

Generating electricity during peak hours in Asuncion, Paraguay, through anaerobic digestion of cultivated water hyacinths

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Abstract- The objective of the present paper is to present an innovative and sustainable proposal for generating electricity in the metropolitan area of Asuncion, the capital of Paraguay, based on a renewable source of energy. Electricity would mainly be generated during peak hours with the aim of reducing power contracted by the Paraguayan Electricity Administration (ANDE) from existing hydroelectric power plants and thus reduce costs and stabilize transmission and distribution grids in the area of Asuncion. Electricity would be generated at a 130 MW combined cycle thermal power plant using biogas as fuel, this being obtained by anaerobic digestion of water hyacinths cultivated in pools, which would be built on the banks of the Paraguay river opposite Asuncion's botanical garden. The main advantage of using water hyacinths is their high growth rate, this being 100 to 500 g/day/m² depending on environmental conditions, thereby allowing plant mass to double every 6 to 15 days. Additionally, carbon to nitrogen ratio in water hyacinth vegetal mass is optimum for biogas generation. About 6.4 kWh/m³ biogas calorific value is high enough to be used for producing heat and, therefore, for generating electricity in a thermal power plant. Such power plant could be directly connected to the national grid through the "Puerto Botanico" transformer station by building a 2 km long 220 kV transmission line crossing the Paraguay River. This project could save ANDE up to 25 million US\$ every year due to reduced contracted power at the Itaipu power plant. Although this reduction will decline by 3% each year due to increased electricity demand, the investment of around 98 million US\$ could be repaid within 15 years and would have 12% IRR and US\$ 107 million NPV.

Keywords: water hyacinth, biogas, electricity generation, peak hour, grid stabilization

I. INTRODUCTION

Electricity supply for the metropolitan area of Asuncion, the capital of Paraguay, mainly comes from the Itaipu hydroelectric plant. The National Electricity Administration (ANDE) has to contract certain power from this bi-national entity which normally has to cover demand during peak hours. However, such contracted power is not used during most of the day, thereby signifying high costs for ANDE and electricity consumers. Electricity demand during summer time

when temperatures are high causes overloads in the transmission and distribution grids due to the increasing use of air conditioners and, consequently, electricity supply cuts.

Both problems could be resolved if ANDE would dispose of one or various thermal power plants during peak hours, a solution which has already been proposed on several occasions by this entity. There are projects to install thermal power plants at several critical points around the country to stabilise the grid during peak hours during the summer. The problem of conventional thermal power plants is the use of fossil fuels (which are 100% imported), therefore costing a large amount in foreign currency and contribute to global warming. The present paper presents a more ecological and economical alternative to ANDE projects by using a renewable source of energy, i.e. biogas obtained by the anaerobic digestion of cultivated water hyacinths.

II. WATER HYACINTH

Water hyacinth (*Eichhornia crassipes*) is an aquatic plant from the family *Pontederiaceae* which is native to tropical areas of South-America. This plant swims on the water surface with its roots hanging in the water without penetrating the ground and is very common in Paraguayan rivers, lagoons and swamps, but can be found throughout almost all of the world's tropical and subtropical regions. Originally it was introduced as an ornamental plant in garden pools, from where it escaped then. Nevertheless, due to its rapid growth and its easy adaptation to any aquatic ecosystem in many countries it has become a difficult to control pest. Practically the only way to control its expansion is periodic harvesting of the plant. It can be used for different purposes like cattle fodder, organic fertilizer, raw material for paper and card board, solid fuel, substrate for biogas generation, etc. [1]

Water hyacinth growth rate is between 100 and 500 g/day/m² according to the actual environmental conditions (solar radiation, temperature, nutrient availability). So, 400 to 1,700 t of fresh material per year can be obtained per hectare, having 5% to 7% dry material content; the rest is water [1].

III. ANAEROBIC DIGESTION

Anaerobic digestion is a natural fermentation process which occurs in the total absence of oxygen by the action of various species of bacteria, resulting in stabilised organic matter and the production of a combustible gas, called biogas. Beside the absence of oxygen, other physical and chemical conditions have to be observed to enable anaerobic digestion in good conditions, such as pH (6.6 to 7.6), carbon/nitrogen ratio (15/1 to 45/1), temperature (15°C to 70°C), the absence of toxic substances and quantity of solids (10% to 40%) [2].

Biogas mainly contains methane (CH_4 : 50% to 70%) and carbon dioxide (CO_2 : 30% to 50%), beside small amounts (<1%) of hydrogen (H_2), hydrogen sulphide (H_2S) and traces of some other gases. According to its methane content the lower calorific value of biogas varies between 5 and 7 kWh/m³.

