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CUTTING ON DIESEL, BOOSTING PV: THE POTENTIAL OF HYBRID DIESEL / PV SYSTEMS IN EXISTING MINI-GRIDS IN THE BRAZILIAN AMAZON

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ABSTRACT

The hundreds of mini-grids fed by Diesel gen sets operated by independent power producers (IPPs) and public power utilities in the Brazilian Amazon all make use of a government subsidy that covers 100% of the fuel. This subsidy has recently been extended for another 20 years. Most of the sites where these mini-grids operate are not easily accessible, increasing cost and decreasing reliability of supply. IPPs willing to invest in renewable generation that displaces Diesel can currently claim the cost of the fuel consumption avoided. We demonstrate that hybrid Diesel / PV systems without storage can be the most competitive option, if the introduction of PV in this sector is intended. We discuss some changes in the existing subsidies in order to make the PV-option viable, evidencing the potential of PV insertion to a level that can justify a local PV module manufacturing plant in the country. Extending the model to a next stage includes the introduction of hybrid PV/fuel cells to rely completely on the local solar resource.

1. INTRODUCTION

Energy supply to dispersed populations in the Brazilian rainforest assumes a number of configurations; no service at all, PV solar home systems with very limited coverage and service, and mini-grids supplied by Diesel gen sets are examples. There are currently hundreds of mini-grids operated by independent power producers (IPPs) or local state utilities in the Amazon, that cover the main share of this demand, which is however only a small proportion of the country's total energy consumption. Mini-grids extend over some 45% of the area, but supply energy to only 3% of the population [1]. Most of the sites where they operate are not easily accessible, increasing cost and decreasing reliability of supply.

The operators of these systems, however, all make use of a subsidy that covers 100% of the fuel, as long as they operate at or below the 0.34 L/kWh specific consumption limit. This government subsidy's life span has recently been extended for another 20 years. Utilities are allowed to include a surcharge to all urban and rural consumers of the national interconnected system to collect funds to subsidize consumers of these isolated systems. This surcharge system, and the funds collected, are directed to the so-called *CCC Account* (Conta de Consumo de Combustíveis) which subsidizes Diesel for the thermal plants in isolated mini-grids.

IPPs willing to invest in renewable generation that displaces Diesel can claim the cost of the fuel consumption avoided, but so far this has not been attractive enough to encourage them to switch to renewables. In this paper we show under which scenarios (*e.g.* system size, PV coverage fraction) hybrid Diesel / PV systems are cost competitive making use of an adapted version of current subsidies. From these scenarios, the potential of PV insertion to this market niche can be assessed. Extending the model to a next stage includes the introduction of hybrid PV/fuel cells, to rely uniquely on the local solar resource, generating and storing H_2 on site, completely avoiding the use of fossil fuels.

2. STRATEGY AND SYSTEM LAYOUT

Isolated systems supplied by mini-grids in the Amazon include Diesel thermal plants ranging from 5 kVA to 500 MVA. Operation and maintenance costs of smaller and remote units are higher than for larger systems in more urban areas. In this context, our first analysis concentrates therefore on these smaller units, with higher specific costs. We will focus the first step of our implementation strategy on small Diesel units (< 100 kVA), proposing a gradual addition of PV arrays to existing Diesel gen sets. In the Amazon region there are currently 86 thermal plants with capacities of up to 100 kVA, totaling some 7 MW of installed capacity. The total installed capacity of thermal plants of the isolated system in the region, which make use of the CCC subsidy, however, amounts to over 2.3 GW, and has burnt some 1.3 billion liters of Diesel in 2002* [1].

Based on field experience with a pilot project of a hybrid Diesel / PV system operating since 2001 in the state of Rondonia [2], we make some suggestions for an initial introduction of Diesel / PV hybrid systems without storage (no battery bank). The assessment of the PV

* Diesel is the bottleneck of the oil refining process in Brazil, since all production is geared to maximize the volume of Diesel with respect to other oil distillates, and which makes the country more dependent on imports. Moreover, because of this need to produce more Diesel, the refining process is conducted at a temperature level which is higher than the recommended temperature, increasing the amount of Diesel produced, but decreasing fuel quality and efficiency [C.Bermann, *Energia no Brasil: Para Que? Para Quem? Crise e Alternativas Para um País Sustentável*, Livraria da Física Editora, São Paulo, 2002, p.33.].

system performance takes into account the local solar resource, based on the Brazilian Solar Radiation Atlas [3], and the typical load characteristics of mini-grids in the Amazon region.

