

Effect of the use of solar street lights and LED lamps in residents on the Paraguayan grid and its profitability

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Abstract— This paper aims to present a new proposal for the generation of sustainable electricity for the metropolitan area of Asuncion, Paraguay, based on a renewable source of energy. This generation will be done mainly during peak hours in order to reduce the power contracted by the National Electricity Administration (ANDE) in existing power plants and thereby reduce costs and simultaneously stabilize voltage profiles in transmission and distribution in the area of Asuncion. Electricity would be generated by implementing photovoltaic panels on street lighting luminaries. Additionally would be reduced power consumption by distributing low consumption light bulbs to residential consumers. Both strategies would reduce by 200 MW the contracted capacity of the Itaipu power plant at peak hours. The main advantage for the implementation of such projects is the relatively high level of global solar radiation reaching per day in average in Asuncion and surrounding around 5 kWh/m^2 making viable in the short and medium term the use of solar energy for electricity generation combined with the use of low consumption light bulbs. With this project ANDE could save annually up to US\$ 40million in respect of the purchase of power at the Itaipu power plant.. The investment of about US\$ 156 million would be repaid within 10 years and will have an IRR of 8% and a NPV of US\$ 134 million.

Key words: photovoltaic systems, LED lamps, load management, national grid system

I. INTRODUCTION

ELECTRICITY supply of Paraguay's capital Asuncion and its surroundings depend mainly on the Itaipú hydroelectric power facility, where the national electricity company ANDE has to contract power. But during most time during the day this power is not fully used what generates unnecessarily high electricity costs. Beside, during hot days in summer the national grid system is often overloaded due to the increasing use of air conditioning in residents generating supply shortages. Both problems could be solved, if ANDE had one or several power facilities exclusively for peak hours. This paper presents an alternative to this solution consisting in reducing dependence on grid-electricity during the critical hours of peak consumption through the use of photovoltaic systems for street lighting and LED lamps for residents.

II. SOLAR RADIATION IN PARAGUAY

Despite of its humid climate solar radiation in Paraguay is relatively high, but dependable terrestrial solar radiation data for Paraguay aren't available due to the lack of appropriate measuring stations. Practically the only available source of data over a sufficiently long period are from the "Atmospheric Science Data Center" of NASA [1] obtained through satellite measurements over a more than 20 years period. The geographical distribution of the data, which have a resolution of 1° longitude to 1° latitude, is quiet homogenous over the whole country. The annual averages of horizontal global radiation in Paraguay varies between $4.7 \text{ kWh}/(\text{m}^2\text{d})$ in the south and $5.1 \text{ kWh}/(\text{m}^2\text{d})$ in the northeastern part of the country. In the area of the capital Asunción and its surroundings it reaches $4.9 \text{ kWh}/(\text{m}^2\text{d})$ or an annual average of $1788 \text{ kWh}/\text{m}^2$. In Germany, the world leader of the installation of photovoltaic systems, it reaches only 940 to $1050 \text{ kWh}/\text{m}^2$ according to the region, a little more than the half of the values of Paraguay. The minimum is registered in June and the maximum in December and January, for Asuncion with 2.9 and $6.6 \text{ kWh}/(\text{m}^2\text{d})$ respectively. As it's during winter, when nights are longest and consequently the energy demand for street lighting is highest, it's necessary to optimize the slope of the solar panels for this season. On a north oriented and 45° (latitude + 20°) sloped, in June can be captured in Asuncion an average of $4.2 \text{ kWh}/(\text{m}^2\text{d})$, 45% more than on a horizontal surface (see fig. 1).