Anaerobic digestion is a very complex process in which several biochemical reactions occur (see Fig. 1) which can be divided into three stages (hydrolysis, acidogenesis, methanogenesis). The molecules which compose the matter become smaller and smaller during the process and end up becoming converted into the different components of biogas and the remaining liquid substrate which is an excellent fertilizer for crops. Characteristic bacteria mediate each stage and their population needs to have certain equilibrium.

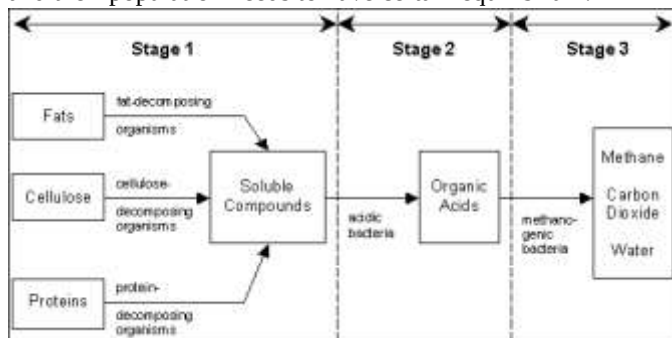


Fig.1: Stages of anaerobic digestion (source: www.daviddarling.info)

Temperature is a very important factor in anaerobic digestion. Three temperature ranges at which biodigesters can operate are usually distinguished; they differ regarding temperature and bacteria flora, this being specific for each temperature range. These ranges are:

- Psicophilic: 10°C to 20°C
- Mesophilic: 20°C to 45°C
- Thermophilic: 45°C to 70°C

The most common range is mesophilic as its temperatures are close to ambient temperature in our climate. Each range has its optimal temperature, this being 37°C for the mesophilic range. The thermophilic range normally requires heating the substrate, thereby consuming part of the energy in the form of biogas. Nevertheless, it has the advantages that pathogenic bacteria are eventually destroyed and that organic matter decomposition is much quicker.

IV. BIOGAS PRODUCTION FROM WATER HYACINTH

Water hyacinths have an optimum carbon/nitrogen ratio (C/N = 23) for anaerobic digestion [1]. Nitrogen comes from its protein components. On the other hand, most fibrous plants, like grass, have an excess of carbon, thereby making their anaerobic digestion difficult. According to simulations realized with the software "UASBplant" about 500 l of biogas can be obtained from 1 kg of dry water hyacinth matter with a methane content of 65% [3], a similar value to that for pig manure. It should be added here that biogas supply would follow a similar curve to that for electricity demand during the year, both being dependant on ambient temperature. It also influences water hyacinth growth rate and biogas production, unless the digestors are equipped with heat exchangers using waste heat from a thermal plant. So, during summer when there is the highest electricity demand, there will also be the highest quantity of harvested water hyacinth and therefore maximum biogas production.

Enough biogas should be produced in the present proposal to make a combined 130 MW cycle thermal plant function for 3 hours a day. This power is enough to mainly cover the additional demand of electricity during peak hours in the metropolitan area of Asuncion. Considering a biogas yield of 500 l/kg of dry water hyacinth matter, 55% efficiency for the thermal power plant and a 6.4 kWh/m³ calorific value for the biogas 110,000 m³ of biogas are required to be produced per day. Considering an annual 100 t/ha dry water hyacinth matter production then about 800 ha of pools will be needed to cultivate this aquatic plant.

There is a floodplain in the riverside areas opposite the city of Asuncion, near the botanical garden, which is big enough to cultivate water hyacinth for this project. 2,000 pools should be built, each measuring 20 m wide, 200 m long and 0.8 m deep, separated from each other by a 4 m wide runway for the circulation of the harvesting machines. These pools will be filled with water from the Paraguay River. The water has to be renewed periodically to maintain a sufficient level of nutrients in the water for the plants' optimum growth and to compensate the water loss by evapotranspiration. The pools will thus be interconnected with a network of tubes and channels connected to the river. A 5 km long defence dam will be built between the river and the installations to protect all these installations from floods during periods of rising water.

Water hyacinths will be removed and ground up by specially designed harvesting machines which will move along the runways between the pools. The ground plants will then be loaded into tank trucks to transport them to the digesters for unloading the substrate to be fermented. Will be needed 14 biodigesters, which will consist of 20 m wide and 50 m long rectangular pools covered with waterproof ground cloth and another special cloth which collects the produced biogas like a balloon. Part of the waste heat generated by the thermal plant will be used to heat up the digesters, thereby enabling them to function in the thermophilic range, resulting

in superior gas yield and lower retention time for the substrate than in the mesophilic range.

Once water hyacinth fermentation, lasting some 15 days, is concluded, the fermented organic matter temporally flows into some storing pools. The resulting product is an excellent organic fertiliser for agriculture; however, due to its very high water content, it would be better to dehydrate it somehow before selling. The produced raw biogas has to be treated before its combustion in the thermal power plant. This treatment by scrubbing eliminates most of CO_2 and H_2S and is followed by a drying process, so that the resulting gas will be almost pure methane with a calorific value of 10 kWh/m^3 .

