Solar photovoltaic micro grid for the automation of a compact water purification plant

Microred Solar Fotovoltaica para Automatización de Planta Compacta de Potabilización de Agua

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***Abstract*— Providing access to water and energy profoundly impacts a community in terms of improving the quality of life, education and the environment. This article is based on a research project whose aim was the design, standardization and operation of a photovoltaic solar microgrid -FV- to meet the energy requirements of a Compact low-cost water purification plant in Barichara (Santander-Colombia) with the help of the Homer Micro grid software. The dependability of the plant was calculated based on variations in water demand and the concomitant energy used by the plant over the space of a year. It was found that an average radiation of 5.34 kW/h/m^2/d is adequate to meet the energy demand of the clean water plant, meaning that water can be supplied to a small group of people over the period of a year without having to resort to the conventional energy grid. The research results make examining the feasibility of developing more complex systems in areas not connected to the national electricity grid in Colombia possible.**

***Key words* — photovoltaic solar micro grid, clean water plant, energy, clean water, Colombian energetic system.**

***Resumen*— Proporcionar acceso de agua y energía impacta profundamente una comunidad en términos de mejora de la calidad de vida, la educación y el medio ambiente. El presente artículo está basado en un trabajo de investigación cuya finalidad fue el diseño, estandarización y operación de una microred solar fotovoltaica -FV- para suplir requerimientos energéticos de una planta compacta de bajo costo en purificación del agua en Barichara (Santander-Colombia) con asistencia del software Homer Micro grid. La fiabilidad de la planta se calculó por las variaciones en la demanda de agua, y el consumo de energía de la planta en una escala de tiempo de 1 año. Se encontró que una radiación media de 5.34 kW/h/m^2/d es suficiente para satisfacer la demanda de energía de la planta de potabilización con total independencia del sistema energético convencional y así cubrir las necesidades de agua de un pequeño grupo de personas en un período de un año. Los resultados obtenidos en la presente investigación permiten dilucidar la viabilidad del desarrollo de sistemas más complejos en áreas que no están conectados al sistema nacional de suministro de electricidad en Colombia**

Palabras clave: microred solar fotovoltaica, PTAP, energía, agua potable y sistema energético colombiano

I. INTRODUCTION

This article is based on research motivated by the fact that there are Colombian towns without access to energy and water utilities suitable for human use. Right in the twenty-fist century this tragic circumstance demands innovations that improve the quality of life for communities, especially those that are vulnerable. This is where supplying potable water using renewable sources of energy can be achieved at moderate cost using ideas such as compact, small-scale water processing plants. At the same time, this proposal demonstrates the importance of academics taking on such issues and carrying out applied research leading to real and direct benefits for society that go beyond calculations and engineering on paper.

Adding to the above, the research to date on solar photovoltaic technologies is synthesized in this article. This technology has reached the point in the sustainable development curve that turns it into a very attractive alternative for projects of the scale and type described below.

Colombia's geography also provides a large quantity of

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solar energy, and this energy is not being taken advantage of in any real way.

Achieving the autonomy of a compact potable water treatment plant using photovoltaic solar energy while meeting standard operation requirements is a real milestone for mainstreaming these kinds of solutions. It also contributes greatly towards shifting the paradigm that perceives getting electrical energy from unconventional sources as something that is technologically and economically out of the question for a developing country such as Colombia.

II. ENERGY SUPPLY IN COLOMBIA

A. Coverage

Improving energy supply conditions for Not Connected Zones (ZNI for the acronym in Spanish) [1] using cost-effective and sustainable solutions over the long-term is a National Government priority. As such, the goal of national energy policy [2] is to: broaden coverage and increase the number of hours of service thus ensuring a dependable, low-cost energy supply for users. The formulation of national energy policy can be found in the National Energy Plan (Plan Energético Nacional) [3] and in the CONPES Documents [4]. The objectives include guiding policy application and proposing strategies within the current legal framework that can lead to legally binding decisions and procedures [5].

B. Progress with respect to unconventional energy sources

Great advances have been made in the area of photovoltaic technologies (FV), and it is for this reason that they can be considered as one of the best alternatives for meeting Colombia's energy demand in the future.