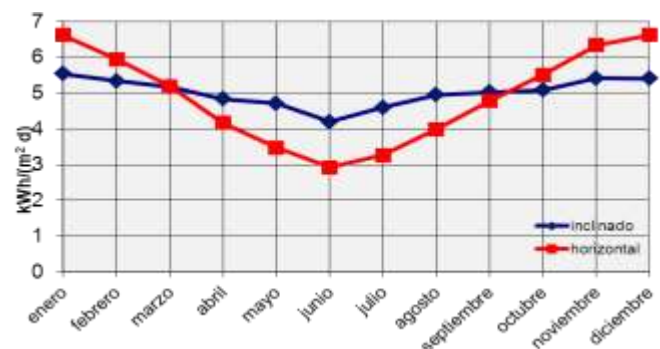


Fig. 1: Monthly averages of daily global radiation for Asunción on a horizontal and a 45° sloped north oriented surface (source: [6] and own elaboration)

III. PHOTOVOLTAIC SYSTEMS FOR STREET LIGHTING

Photovoltaic systems use so called solar panels, which generate electricity in direct current directly from solar light. They are made from semiconductor materials, in most of the cases silicon, and exist in a wide range of models with power outputs varying between about 5 and 300 Wp (Watt peak). The amount of energy they generate is practically proportional to the incoming solar radiation with a conversion efficiency of 15 to 20%. Solar panels have a long life cycle of about 30 years, need few maintenance and are easy to be installed. Thanks to the strong growth of the solar panel demand in many industrialized countries during the last decade their cost has decreased enormously and reaches actually less than 1 US\$/Wp. At the end of 2012 were installed in the world 102 GWp of photovoltaic systems, most of them grid connected, an increment of 32 GWp compared to 2011 [2]. Actually the world wide biggest photovoltaic solar plant has an installed output of 290 MWp. It's the "Agua Caliente Solar Project" in Arizona, USA. By 2014 it will be upgraded to 400 MWp [3]. Small systems are often installed on roofs of existing constructions, but large ones more likely in rural areas, as they need huge surfaces of free land. The generated electricity of on-grid photovoltaic systems has to pass first through converters, which transform direct current to grid like alternative current.

Off-grid solar systems are used mainly in rural areas of developing countries, where there is no public grid. These systems usually are equipped with batteries needed for energy storage. So, electricity generated during day time can be used during night time or when solar radiation is insufficient. Solar street lights are a special type of off-grid solar systems, being normally each light an independent system, with its own solar panel, battery and charge controller. This has the advantage, that there is no need for wiring the street lights (SL) with each other reducing costs. Charge controllers are electronic devices, which protect the batteries from overcharging and overdischarging. In the case of solar street lights they also control the turning off and on of the lamp automatically according to the actual daylight availability. There are also smart controllers, which can be programmed to dim the light during certain hours of the night to reduce energy demand and so reduce costs of solar panels and batteries (example: Phocos CIS-N series). The batteries need to have a sufficient capacity to offer an energy autonomy of 3 to 4 days, so that the street lights work even after several days of bad weather conditions.

IV. LED LAMPS

To reduce the cost for solar street lights to a minimum, only the most efficient lamps should be used. Light Emitting Diodes (LED) are the best solution for solar street lights, since they work with direct current and are actually more efficient than any other type of lamp for white light (up to 150 lm/W). It's expected that their energy efficiency will still increase in a near future, since the theoretical limit is around 300 lm/W. Only high pressure sodium vapor lamps have a similar

efficiency, but their chromatic reproduction is very poor due to its yellow color. LED lamps emit white light. Beside their life span (up to 50,000 hours) is much longer than the one of conventional lamps, what reduces maintenance costs considerably in street lighting. Another advantage they have is that they are dimmable, so that in any moment light intensity can be adapted to the actual need. More and more models of LED lamps are also available for residential use to reduce electricity costs. Due to their more or less directional light, LED lamps need to have just about the half of the power than CFL lamps for the same lighting intensity on a given surface.

For instance, a 150 W high pressure sodium vapor lamp can be replaced by a LED lamp of only 90 W. For its functioning in winter, when nights in Paraguay are about 14 hours long, there are needed 400 Wp of solar panels and a battery pack of 5000 Wh. But it has to be mentioned, that during the rest of the year there will be more energy available than needed, energy which normally is lost. In case that an automatic dimmer is used these capacities can be reduced. Considering a reduction to half of the lighting power during 6 hours a night during the period with less traffic, only 300 Wp of solar panels and 3800 Wh of battery capacity will be needed. So, the cost for each street lighting system will be less.

