Electrical Power and Energy Systems 101 (2018) 139–150

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Future Hybrid Local Energy Generation Paradigm for the Brazilian Sugarcane Industry Scenario

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ARTICLE INFO

Keywords:
Biomass
Renewable sources
Green Energy Technology
Future energy generation
Brazil

ABSTRACT

This paper proposes a profitable, affordable hybrid generation power plant, to be integrated upon sugar cane plants, considering the Brazilian energy scenario. The future of energy generation is discussed and highlights are given to the Brazilian sugar cane industry, key national activity for the production of sugar and ethanol. A *novel microgrid* structure is proposed as a new approach to hybrid generation, which integrates the recycling of the sugar cane remains (as *biomass* and *biogas*) combined with the use of renewable sources, such as photovoltaic panels and wind power turbines, aiming to reduce environmental impact. The plant modeling is based on the *Energy Hubs* methodology, that allows the integration of different energy carriers in the same model. Simulation results show the satisfying microgrid operation and its flexibility to fulfill different energy production scenarios, as well as economic and sustainability gains. Profits and possible implementation costs are discussed, through a payback analysis.

1. Introduction

The use and generation of energy in efficient ways are key elements for achieving more ambitious goals for sustainable and eco-friendly development. The current foundations on energy generation are about to change [1] in a profound way: the price of fossil fuels are rising each year (due to future scarcity, shortage and other factors – see [2]) whereas, at the same time, energy demands grow in every country and the search for viable renewable sources becomes evermore important [3].

There is a crescent of the smaller and more distributed energy plant structure [4] for generation of power and heat, and the highlights in the forthcoming years will be given to *clean*, renewable generation. Recent academic research has also given focus to generalized energy systems, with multiple generation and different energy carriers. The growing scope of research in this topic can be illustrated by some references: a large review of the *state-of-the-art* on multi-objective planning of these distributed plants is seen in [5]; a robust optimization approach to their management is seen in [6]; in [7], a real-time coordination of theses systems is considered for their control of frequencies.

Much is discussed on the use of renewable sources, but it important to remark that, although these seem very appealing, they are intermittent, difficult to predict (specially solar radiation curves), heavily dependent on the weather conditions upon the energy plant and dealing with them is a defying factor for system safety and technical-economical network management.

In sum, the biggest affair related with this kind of system is the unreliability and inconstant quality of the renewable energy sources, these being intermittent and inducing unpredictable fluctuations in the energy output. A practical solution to this matter is to include intermediate energy storage units banks, such as batteries, super-capacitors, fly wheels and others, as it is proposed in [8].

Notably, in the instance of this work, the Brazilian energy scenario will be taken deeply into account. Brazil is a country with an immensely diversified energy matrix [9]. Solar energy can be considered as one of the possible energy sources to enlarge the renewable energy share, as the country has great potential for solar energy generation in several regions. The investment in this sector has vastly risen in the latter years, showing competitive costs (as it is seen in [10]).

The sugar cane distilleries are particularly significant to this study, for the sugar cane distillation process has a great amount of residue and waste that can be treated as *bio*-sources of energy. In sum, there are three important renewable sources from the canebrakes: the bagasse, the straw and the vinasse. In the Brazilian context, sugar cane is one of

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https://doi.org/10.1016/j.ijepes.2018.03.024
Received 20 April 2017; Received in revised form 23 November 2017; Accepted 17 March 2018
0142-0615/

the main harvests of the country's economy and the country is responsible of being the world's largest producer of sugar cane, as states [11].

Given the importance of the sugar-ethanol plants in the Brazilian energy setting and knowing that these are mostly established in high insolation sites, with low amounts of day-time rain during the harvest period, the sugar-ethanol plants are potential candidates to be managed as distributed power plants of hybrid sources [12], considering the use of biomass and biogas, but also solar and wind power energy generation.

Distributed power generation refers herein to a set of energy plants, located near the end user, that can be integrated into a network or operate autonomously, that progressively (in the literature) have been called *microgrids*, refer to [13].

The problem that is researched on this article is how to adquately answer the following (open) question: how to integrate the use of renewable sources to the present Brazilian energy matrix, in a feasible and profitable way?

This work exposes the current technology present on most of the Brazilian sugar cane power plants and, then, proposes a new hybrid energy generation solution, with the reuse of the sugar cane residues coupled with the use of other renewable sources, external to the plant, as photovoltaic panels and wind turbines, that aims to prevent and, when not possible, reduce emissions and the global environmental impact.

This proposed microgrid solution is based on a real sugar cane power unit, with the addition of subsystems based on renewable generation. This plant is modeled based on the *Energy Hubs* methodology, which is defined in [14] as a general interface among energy producers, consumers and transmission lines. Such general formulation allows high flexibility in terms of modeling detail and accuracy, as any technology for transmission, conversion, and storage of energy can be considered.