V. THERMAL POWER PLANT

The proposed thermal power plant will be of the combined cycle type which consists of gas turbines and steam turbines, using part of the residual heat from the gas turbines. This type of thermal plant has the highest current energy efficiency (55% to 60%). The plant will be located close to the digesters to avoid having to transport the gas and will consist of two combined cycle turbines units having a total 65 MW power each and 70 MVA generators for each unit. Transformers will then raise the generated tension to 220 kV, which will allow the power plant to be connected to the national grid system [6]. Such generator configuration enables ideal generated energy adaptation to its demand during peak hours following the demand curve as far as possible. Normally, only the gas turbines would be started first followed by the steam turbines according to need; the opposite procedure would be applied to reduce the generated power.

The location of the proposed power plant is quite close to the 220 kV Puerto Botanico transformer station; only a 2 km long 220 kV transmission line crossing the Paraguay River is needed to interconnect both installations [5].

VI. IMPACT ON THE NATIONAL GRID SYSTEM

Two consumption peaks can clearly be observed taking into consideration the data for a typical Paraguayan grid system load curve during a hot summer's day (see Fig. 2). The first smaller amplitude peak occurs between 15:00 and 17:00 h and the second, more important one between 22:00 and 00:00 h, reaching a maximum of almost 2,500 MW. These peaks are mainly due to an intensive use of air-conditioners. The minimum consumption during the early morning hours is only about 1,700 MW; this stresses the need for a power plant for peak hours.

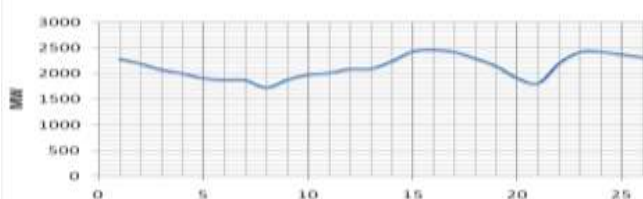


Fig. 2: Typical load curve on a hot summer day in 2013 (source: ANDE)

The thermal power plant would then function during these peak hours, together with the Acaray hydroelectric plant totalling 340 MW power. The existing line from Puerto Botanico to the Parque Caballero transformer station can be used as a transmission line to down-town Asuncion, as it has enough capacity.

It should be born in mind that although the recently concluded 500 kV transmission line between Itaipu and Villa Hayes is also considerably increasing transmission capacity in all other tension levels (220, 66 and 23 kV); [4]. It will not solve the problem regarding consumption difference between peak and trough hours [5]. This means that a power plant for peak hours is needed to reach a more balanced load factor. Another possible strategy would be that of promoting energy consumption during trough hours by offering special fees according to the timetable, for example electric cooking stoves or electro-intensive industries. [7].

Another point to consider is the savings that would have on the construction of a new line of 220 kV Airborne, taking into consideration the existing line that could be used as a first step and then force the construction of an underground line in XLPE 220 kV if demand requires; from Puerto Botanical Station to Park Station in Armored Knight SF6. [6]

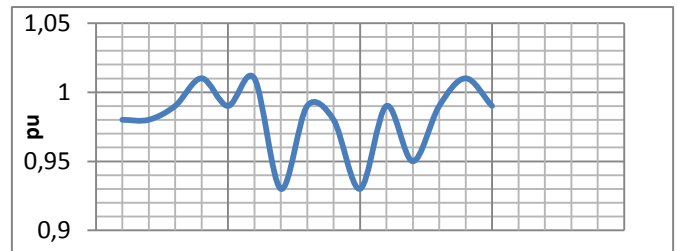


Fig. 3 Curve characteristic of voltage 220kV bus between the hours of peak load in the SIN, 2013, (Source: Ande).

In the fig 3. You can see the behavior on the 220Kv voltage bus of the main power stations in the Paraguayan electricity system peak load hours allowable value within the criteria of power system is observed, note the voltage drop at 0.93pu,[4], which requires some kind of implementation of technology to overcome the drawback of the voltage drop in service until the 500kV line.

A further point that we find in the Paraguayan Electric System is currently limited to generation and transmission of power flow in the Central Binational Yacyretá (Paraguay - Argentina) Paraguayan side, which currently is 500 MVA, this due to not 2 features of 375MVA 500/220kV autotransformers, totaling 750MVA, over all the adjustments that must be made on the 500kV bar for commissioning of equipment, limited carry more power schedule peak load Line Airborne 2x220Kv Ayolas - San Patricio this requires hiring more power Itaipu Hydroelectric and thus the annual payment that ANDE has to perform a binational is encouraged. [5].