V. THE FUNCTIONING SCHEME

This configuration would allow an optimal fit of the energy generated according to demand during peak hours as well as possible following the curve of increase and decrease of the same to reduce the power generated proceeds inverso. Between in the sense that the company forecasts ANDE state should bear in mind during the implementation of these technologies is the THD, which will determine the quality of the electricity supplied to the user.

The same must be measured and evaluated from the output of distribution feeders located at Stations until the Post Distribution. The measuring equipment shall be located specifically in the living cells. Once the information is processed the same shall be sent to the control room of the station, centralizing information 23kV panel providing the installation of a special display on the panel.

Given that the load demand in the SIN is practically residential [4], it is estimated that for every 5 feeders, 5MVA power feeders will have 1 capacitor bank 6MVAR capacitor bank power. For each bar 23kV simple wiring system capacitor banks would be in star with neutral terrified and would have a current transformer and relay current imbalance protection and over current respectively [5].

Assumes no distortion control and load voltage that can cause a lot of non-linear loads in the system, since the capacitor banks in different seasons Electric System are designed only to reduce the effect reagent lines distribution that can cause purely reactive loads and partially act as filters to attenuate the

sine wave voltage and current. As an additional point to the above should also be taken into account the increase in the center of the neutral sizing capacitor bank star connection over this incorporate filters to attenuate the sine wave and thus avoid harmonics that cause bad synchronization in the actions of power system protections.

VI. IMPACT ON NATIONAL GRID

Observing the data of a typical load curve of the National Grid System (SIN) on a summer day on February 2nd of this year (see fig. 2) can clearly be noticed two consumption peaks. The first of lower amplitude occurs between 2 and 4 p.m. and the second a little higher between 8 and 10 p.m. with a peak of nearly 2430 MW. On the other hand, in the valley at dawn the demand is only about 1730 MW. This same pattern can be observed during hot days in summer caused by the increasing use of air conditioners in residents. Therefore, it is evident the need for one or several additional power plants for peak hours or any other solution to solve this problem.

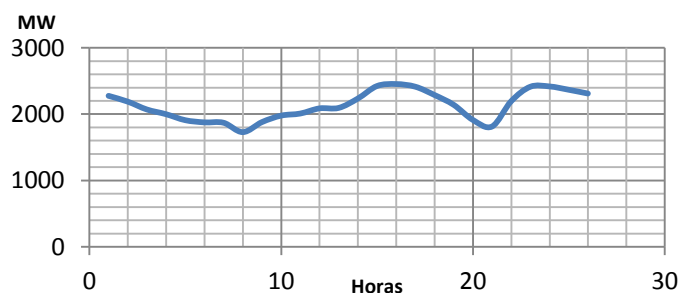


Fig. 2: Typical load curve of Paraguayan national grid system in summer (source: ANDE)

The implementation of photovoltaic solar panels and the use of low consumption LED type luminaries operating during these peak hours together with the Acaray hydroelectric plant will greatly palliate the existing inconvenience for the public enterprise, considering that there would be a total of 200MW of electric power, which doesn't have to be provided during peak load hours, equivalent to 8.23% of the total peak load demand. (See fig. 2). Of this quantity 15% correspond to the implementation of solar street lights and 85% to the implementation of residential LED luminaries.

If we analyze separately the implementation of both technologies we would meet with economic hardship, given that the investment cost of PV systems would be very high and would not allow their amortization in a reasonable period. That's the reason why both technologies, solar street lights and LED luminaries for residential use, have to be implemented together.