2.1 Load Curves vs. Hybrid System Configuration

One particularly important assumption of the proposed configuration relates to the load curve. While most of the hybrid systems described in the literature [4-8] apply to load curves peaking in the early evening, with small loads throughout the night, the situation in the Amazon region seems to be different. Figure 1 shows a typical average load curve of the Araras-RO (10°S) mini-grid, where we have installed a hybrid Diesel / PV system without storage described elsewhere [2].

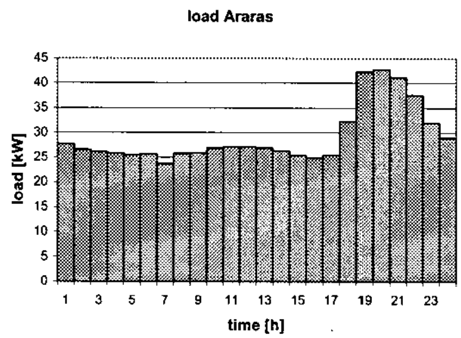

Figure 1: Typical average load curve of the Araras-RO hybrid Diesel / PV plant [2].

This virtually flat curve is caused mostly by refrigeration loads, due to the commercial and domestic fridges and freezers used in the region. A similar load curve is reported by Rosenthal for a system in Australia [9].This load characteristics and load profile led us to rethink the proposals for system design and operation as presented by other authors [5-8]. There, the introduction of batteries to the systems is, among others, motivated by the fact that batteries may avoid the operation of the Diesel gen set to supply low nighttime loads, with the associated low efficiencies of partial load operation of Diesel units. With a reasonable sizing of the Diesel unit, taking into account load curves as shown in Figure 1, it can be operated at an efficiency level which is only marginally lower than the nominal efficiency of the gen set. On the other hand, the application of batteries for the supply of nighttime loads is associated with energy losses related to the charging/discharging cycles, which can amount to 10 – 15%. Thus, the use of storage batteries to supply energy in the evening and at night would represent not only a considerable investment for a large battery bank, and potential environmental hazard, but also a significant amount of energy wasted in the charge-discharge process and other associated battery losses. We have thus proposed a configuration without batteries, where the Diesel gen set (one or more units, depending on particular plant and dispatch schedule) is operating at all times. The renouncement of a battery bank will, however, put some constraints to the share of PV that can be reasonably integrated in the system (% of PV penetration). The potential for PV under these circumstances is discussed in the next section.

2.2 Suggestion for the Sizing of PV Generators for Systems Without Storage

In this context, we suggest the following configuration for the hybrid system: - a Diesel / PV hybrid installation without energy storage system [2], comprised of a PV array with nominal power equal to some 70% of the average daytime load (06:00 to 18:00). This is the structure and approximate sizing of the pilot system currently in operation in the Amazon. A schematic diagram of that installation is shown in Figure 2.

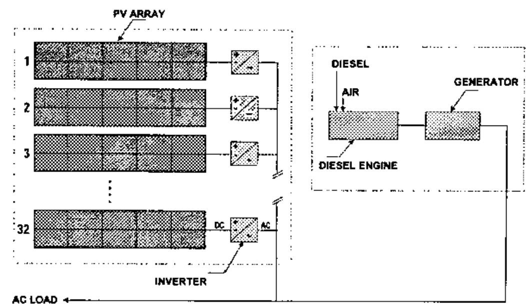

Figure 2: Schematic diagram of the proposed hybrid Diesel / PV system without storage currently under operation in the Amazon [2].

In our case, this represents some 90% of the power being fed by Diesel gen sets, and about 10% of the total energy generated by the plant. The magnitude of these figures corresponds to the results of calculations for the system performance carried out for various sites in Brazil [10]. These calculations have shown that the limitation of the PV capacity to a value of about the average daytime load is a reasonable choice. As shown in Table I, from simulations using meteorological conditions, and the load curve as given in Figure 1, relative fuel savings in the same order of magnitude can be expected. The table also confirms that for the given situation, the use of batteries does not offer any advantage at all.

Based on the design considerations discussed, we analyze the overall technical potential for the introduction of hybrid Diesel / PV systems without storage, and comment on present and future conditions for their successful implementation.

Table I: Diesel fuel consumption simulation results for hybrid Diesel / PV systems with and without battery storage, based on results from [10].

