	6
Uniformity	18	18	20.1	17	21	22.3
Mean Illum.	0.52	0.34	0.35	0.34	0.38	0.44

3.2 Generation system

The generation system consists of a turbine and the necessary instrumentation to adapt the electrical signal of power and send it to the circuit of lamps or distribution system. Figure-13 shows the electric connection diagram of the turbine with the energy management system (system that will treat the electrical signal).

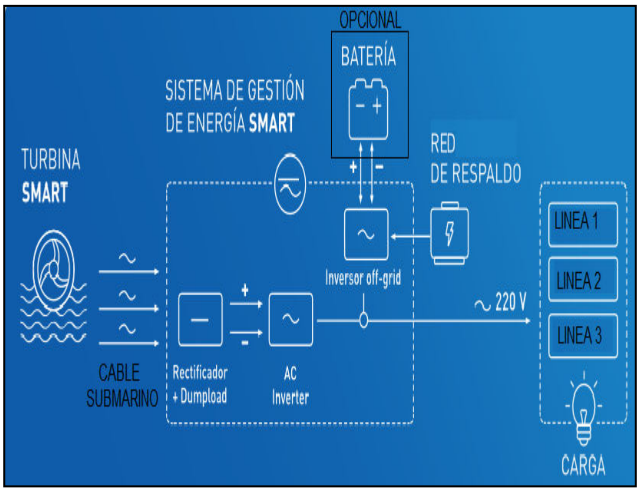

Figure-13. Electrical scheme of connections of the generation system.

The power management system is able, independently of the generation, to establish a biphasic, three-phase, single-phase output, with frequencies of 50 and 60 Hz, at 120, 220 and 360 VAC.

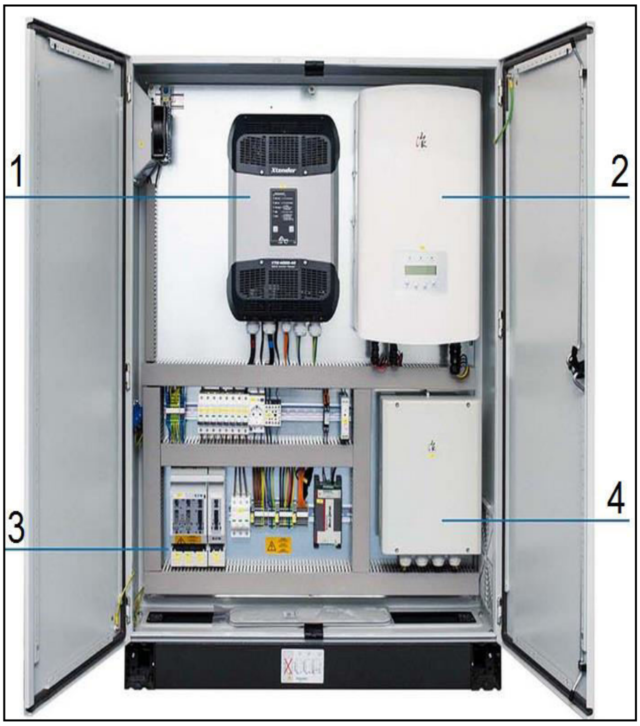

Figure-14. Energy management system.

The inverter, not connected to the network, creates a stable network of 220 VAC that the inverter connected to the network synchronizes. If the generation system does not provide necessary energy, an existing electricity network such as the public network can support this, the switching in these devices is automatic.

The grid connection inverter receives the electrical signals in DC coming from solar panels, from the turbine rectifier and those that are necessary to enter as

©2006-2020 Asian Research Publishing Network (ARPN). All rights reserved.

backup form to the generator. This is carried to 220 VAC and this is synchronized with the inverter not connected to the network.

The rectifier rectifies the alternating current coming from the hydrokinetic turbine to continuous voltage. It applies an excessive load in case of passing the voltage of 500 volts in direct current.

3.3 Control system for lighting work

The control system will give the flanks on and off to the lamps in the schedule established by the park builder in the framework of their requirements. The control system consists of a timer connected to the two phases from the generation system and the work schedule will be programmed. This will in turn give the ignition signal to a relay who will supply current to the lamp circuit by operating an alternating protection contactor. Figure-15 shows the electrical diagram of the control system.

3.4 Distribution system

The distribution network was made following the guidelines and parameters of the Retie for underground low voltage networks. Three branch circuits were drawn to avoid overloads in the electrical wiring, and the Electrohuila standard was applied to the inspection boxes, connection boxes and distribution board.