It should be noted that currently there is only one power plant for peak hours, which is the Acaray hydroelectric plant. Actually, it is not operating at its full capacity due to the lack of investments. The hydroelectric plant of Yguazú is currently in the process of bid. It will work only during peak hours and will have an installed capacity of 200MW [4]. Then, together

with the Acaray facility, which has an output of 210MW, would be available a total power schedule of 410MW.

An additional issue to the above power limitation is found at the Yacyreta power plant, which Paraguay shares with Argentina and where on the Paraguayan side currently only 500MVA are available, because of the of two 375MVA 500/220kV auto-transformers, totaling 750MVA. Beside, adjustments must be performed in the 500kV bar to make possible the functioning of this equipment. So, the commissioning of more power from Yacyreta at peak load hours is limited, what requires the contracting of more power at the Itaipu Hydroelectric plant, generating higher monthly payments, that ANDE has to perform to the that facility. In fig. 3 the observed behavior 220kV busbar voltage of the main power stations in Paraguay Electric System peak hour load, the voltage drop observed at 0.93 pu, value permissible under the criteria of the power system Ande [4], which requires some kind of implementation of technology to overcome the disadvantage of the voltage drop, pending commission the 500kV line.

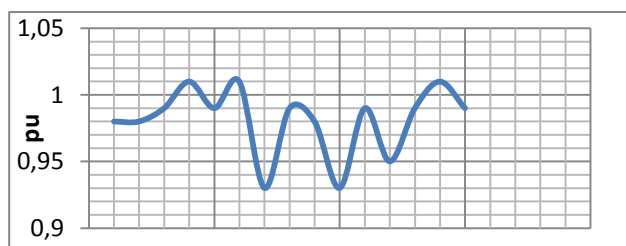


Fig. 3: Characteristic voltage curve of 220kV bars in peak hour load on the SIN, 2013 (source Ande).

Another point to consider is that the SIN is currently supplied through 7 overhead transmission lines of 220kV [6]. They are saturated due to high load demand and the lack of an efficient use of electricity in residents, reason that the implementation of alternatives, whether conventional or unconventional, merits attention in the short term to overcome this disadvantage. For this reason the implementation of low-consumption lighting for residents and the use of photovoltaic panels for street lighting would be a valid option.

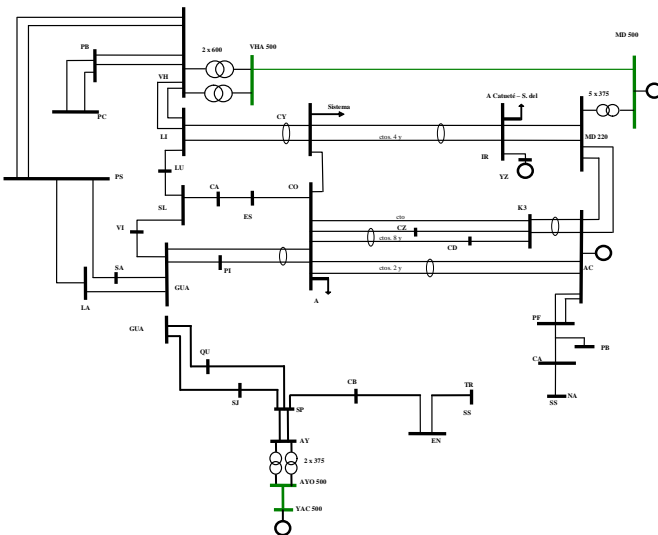


Fig. 4: Setting Interconnected National System, year 2012-2015 (source: ANDE)

For technical and economic evaluation of the implementation of photovoltaic solar panels and low energy lighting in the INS and its effects on the same were taken into account the current electrical system, the commissioning of the hydroelectric Yguazú, but not the entry into service of Yacretá autotransformers in 2016. It should be noted that for all scenarios it was assumed that the line of 500kV Itaipu-Villa Hayes is in service. Also drew a comparison between the non-revenue budgets by ANDE from energy sales in the case of implementing the project and reduced the contracted capacity of Itaipu Hydroelectric Power Plant that this implementation would generate, so to find the point of balance between the two and see how much the state pays for this type of renewable energy projects.