Average load		29 kW
Night-time load		20 kW
Diesel gen set size		60 kVA 54 kW
PV array		21 kWp
Battery operation conditions	Max. discharge to 40% DOD*	
Case	**Annual fuel Consumption (L)**	**Difference to Case A (L)**
A: Diesel only	66,373	---------
B: Diesel + 21kW PV	58,747	- 7,626
C: Diesel + 10h battery	68,554	+2,181
D: Diesel + 10h battery + + 21kW PV	58,735	-7,638

*Battery efficiency characteristics from Varta OPz.

In table II, we present cumulative results of annual energy production and Diesel consumption for all Diesel thermal units ranging from 5 kVA to 100 kVA operating in the Amazon [9], assuming a 64% capacity factor and 0.34 liters/kWh specific consumption. From the results presented in Table II, taking into account our proposed PV system sizing of some 70% of daytime load, the total demand of PV modules for hybrid installations below 100 kVA in the region is some 3 MWp, which in a first phase would serve the purpose of gaining experience in the installation, operation and maintenance of hybrid Diesel/PV systems without storage, but would not be enough to justify local PV module production. The establishment of local a PV module production plant assumes a 5-10 MWp/year minimum production capacity to be cost competitive. However, considering annual yields of 1600 kWh/kWp for PV operation in the Amazon region and our proposed sizing of hybrid Diesel / PV systems without storage, we can estimate a potential for PV of around 1 GWp, with close to 300 million liters of Diesel saved annually. The scale of this market would justify local PV module production at the 100 MWp/year level necessary for production costs to drop to the 1US$/Wp range [11-12].

Table II: Installed capacity, annual power production and Diesel consumption for all thermal plants ≤ 100 kVA operating in the Brazilian Amazon, grouped in four different power ranges [9].

	POWER RANGE (kVA)				
	5 – 12	12 – 25	25 – 50	50 – 100	Total
Installed Diesel power capacity (kVA)	91	554	1,625	4,775	7,045
Total annual power production (MWh)	510,2	3,105.9	9,110.4	26,770.6	39,497.1
Total Diesel Consumption (10^3 liters)	173.5	1,056.0	3,097.5	9,102.0	13,429.0

Assuming 64% capacity factor and 0.34 liters/kWh specific consumption.

3. PERSPECTIVES

Figure 3 presents a proposal for a further step in efforts to make the Amazon region more independent of Diesel or any other external energy inputs. It is proposed that in the future, with the further development of hydrogen storage and fuel cells, it will be possible to generate electricity for the local grids by means of the local solar resource alone.

In this scenario, PV arrays will simultaneously feed the loads in the mini-grids and, depending on the actual power balance, also power an electrolyzer for hydrogen production on site. A fuel cell can then be used to run baseload and nighttime loads. It has to be emphasized, however, that this system concept is different in size, structure and temporal pattern from the power flows from the systems proposed *e.g.* by Sauer *et al.* [13] for the supply of small stand-alone loads. As such, there is still a need for an extended assessment of this concept. Areas of concern are the performance of the components under long term operation at variable operation conditions, their lifetime efficiencies and lifetime with adapted control strategies.

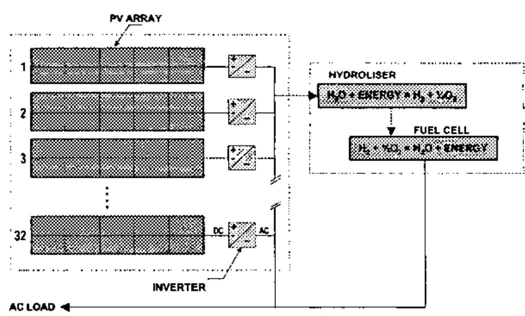

Figure 3: Schematic diagram of the proposed hybrid fuel cell / PV system, where hydrogen produced by water electrolysis powered by PV runs the fuel cell in the hybrid installation.

4. CONCLUSIONS

We have presented simulations and operational results that justify the concept of hybrid Diesel / PV systems without storage to feed the large number of existing mini-grids in the Amazon region. There are government subsidies that can be used to finance renewable energy generation that displaces Diesel, but their uptake has been very poor so far, mostly due to lack of previous experiences by IPPs in the field, and also to inertia in adopting new technologies in exchange of the guaranteed returns of the present scheme where Diesel is subsidized. We believe that only with additional incentives and/or mandatory renewable energy targets will any private capital enterprise be interested in cutting on Diesel and boosting PV in existing mini-grids in the Brazilian Amazon.

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