Integrated Control System for the Energy Supply to Isolated Communities in Cuba, using Hybrid Systems

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***Abstract*—This document summarizes some of the activity carried in Cuba during the last years, related to the development of hybrid systems for rural electrification of isolated villages. The design of these systems has been centered in the presence of a biomass gasifier, identified as an appropriate technology for this country in particular. Apart from the gasifier, the solar PV and wind technology have been considered. The opportunities and challenges for this solution to be implemented appear in the described activities.**

Keywords; Cuba; hybrid systems; biomass gasifier

I. Introduction

During the last four years, CIEMAT has been involved in projects to hybridize renewable systems for the electrification of isolated places in Cuba. The projects have been widely accepted and have had as a main objective to design and adapt hybrid systems for the gasification of biomass and solar photovoltaic (PV) and wind energy to local conditions based on proven technologies. This objective has been achieved through a series of studies on the conditions and replicability of these technologies in the Cuban environment and with the development of a series of training actions that have given rise to an emerging community of knowledge, leading to the design, installation and commissioning of a hybrid demonstrative system.

These projects began at the end of 2015 and will last till 2021, and have been carried out in two phases. The first phase (named HYBRIDUS Project) has developed an electric and thermal energy cogeneration model by means of a biomass-solar hybrid system for agricultural operations on the island of Cuba, with the final objective of transferring that knowledge to the populations who would potentially benefit from the technology. The second phase (named HIBRI2 Project) is on-going and will start up a demonstration facility in Matanzas province that will serve to analyze the scope of the proposal developed during the project. This paper will describe the overall activity, focusing on the design of the hybrid systems.

II. Background

During the first years of this century, CIEMAT has made a considerable effort to collaborate with the Republic of Cuba, aimed at gaining in-depth knowledge of the role of renewable energies in Cuba, as well as their territorial and social dimension, successfully combining the role of renewables with the potential of geographic information technologies for their implementation, especially GIS, as a spatial analysis tool, and geoportals as an instrument for dissemination and support for decision-making. This work [1] was in some way the seed for the activity on hybrid systems and microgrids described in this publication.

III. First Phase: the HYBRIDUS Project

The project "Cogeneration of electrical and thermal energy by means of a hybrid biomass-solar system for agricultural and livestock farms on the Island of Cuba" (HYBRIDUS Project) (2015/ACDE/001558) aimed to create a cogeneration system that provided power for agricultural and livestock farms and facilitates the electrification of isolated areas [2]. In this way, the purpose was the local capacity building on renewable energies technologies for these isolated areas.

The emphasis was placed on the eastern part of the island, with special attention on the municipality of Guamá in the province of Santiago. Appropriation of the technology by the population was addressed throughout the project by two strategies. The first one, consisted on adapting the proposed technology (the biomass gasification and PV hybrid system) to local conditions, considering both the resources and the needs of the population under these conditions. This adaptation also started with an in-depth analysis of the previous experiences. The second strategy to achieve the objective was the creation of local capacity, using various agents involved (beneficiaries/users, operators, technicians, professionals in the energy sector…) in such a way that a process of technological appropriation was produced and to ensure sustainability over time and the ability to replicate the experience for other populations.

In order to achieve this objective, different actions were envisaged, such as the development of different workshops with technical staff from the electricity company and from some universities and technology centers, as well as the development of a design for a case study: the community of La Veguera was selected. The community of La Veguera is an isolated community in the north of the municipality of

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Guaimaro, Camagüey province, which was not electrified. Its inhabitants are mainly cattle breeders. The starting situation of this population constitutes a great advantage when planning the system, due to the existence of a gasifier [3]. Therefore, the hybridization model proposed was based on a system made up of biomass and in which solar PV and wind technologies were analyzed for hybridization.

IV. Second Phase: the HIBRI2 Project

HIBRI2 project ("Integrated control system for energy supply through hybrid systems in isolated communities in Cuba. Phase II" - 2018/ACDE/000600) arose as a continuation of the HYBRIDUS project, previously presented, with the main objective of completing the action with the implementation of a demonstration project. Initially, the project was planned in La Veguera, as a previous design had already been carried out in the HYBRIDUS project, but throughout the HIBRI2 project, both the site and the scope, and therefore the design of the system, have undergone numerous changes which, in a way, also serve to show some of the difficulties encountered by this type of systems.