It is important to remember that while the Air Transmission Line 500 kV Itaipu and Villa Hayes, who is currently under construction, will greatly increase the transmission capacity in INS at all voltage levels (23, 66, 220 kV), it will not be solved with the significant mismatch between demand in peak hours and beyond. This means that the need will exist central point to reach a more balanced load factor.

The other possible strategy to achieve this goal would be to encourage consumption in off-peak times to offer differential rates depending on the time, for example for household electric ranges or electro-intensive industries. As found favorable point load relief transmission lines, distribution lines, power transformers and distribution feeders operate with less load and significantly decrease transmission losses, more than ensure stability of tension in the electrical system, allow a reorientation of system load flow thus allowing the system to help northern SIN.

VII. PROJECTION

According to data released by the public company Ande so far the number of luminaries for SL, with country-level counts of

250,000 in different types of power. According to the Integrated Management System of Electrical Distribution (SGIDE) this amount would increase to 400,000 lights within 10 years [3]. For the pre-feasibility study that we propose here, we consider only 160,000 lights to be converted to solar power, distributed power class according to the amount shown in Figure 5.

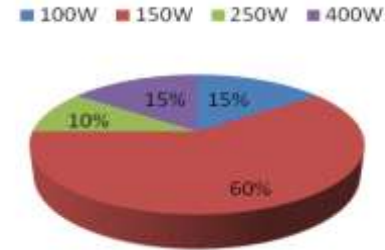


Fig. 5: Power distribution of Street Lighting Luminaries type, year 2013 (source: ANDE)

With the implementation of this type of project estimate a decrease in power demand on the Paraguayan electrical system of the order of 30MW peak hour load. If to this we add 2,000,000 incorporating low energy lighting assimilating to a 100W incandescent lamp and similar low 15W LED type together, we found a decrease of 170MW, totaling a decrease of 200MW power demand in INS. In the area of large Assumption only have 120,000 lights, so it could be considered for the implementation of a pilot.

VIII. ECONOMIC CONSIDERATIONS

To carry out the proposed project is estimated a total investment of about US\$ 190 million. Considering an own contribution of entrepreneurship by ANDE of about US\$ 34 million, it will be necessary an external funding of about US\$ 156 million, considering the benefits granted by Law N°60/90 on the promotion of investments. For this type of projects based on renewable energy and energy efficiency are available funds at very low interest rates and longer payment terms. An example to cite here is the loan offered to Paraguay by the government of Japan to finance the mechanization of Yguazú dam. For calculations of profitability of this project we have then considered a 1% annual interest rate and a 2-year grace.

The economic approach in this case is that the investment would be repaid not by the sale of energy, but through savings that ANDE will obtain by reducing the contracted capacity in the Itaipu hydroelectric plant. The savings would amount to an annual value of about US\$ 40 million. Investments could be amortized within 10 years resulting in an IRR of 8% and a NPV of US\$ 134 million. As enterprise revenues were considered, as mentioned above, the savings in contracting power at the Itaipu facility.

Being a renewable energy project it could benefit from the Clean Development Mechanism, which would enable the issuance and sale of carbon credits, where as a baseline is

considered a thermal power plant project with the same power using natural gas as energy source. Considering for these credits 10 US\$/t of carbon dioxide, they could generate an additional annual income of about US\$ 8 million. The IRR would increase then to 12% and the NPV to US\$ 240 million.

IX. OPINION

This work, which represents just a pre-feasibility study, wants to show that it is technically and economically feasible to implement these technologies, for hours on end without polluting the environment, whose source is a completely renewable energy and also a locally generated one. The economic benefit of implementing renewable energy projects in terms of savings on hiring Itaipu power is considerable and would repay the investment needed in a reasonable time. Another important benefit would be the creation of a significant number of jobs, not only during the implementation of the project, but also during operation. The proposal is absolutely innovative, since so far there are not known projects with a similar focus.

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