Currently, annual global energy consumption is of the order of 10 Tera Watts (TW), and it is foreseen that by 2050 approximately 30 TW will be needed. Thus, the world needs to find about 20 TW of energy that comes from sources free of CO_2 emissions, if atmospheric CO_2 levels are to be stabilized by mid-century. The simplest scenario is one in which electricity needs (10 TW) are covered by FV technologies and other renewable sources; hydrogen is used for transport (10 TW); and fossil fuels are used for meeting heating needs in residential and industrial contexts (10 TW) [6].

In order to meet part of Colombian demand, precise solar information is needed so that high potential zones can be identified. However, existing information and data about insolation on horizontal surfaces is scarce and imprecise. The majority of meteorological stations set-up by IDEAM [7] do not have sensors equal to this task. Even so, there are ways to calculate radiation for any location and tilt, and there are tools that can be consulted such as the "NASA Surface meteorology and Solar Energy: RETScreen Data" [8]. Indirect historic data compiled using mathematical models where radiation and sunglare are correlated, can be found at this *Website*. This data was of great value for the research described in this article and was used to corroborate other data sources, as well as propose alternatives with real and lasting impact for communities that are not connected to the electrical grid.

III. INNOVATIVE TECHNOLOGY

A. Energy demand of the PWTP

In accordance with the results obtained in the research, the Potable Water Treatment Plant (PWTP) possesses an operating voltage of 95.49 VAC RMS, and an average current strength of 0.03 IAC when on "Stand by" and 0.96 IAC when in operation. The power output for the PWTP ranges between 2.86 W and 91.61 W [9]. These results lead to the conclusion that the energy demands of the plant depend on the amount of time it is in use, and this lapse is proportionate to the final users' water demand. In order to quantify this demand, the 2013 consumption records of the municipal public service provider were consulted [10].

In this study the highest consumption (Figure 1) was found to be in December (50 m^{3}), this translates into 1,66 m^3 per day for the 30 days reviewed. Taking into account an allowance of 135 l/inhabitant, this is equal to serving between 12 and 13 people a day, thus emulating the habitual usage of 3 Colombian households.

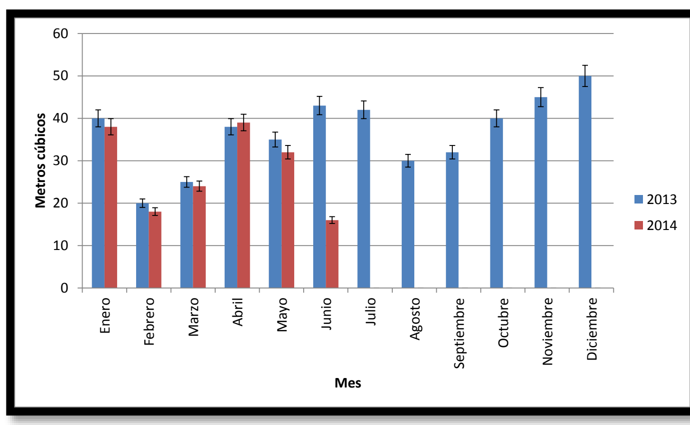

Fig. 1. Potable water consumption log.

Source: Empresa de Servicios Públicos de Barichara (*Public Services Company of Barichara*)

Considering that the plant is designed for an output flow of 0.1 l/s, it computes that the plant must operate for 4.61 hours a day in order to supply the maximum level of water consumption [9]. With an operating power of $Po = 91.61W$ 422.42 Wh of energy are consumed, in other words the maximum daily AC energy needed is 0.422 KWh.

At the same time, the plant processes 360 l/h at an energy cost of 91.61 W.h meaning that 0.2545 W/h are needed to produce one liter of potable water.

The next step involves evaluating the installation, given that the set-up was based on the lowest available solar radiation (corresponding to the month of May 1993 according to the data) and the highest energy demand (daily average in a month corresponding to December 2013).