HIBRI2 is included in the AECID innovation projects (2018), the project coordinator being CIEMAT. On the Spanish side, the participants are, in addition to CIEMAT, the NGO SODEPAZ, which is in charge of communications between Cuba and Spain and logistics, and BORNAY, which provides the technical installation of the renewable generation equipment. On the other hand, in Cuba, the organizations CUBAENERGÍA, CUBASOLAR, UNE (Unión Eléctrica, the public utility), the Municipal Government and the Forestry Sector stand out.

Shortly after the start of the project, the Cuban counterpart proposed a change of location, as the initially proposed site (La Veguera) did not meet the sustainability requirements demanded by the utility. The proposed site was Guasasa, an isolated coastal village next to the Ciénaga de Zapata National Park. Guasasa is located to the east of Playa Girón, a locality in the municipality of Ciénaga de Zapata, in the province of Matanzas. This new location is situated in the south of Cuba, bordering the Caribbean Sea.

Regarding the situation in Guasasa, the site met all the requirements for the implementation of a system such as the one proposed in the project: the starting point is the existence of an 80 kW diesel generator that provides a 12-hour power supply to the population. This is the starting point to carry out hybridisation with a series of renewable energies considered, such as solar PV, wind and biomass, so that electricity is produced from non-conventional sources and an increase in the hours of consumption is made possible. Therefore, it is considered that through the introduction of renewable generation, the supply is increased to 24 hours.

After the appropriate discussions and negotiations, it was accepted by the consortium. All the necessary phases for the design were carried out, including the relevant field visits, as well as some of the social work with the users, and therefore this will be the site that will be described in the design section.

However, subsequent turns of events led to a rejection of this solution for this site as well, so this solution also had to be abandoned, leading finally to the proposal that will be presented in the Implementation Project and Future sections.

V. Design of the System

In both initiatives presented above, the HYBRIDUS and HIBRI2 projects, the necessary hybrid power generation systems were designed; in the case of the HIBRI2 project, it was based on an existing installation, powered by a generator set; while in the case of the HYBRIDUS project, it was a new installation, since, although it was based on an existing gasifier, the distribution network to potential users had not yet been set up. In this section, the design methodology used in both proposals will be described jointly.

The design procedure described here deals only with some technical considerations of the design related to the consideration of wind technology; the development and management of a REDPS system is a relatively long and complicated process, and involves other key aspects like for example social, environmental, management, contractual, quality assurance, training and some other aspects. These aspects obviously have to be taken into account through the project development, but are out of the scope of this work for time and space limitations. The design methodology includes basically the following stages [4]: Data collection, Sizing study and Implementation project. These three stages will be briefly described for both designs.

VI. DATA COLLECTION

The different aspects that influence the functioning of the system are listed below and are characterized in the following chapters. These are: characterization of the site (loads, topographical information, available resources, i.e., biomass, solar and wind); the components (biomass gasifier, generator set, PV generator, wind turbine, batteries and electronic converter); and the economic parameters

Although each project has been planned in a different location, these sections will be presented together, given their proximity and similarity in the methodology used, expressing the differences arising from the case in question where necessary.

A. Load characterization

Load characterization is obviously dependant on the particular case study, so, it will be presented separately for La Veguera and for Guasasa.

1) La Veguera

A detailed description of the design for La Veguera can be found in [2]. In this case, in the absence of a previous centralized supply system, there was no description of the existing consumption, so estimates based on a few available baseline data were used.

The information available for the characterisation of the community of La Veguera is not precise: it is known that it consists of a number of houses (between 25 and 50, depending on the source), a bodega, a small rural school and a video room, the latter two of which are electrified with photovoltaic panels. The main consumption group to be analysed is that corresponding to the consumption of the community. The following criteria have been used to estimate the consumption of the community: consider the average consumption per inhabitant per day of 900 Wh/day, for each inhabitant, so that, considering a number of inhabitants equal to 120, the total consumption would be 108 kWh/day for the entire community; the hourly and seasonal distribution of the loads is established according to the criteria used in similar studies [5].

2) Guasasa

The population of Guasasa is made up of a total of 214 people, distributed among 85 dwellings, a health care, a pharmacy, a school, and some other collective use dependencies. As for its economy, the main activity of the population is based on fishing, which constitutes around 60% of the total economy. Apart from fishing, other activities carried out by the population are forestry and community work, accounting for 25% and 15% of the total economy, respectively.

In this context, as mentioned above, it is proposed to increase the hours of supply (currently 12 hours) to reach a situation of 24 hours a day consumption. Even though some measuring campaigns of the existing situation (12 hours supplied from the genset) were undertaken, the design load profile (24 hours supplied from the microgrid) was estimated, as shown in the Figure.