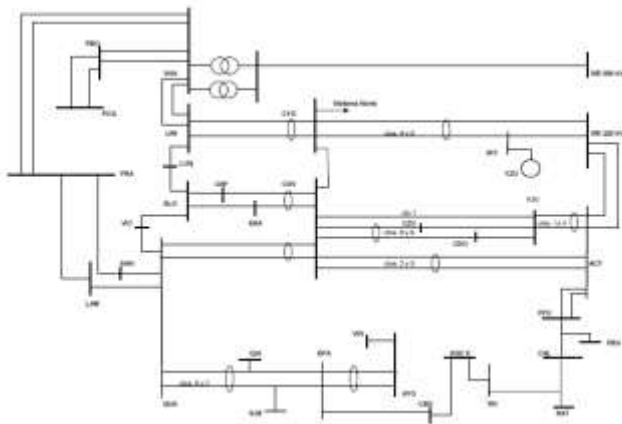


Fig.4: National Interconnected Grid System Configuration, 2013 (source: ANDE)

For the technical and economic evaluation of the implementation of this research in the SIN and its effects on the same were taken into account the current power system, the commissioning of the hydroelectric Yguazú commissioning of autotransformers Yacyretá in 2016. It should be noted that for all scenarios it was assumed that the 500kV Itaipu -Villa Hayes is in service. As redeeming find relief load transmission lines , distribution lines , power transformers and distribution feeders operate with less load and transmission losses diminish considerably more to achieve stability of tension in the electrical, allow a reorientation of the flow of charge altering the center of gravity of the power system thereby allowing north SIN assist system .

VII. ECONOMIC CONSIDERATIONS

An investment of about 98 million US\$ will be needed to implement this project. Considering a contribution by ANDE of some 13 million US\$ then external financing of around 85 million US\$ will be required. Also benefits granted by the Paraguayan law N° 60/1990 “About tax incentives on national and foreign investments” have been considered within investment needs. Beside, funds are available having very low interest rates and long repayment periods for this kind of renewable energy project. One example would be the Japanese government’s loan to Paraguay for financing the Yguazu power plant. An annual 1% interest rate has been considered for the present project and a 2-year amnesty period, the expected time taken for constructing the plant.

The economic approach in this case is that the investment will not be repaid by selling energy, but by the saving that ANDE will obtain from reducing the amount of power contracted at the Itaipu hydroelectric plant. This saving would reach an annual amount of around 25 million US\$ for the first year of operation. This amount would decrease 3% each year during the following years due to the increasing demand for electricity.

The investment could then be repaid in 15 years with a 10%

IRR and 85 million US\$ NPV. Selling of dried organic fertiliser at 10 US\$/t has been considered as a source of income. As a renewable energy project, this scheme could benefit from the clean development mechanism (CDM) which would allow issuing and selling of carbon emission reduction (CER) certificates. An additional 2 million US\$ per year income could be obtained by considering as a base line a project with gas turbines having the same power, using natural gas and a CER certificate price of 20 US\$/t (mean value in Europe). Though, IRR would increase to 12% and NPV to 107 million US\$.

VIII. OUTLOOK

From now on, feasibility of this project should be studied more in depth, mainly what the real growth rate of water hyacinth throughout the year under local climatic conditions is concerned, but also the practical biogas yield from substrate based on ground water hyacinth under different digestion conditions to confirm the actually available results obtained by simulation. Pulfer has recently submitted to CONACYT, a Paraguayan governmental institution for research funding, a project with these objectives.

The available space in the proposed site is big enough to increase the plant during a second phase; its capacity could practically be doubled by building another 2,000 pools for water hyacinths and all the other needed installations. Another possibility for increasing biogas production would be to incorporate waste water treatment into the plant’s technology. The main outflow of untreated waste water from Asunción into the Paraguay River is located near the botanical gardens. An underwater tube would thus have to be built to cross the river where it will feed such a plant with waste water. The raw waste water would first pass through a decanting process. The sludge so obtained would then be treated by anaerobic digestion, like the water hyacinth. The pre-treated waste water will then be sent to the oxidation pools containing water hyacinth, where the water will be cleaned. This water hyacinth will probably have an even higher growth rate than the one in river water due to the higher nutrient concentration in the water.

IX. CONCLUSION

The present paper only represents a first pre-feasibility study to demonstrate that it is technically and economically possible to install an environmental contamination-free thermal power plant close to the capital of Paraguay for peak hours, whose energy source is totally renewable and even locally produced. The economic benefit of such a plant in terms of savings on contracted power at Itaipu is considerable and would allow the investment to be repaid within a reasonable period. Another benefit would be the creation of a large number of jobs, not only during the building of the plant, but also during its operation. The proposal is totally innovative

as until now no other project using a similar approach is known.

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