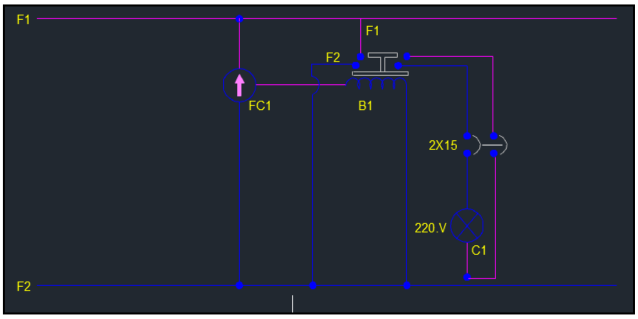

Figure-15. Electrical diagram of the control system.

The grounding system was designed according to the parameters required for a floor of the property where the distribution network is intended to be made. The posts are certified by Retilap and conform to the connections table of the lamp worked, since manufacturing a post and certifying it brings additional costs. Figure-16 shows the electrical plan of the distribution.

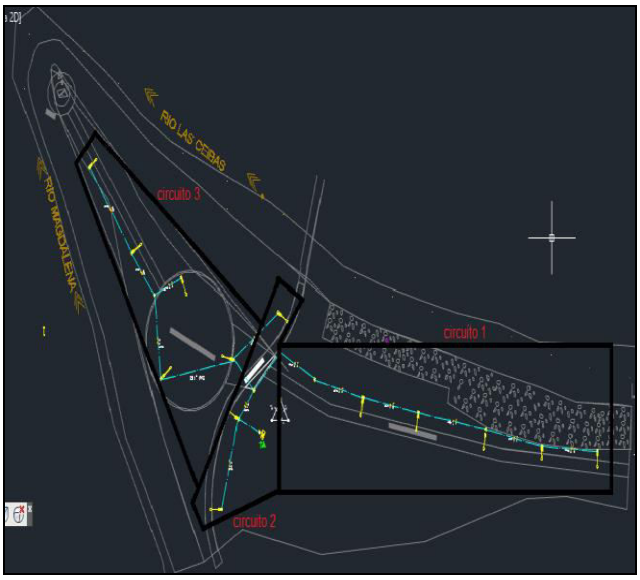

Figure-16. Electrical layout of the distribution system.

3.5 Economic analysis of the project

The direct costs of the project are: Acquisition of equipment, transportation and labor.

Table-6. Direct costs of the pico-hydro power plant.

Description	Cost (COP)
Pico-hydro power plant equipment	$34.000.000
Transportation cost	$4.500.000
Installation cost	$6.000.000
TOTAL	$45.000.000

In order to determine the cost of the generated energy, the daily generation was first determined, to then calculate the monthly consumption and multiply it by the value of the Kw-h price. The cost is determined based on the projection made by the authors, estimated in the horizon of fifteen future years, thus finding the monthly value of energy.

According to the specifications of the pico-hydro power plant, at 2.8 m/s and a minimum depth of 2.0 m, a nominal power of 5KW is generated. Based on the experimental results that were developed in the Magdalena River, the minimum power of the pico-hydro is 1.3 KW, understanding that the speed for this generation is 1.75 m/s. If the aforementioned speed and depth conditions are presented, the impact generated in relation to the power and cost of the electric power would be: 31.2 KW-h/day and 936 KW-h/month.

Table-7 sets out the estimated costs and benefits during the useful life of the pico-hydro power plant, for a discount rate by the Consumer Price Index of $i = 6.9\%$.

©2006-2020 Asian Research Publishing Network (ARPN). All rights reserved.

Table-7. Costs-benefits of the pico-hydro power plant.

Año	BENEFICIOS			COSTOS		
	Beneficio ($)	Factor valor actual	Beneficio actualizado ($)	Costo ($)	Factor valor actual	Costo actualizado ($)
1	0	0,9355	0	45.900.000	0,9355	42.937.325
2	5.092.991	0,8751	4.456.742	750.000	0,8751	656.305
3	5.482.760	0,8186	4.488.137	750.000	0,8186	613.943
4	5.276.578	0,7658	4.040.560	750.000	0,7658	574.315
5	5.545.098	0,7163	3.972.105	750.000	0,7163	537.245
6	5.622.702	0,6701	3.767.722	750.000	0,6701	502.568
7	6.229.024	0,6268	3.904.596	750.000	0,6268	470.129
8	6.183.909	0,5864	3.626.114	750.000	0,5864	439.784
9	6.449.115	0,5485	3.537.535	750.000	0,5485	411.398
10	6.603.489	0,5131	3.388.414	750.000	0,5131	384.844
11	6.760.045	0,4800	3.244.851	750.000	0,4800	360.003
12	7.115.874	0,4490	3.195.184	750.000	0,4490	336.766
13	7.087.233	0,4200	2.976.916	750.000	0,4200	315.029
14	7.179.728	0,3929	2.821.111	750.000	0,3929	294.695
15	7.313.998	0,3676	2.688.371	750.000	0,3676	275.674
Total beneficios ($)			50.108.357	Total costos ($)		49.110.025