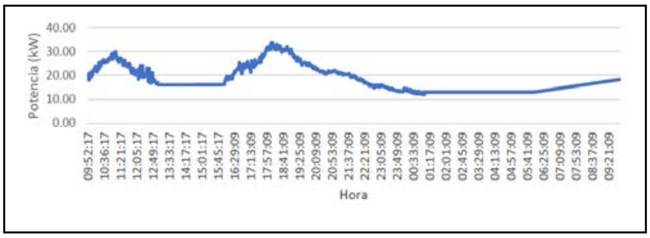

Figure 1. Proposed Load Profile for Guasasa

B. Characterization of the renewable resources

Only solar, wind and biomass resources have been considered and their characterisation is described below.

1) Solar Resource

In this case, various databases are studied, such as Meteonorm [6], NASA's meteorology and solar energy database [7], or the Global Solar Atlas [8], based on SolarGIS.

2) Wind Resource

Several databases consulted are presented here. The first is NASA's Solar Energy and Meteorology Database; the second is Global Wind Atlas [9].

Global Wind Atlas is a database that can provide both wind roses, velocities, energy density, etc. (at heights of 50, 100 and 200 meters), as well as GIS layers to work with them in ArcGIS. However, they do not provide hourly mean values, so data from the NASA database are used for this purpose.

3) Biomass Resource

The characterisation of biomass as a renewable resource is based on the following parameters:

- *Available Biomass* (tons/day): It is assumed that the biomass is fed to the gasifier to produce syngas, and the generators will consume this syngas to produce electricity. The biomass to be used in La Veguera is mainly marabú, while the existing biomass in Guasasa is mainly composed of yarúa, soplillo and ocuje. In both cases, it is considered that the availability of these biomasses is several times higher than what is required by the plant. Therefore, the biomass necessary to provide the electricity consumption calculated in the corresponding section has been estimated, using the following expression:

Biomass (kg/h) = Gas Consumption (kg/h) / Gasification Ratio (kg/kg)

The *gas consumption* is established from the electrical power delivered by the genset and the fuel consumption curve of the genset, while the value of 1.89 kg/kg has been taken for the gasification ratio; both of which will be analysed in later sections.

- *Average Price* ($/t): 120 CUP/ton = 5 USD/ton; applied change: 1USD = 24 CUP
- *Carbon Content* (%): based on the analysis of samples carried out in the CIEMAT-CEDER laboratories in Soria, the value used for the Carbon Content is 48%, and it will be considered the same in both cases.

C. Characterization of components

The following is a brief description of some of the main characteristics of the components considered, starting with the gasifier, which is probably the most peculiar of the components of the configurations analysed.

1) Gasifier

The main parameters that will characterise the gasifier are:

- *Gasification ratio* (kg/kg): understood as the ratio between the syngas generated and the biomass consumed in the gasifier. The value obtained is 1.87 kg/kg. The plant technology is from the Indian company Ankur. This type of gasifier accepts various types of firewood, wood chips, chopped bamboo, etc., as long as they have a moisture content of less than 20% [10].
- *Lower Calorific Value* of syngas (LCV), in (MJ/kg): According to the manufacturer's data the LCV of the gas is approximately 1050 kcal/Nm3 (1468,89 kcal/kg) or 6.15 MJ/kg.

2) Generator Set

In the case of La Veguera, the proposed genset was the one associated with the gasifier (40 kWe), while in Guasasa, in addition to the genset associated with the gasifier, the existing genset prior to the project (80 kWe, DENYO brand, model DCA-100ESI) was considered.

3) Solar PV Generator

The PV generator will be installed on a fixed structure on the ground, and will be connected on the AC side through an inverter, or on the DC side through a charge regulator.

For the design, a module belonging to Canadian Solar has been selected, model "SuperPower CS6K-295MS". As for the size of the solar part, it is set at 40kW. A cost of 1,750 $/kWp is considered.

4) Wind Generator

In this case, the wind turbine to be included is from the manufacturer Bornay, a participant in the project, and the model is the 3000W, so its characteristics will be used (power curve; useful life of 20 years, hub height of 17m, cost of 3500 $/kW).

5) Battery Storage

Electrochemical storage based on Lead-Acid batteries has been proposed for the storage system. Initially, the "BAE Secura PVS BLOCK Solar Battery" model has been selected, with a nominal capacity of 2.17 kWh/element and a cost of about 200 $/kWh.

6) Power Converter

It is necessary to incorporate a bidirectional electronic converter into the system that allows the change from direct current to alternating current and vice versa. A cost of 300 $/kW is considered.