Given the above, two FV modules were proposed, each with a 100W capacity, an irradiation of 1 kW/m^2 under standard conditions defined by the mean value of daily radiation and the "performance ratio". Externalities include ambient temperature, soiling of the panels and the efficiency of the elements in the installation, with an assumed coefficient of 0,6, since the installation of a solar charge regulator and inverter is involved.
The following expression is used to calculate the daily load that can be supplied by the microgrid for the maximum energy that could be generated by the FV arrangement:

$$NT = \frac{L_{dm} * G_{CEM}}{P_{MOD} * G_{dm}(0) * PR} \quad (1)$$

Where:

NT: Number of $FV\ modules$

$P_{MOD} = Peak\ Power\ of\ the\ FV\ Panel\ \ or\ Wp$

$L_{dm} = Mean\ daily\ consumption\ in\ a\ month$ (w.h)

$G_{CEM} = Irradiance\ under\ standard\ test\ conditions$

$G_{dm}(0) =$
$Monthly\ mean\ for\ daily\ insolation\ on\ a\ horizontal$ surface ( )

$PR = Performance\ Ratio\ or\ energy\ yield$

$of\ the\ installation$

B. Implementation of the microgrid

In order to determine the potential of implementing the PWTP coupled to a FV microgrid, a technical and financial assessment was made with the aim of identifying the advantages and drawbacks of the project. This was done by comparing the plant to a group of conventional power generators run on diesel in areas that are off the grid. The HOMER® Micro grid Software [11] was used to do this since it is the global standard for optimizing microgrids.

So, this case was modeled using two scenarios based on the real demand reflected in the acquired data about users water consumption during the year 2013, and the energy efficiency of the PWTP.

The first scenario simulated actual operating condition in Barichara: a FV generator of 0.2 KWp via two modules with a 100 Wp capacity each, a regulator which is inputted as an additional cost to the accumulator since this is what is indicated by the tool, an accumulator with a 155 Ah capacity and a DC/AC inverter of 1 Kw. Capital and replacement costs, as well as salvage value are inputted for each item, along with the operation and efficiency ranges provided by the manufacturer. The software allows for carrying out sensitivity analysis based on varying projections; in other words, altering the fractions of the general capacity of the FV modules and inverter in order to select the option that gives a levelized cost for the lowest amount of energy needed. (See Figure 1)

In the second scenario, covering the demand of the PWTP using a conventional diesel generator with a 1 Kw capacity and a fuel cost of $0.85 USD per liter was examined. Fractions of the nominal capacity for the generator being evaluated are inputted in the same way.

Finally, the net value of the microgrid ($2,712 USD) is taken into account. In addition, the main cost represented by the battery (Figure 2), which has to be replaced every 2.67 years during the life of the project, is also included.

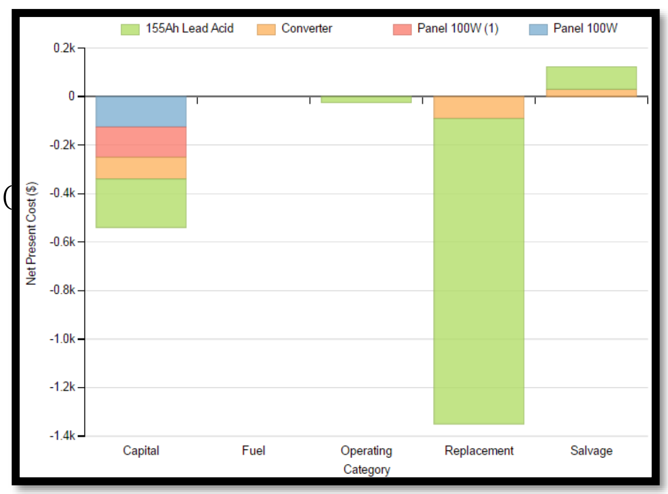

Fig. 1. Summary of costs associated with the microgrid.
Source: Author based on the use of the HOMER software

The "Levelized cost of energy (LCOE)", calculated by the program is 0.526 $/kWh for a FV solar microgrid. Three hundred and seventy (370) kWh/year are produced, of which 229 kWh/year are residual excess. Operating time for the FV microgrid is 4,351 hours a year.