$$R_{C-B} = \frac{50.108.357}{49.110.025} = 1.02 \qquad (1)$$

As the benefit/cost ratio is greater than 1, it is an indicator that the project is profitable.

4. CONCLUSIONS

Hydrokinetic technology is the one that best adapts to the requirements given by the construction company of the park and specifically the chosen one is the one that best fits the conditions of the Magdalena River.

The speed parameter was sampled under two different techniques, floating body and reel. It was determined that between both there is only an error of 0.3064% which verifies the accuracy of the floating body technique that was the most used.

The energy consumption of the park according to the construction company is directed to a specific function. However, the power generated covers an energy demand that can supply an irrigation system, cafeteria, kiosks that can supply electronic equipment (mobile devices, portable computers, etc.).

The cost of the generated Kw-h is $ 358.67 COP. This represents a considerable saving throughout the useful life of the pico-hydro power plant for the ecological boardwalk with respect to the projected commercial value of Kw-h that the city's energy trading company would have.

The power generation of the pico-hydro power plant can expand its lighting infrastructure, in 14 more lightings for trails with the same working hours.

ACKNOWLEDGEMENT

We would thank the reviewers of this work and the Vice-Ministry of research and social projection of the Surcolombiana University.

REFERENCES

[1] BERNAD, Sandor, *et al.* 2008. Flow investigations in Achard turbine. Proceedings of the Romanian Academy. 9(2): 000. [En línea]

[2] DE INSTALACIONES ELÉCTRICAS, Reglamento Técnico. Ministerio De Minas y Energía. 2005. [En línea]

[3] DE MINAS, Ministro, *et al.* 2007. Alumbrado público exterior. [En línea]

[4] GUARÍN RESTREPO, Javier Andrés, *et al*. 2013. Diseño de un sistema de generación a partir de una picocentral hidroeléctrica. Tesis de Licenciatura. Pereira: Universidad Tecnológica de Pereira. [En línea]

[5] RODRÍGUEZ RAMÍREZ, Julián Andrés, *et al*. 2012. Guía para el diseño de instalaciones de iluminación Interior utilizandodialux. Tesis de Licenciatura. Pereira: Universidad Tecnológica de Pereira. [En línea]

[6] SÁNCHEZ BOLAÑOS, David, *et al.* 2008. Manual del código eléctrico colombiano (NTC 2050) alambrado y protección de las instalaciones eléctricas secciones (250-280). Tesis de Licenciatura. Pereira: Universidad Tecnológica de Pereira. [En línea]

[7] SC̀HICA, Ricardo Alonso Rojas. Propuesta de un manual para inspectores para sistemas de iluminación-RETILAP. 2011. Tesis Doctoral. Universidad Nacional de Colombia. Facultad de Ingenieria. Departamento de IngenieriaEléctrica y Electrónica. [En línea]

[8] SISA AMAGUAYA, Edison Fabián y VILLARROEL HERRERA, Wilmer Mauricio. Diseño e Instalación de una Pico Central Hidroeléctrica en la Hacienda La Isabel. 2010. Tesis de Licenciatura. [En línea]

[9] TENORIO ZURITA, Néstor Germán. Diseño e implementación de un prototipo de una picocentral hidráulica para uso rural. 2005. [En línea]

[10] VALENCIA MARÍN, Ricardo Andrés, *et al*. 2009. Inspección Eléctrica en el edificio de Educación según el RETIE. Tesis de Licenciatura. Pereira: Universidad Tecnológica de Pereira. [En línea]

[11] VILLA CASTAÑO, Mauricio, *et al*. 2008. Manual del código eléctrico colombiano (NTC 2050) métodos y materiales de las instalaciones secciones (300-324). Tesis de Licenciatura. Pereira: Universidad Tecnológica de Pereira. [En línea].