D. Economic Parameters

It is worth noting a series of basic parameters that are common to both cases [11]: as for the inflation rate, the value taken is 2.8%; for the discount rate, a value of 8.9% stands out, a figure that has been estimated to increase in the period 2016-2033, so that for the cases studied an assumption of 10% has been selected as the value for this parameter; on the other hand, the project life time is estimated at 15 years.

VII. SIZING STUDY

The output of this stage in the design is a detailed behaviour of the selected configuration in terms of stability and performance. The software used in both initiatives was HOMER, an international reference for the design of hybrid and microgrid systems, with the HOMER Legacy version being used in the HYBRIDUS project and the HOMER Pro version in the HIBRI2 project.

In both sites, La Veguera and Guasasa, the sizing study has been similar: establishing the Base Case as a reference, which is the existing system (a 40 kWe gasifier in La Veguera and a 80 kWe genset in Guasasa), and then design the optimal configuration according to the particular conditions in each site.

Results show that the inclusion of renewable generation in the microgrid is always favourable, both from an environmental and an economical point of view. The following table shows, for example, the results for Guasasa's sizing study, in terms of configuration.

TABLE I. CONFIGURATIONS FOR THE BASE AND PROPOSED CASES, IN GUASASA

Base case	*Proposed design*
Genset (80kW)	Genset (80kW)
	Gasifier (10kW)
	PV Generator (40kW)
	Wind Turbine (3kW)
	Battery(50kWh)

And in the following table, the main results for both Cases in Guasasa are shown, taking into account that both of them are for a 24h service.

TABLE II. MAIN PERFORMANCE PARAMETERS FOR BASE AND PROPOSED CASES, IN GUASASA

Parameter	*Base case*	*Proposed design*
Generation share	Genset 100%	Genset: 39,7% Gasifier: 10,4% Solar PV: 47,5% Wind Turbine: 2,3%
Renewable Fraction	0%	53,2 %
Excess electricity	0 %	12,3 %
Fuel consumption	63.540 l/año	20.693 l/año
Capital investment	0 $	140.750 $
LCOE ($/kWh)	0,991	0,536

Both from an environmental point of view (fuel consumption, genset share, renewable fraction) and from an economic point of view (LCOE), the Proposed system results much more favourable; the only known obstacle for this installation is the high initial investment, which may be softened with projects like this one in order to encourage the market of microgrids through the appropriate financing mechanisms.

VIII. IMPLEMENTATION PROJECT

It has already been mentioned that the objective of the HYBRIDUS Project only reached the training and design definition phase, but not its implementation; the HIBRI2 Project, on the other hand, does contemplate the implementation phase but, due to the different conditions of the HIBRI2 Project, some of which have already been mentioned above, even though a part of the implementation stage had already been started in Guasasa, the implementation project that will finally be carried out is that of a microgrid for training and research in the CUBAENERGÍA facilities. So, this will be discussed briefly in this chapter.

In ANNEX 1 a single line diagram the layout of the final microgrid is shown. It can be seen that it is composed of a 20kWp solar PV generator, 10 kWp of which are connected to the AC bus through two solar inverters, and the other 10 kWp are connected to the DC bus through the respective two charge regulators; there is one 5 kW wind turbine, a 10 kW gasifier, 50kWh Li-Ion battery (the evolution of this technology through these years has made it possible to enter in the final configuration); there are three bidirectional converters 10 kW each, one for the gasifier and two for the microgrid; the role of the genset is performed by the grid, which is a particular bi-phase one; and includes also all the necessary equipment for the implementation of the microgrid.

IX. THE FUTURE

The HIBRI2 project is currently in the stage of acquisition of the materials for the microgrid. The microgrid includes the main technical characteristics of the case studies analysed in the two projects described, such as incorporating wind generation, solar PV, biomass gasification, and storage in the form of batteries with control by electronic converters, all for the scale of tens of kWs, considered to be the most replicable in Cuba. It is hoped that this installation will overcome the obstacles described above by providing experience, familiarity and knowledge of these systems, and may also serve to train the technicians in charge of designing, installing and operating these installations in the future.

The collaboration in the field of microgrids in Cuba continues, with new initiatives that include other stakeholders that might come up with new options for the implementation of these technical solutions in the island and allowing to analyses issues such as replicability and sustainability. So, maybe this story might have new chapters…

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ANNEX 1: SINGLE LINE DIAGRAM OF THE MICROGRID TO BE IMPLEMENTED IN CUBAENERGÍA'S FACILITIES