For the reader to bear in mind, the rest of this article is organized as follows: Section 2 elucidates the current Brazilian sugar-cane industries and proposed a new hybrid generation system; Section 3 details this microgrid's modelling; some simulation results are seen in Section 4 an a cost analysis is seen in Section 5. The paper ends with a final discussion and conclusions.

2. A hybrid power generation structure for the Brazilian scenario

As explained, this work proposes a generic hybrid energy generation system, based on a sugar cane processing plant that produces sugar and ethanol, in order to integrate the use of renewable sources to the present Brazilian energy matrix in a feasible and profitable way. This Section begins by elucidating details about the sugar cane industry present in Brazil and, then, ends with the described proposition.

2.1. Sugarcane base industry

To detail the Brazilian Industries that deal with sugar cane, the overall processing of this plant to produce ethanol and sugar has to be understood. This process is based in some main steps, schematized by Fig. 1 and detailed below:

1. Firstly, the sugar cane is prepared and milled (where bagasse and straw appear as sub-products);

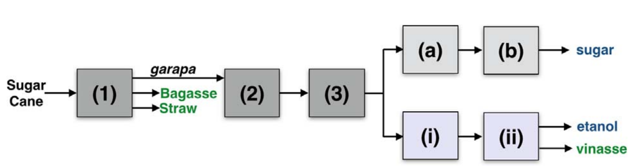

Fig. 1. Sugar cane processing flow chart.

2. The sugar cane juice (*garapa*) is clarified and purified;
3. This treated juice is concentrated via evaporation;

To produce sugar:

(a) Crystallization of the concentrated, treated juice is done;
(b) Then, a centrifugation is done and sugar is dried and packed.

To produce bio-*ethanol*:

(i) The remaining sugar cane juice is prepared into a must and fermented;
(ii) Then, the alcohol is distilled from this fermented must (vinasse is the main sub-product of this stage).

All these steps are very well detailed in [15].

From this procedures, there are some important residues that can be considered as bio-fuels, like the bagasse, the straw and the vinasse, as stated beforehand.

The bagasse is the main residue from sugar cane processing. This residue is very polluting when improperly discarded. It is often used in the industry as burn fuel for boilers, as explains [16]; an assessment on the different technological routes for energy generation from this kind of sugar cane waste is seen in [17].

The sugarcane straw is composted of unseasoned leafs, dry leafs and by the sugar cane pointer. It is responsible for approximately one third of total primary energy source from the sugarcane, as detailed in [18], although it is not yet explored in its plenitude, given that, in Brazil, it is mostly left on the ground or burned, for a common practice is to preburn the canebrakes during the pre-harvest period. As these residues are either discarded or burned, new legislation (2013) has been introduced [19] to avoid this issue and, as an outcome, novel ways to reuse this residues have to be considered.

Finally, there is the vinasse [20], a destilation residue from the sugar cane juice (*garapa*), that can be transformed into biogas, with the technology of anaerobic digestion [21]; the economic feasibility, energy potential and avoided CO_2 emissions with the use of vinasse biogas is discussed on [22].

In terms of quantification of these wasted residues: for every ton of processed sugar cane for the production of ethanol, around 730 kg of *garapa* and 250 kg of bagasse are obtained, see [23]. In other terms, for every liter of ethanol produced in the distillation units, 12 l of vinasse are obtained.

A complete discussion on the use of some of these sources as *biofuel* possibilities and some future projections are seen in [24]. This work, on the other hand, is interested on the possibility of this sources for the *direct-to-electric-energy* generation, but it has to be clear that the sugarcane processing plants produce sugar and, also, ethanol (*biofuel*).

Most of the current industrial Brazilian sugar cane processing plants have a similar structure. These plants have internal demands, corresponding to the sugar and ethanol processing requirements: to produce steam in different pressures (used to boost water bombs, spray bombs, exhausters, chippers, shredders and other equipments), to produce cold water for refrigeration needs (used to cool down generators, oil tanks from the distillery process and other systems present on the plant) and, finally, to produce electric power to sustain the plant. Apart from these internal demands, most sugar cane processing plants also sell the excedent electric energy to a local distributor (external network).

The commonly used subsystems on these plants are: boilers that burn bagasse to produce high pressure stem; turbines to generate electricity from the steam flows; pressure reduction valves to deal with stem flows on different levels of pressure.

In Fig. 2, it is seen what shall be herein named the *Sugar Cane Base Industry*, a representation of a common sugar cane power industry in Brazil, with all its subsystems, inputs and outputs.

It is important to remark that the stockage of bagasse residue is a