As can be deduced, the second scenario is much simpler. In order to run it, a diesel generator was inputted as a direct AC energy source. Factors from 0.1 to 0.8 of global capacity for the diesel generator were considered. The calculation using HOMER software [11] predicts that the most efficie solution requires a generator with a 0.5 kWp capacity and th consumes 777.43 liters of fuel over the life of the project (2 years), operating a total of 3,030 hours a year and giving current net value of $32,000 USD, and a Levelized Cost c Energy-LCOE in the order of 5,809 dollars/kWh. Replacing the generator approximately every five (5) years is a high cos but the highest cost without a doubt is that of fossil fuel to ru the generator.

IV. SOCIAL-ENVIRONMENTAL VALUE

According to reports by the Mining and Energy Plannin Unit (Unidad de Planeación Minero Energética –UPME [12], even if 2017 targets for implementing convention energy solutions using diesel generators on a mass scale in o the grid zones are met, some 50,000 people in the ZNI i Colombia will still not have access to this service. This because there are still overriding technical aspects getting in the way, such as the prohibitive cost of transporting fuel to very isolated communities.

The country has sufficient hydraulic resources to provide potable water services according to the National Water Report [13], however the quality is questionable and the resource is poorly managed. Thus, this photovoltaic solution improves water quality while meeting the demand and allows users to take advantage of the excess energy for household use.

A technology for approaching the critical situation of lac of access to potable water and electricity in communitie outside of the grid, in a way that will significantly improv their quality of life, has been described in the briefest possib way. At the same time, hygiene conditions have been seen to improve and even a more diversified diet has been mad possible where foods requiring refrigeration are now include

It is understandable that it is difficult to shift a paradigr that presupposes that renewable energies, and especially sola FV energy, is high-cost with low dependability. However, as has been shown, by designing methodologically correct structures it is possible to develop viable and dependable solutions for these populations, while keeping the environmental impacts to a minimum.

This kind of application not only works; its wide spread implementation is strategic for national development given that substituting these for conventional plants leads to a reduction in gas emissions with a high GWP [14].

In addition, the life span of solar photovoltaic systems far exceeds the investment, maintenance and replacement implied, which translates into economic and environmental gains.

V. RESULTS

The current configuration of the solar photovoltaic microgrid meets the energy requirements of a PWTP such as the one needed in Barichara. It complies with widely accepted design criteria and shows great potential for widespread application in water treatment for off-the-grid zones in Colombia.

An evaluation of the current microgrid configuration was carried out in the month with the lowest available radiation and on the worst day showing an available radiation of 0.7Kwh/m^2/day. It was found that 100% of the energy demand for the plant was met and still excess energy was generated.

The potable water treatment plant met the potable water demand for between 12 and 14 users in Barichara, Santander over the period of one year using energy generated by the microgird under average solar radiation conditions of 5.34Kwh/m^2/day.

The simulation of a zero-energy-generation-with-maximum-demand situation showed that the microgrid can function autonomously for 100 hours.

A technical and financial analysis showed that the “Levelized cost of energy” for the solar photovoltaic microgrid is 0.526 $/kwh while the LCOE for a diesel generator set-up is 5,809$/kwh. The stark difference is due to the use of fossil fuel and the lower operation and maintenance costs associated with the FV microgrid.

It was also calculated that the use of a solar photovoltaic microgrid to run a potable water treatment plant, as opposed to a diesel generator, results in 2.047 Kg/year less carbon dioxide emissions, as well as reducing nitrous oxide, particulate matter, hydrogen sulphide and unburned hydrocarbons.

It was also found that the FV microgrid exceeds the cost of 1,200 COP per kWh for off-the-grid zones by 115 COP. When the representative market value of 2,500 COP was used in the Homer Energy simulation, the resulting LCOE was 0.526 $/kW.

VI. CONCLUSIONS

National energy coverage is good, however, over the medium-term, scarcity is foreseen in difficult to reach areas.

Given the global energy deficit, it can be concluded that it is necessary to propose non-conventional energy solutions.

The PWTP for which the microgrid is suggested uses little energy and achieves high levels of efficiency owing to the implicit automation.

The microgrid design put forward here is easily replicated in situations with similar conditions where energy and / or potable water requirements need to be covered.

As such, the microgrid represents an economically viable alternative that is socially applicable and causes low environmental impact since no greenhouse gas emissions are present.

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