GRADUAL INTRODUCTION OF PHOTOVOLTAIC SYSTEMS IN GREEK, ITALIAN AND FRENCH ISLAND UTILITY GRIDS

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ABSTRACT: This work deals with the issues raised and the solutions developed for a potential strategy for the gradual introduction of photovoltaic systems into Greek, Italian and French islands with autonomous grids. During the course of the project JOR3-CT97-0158, titled: “PV System Technology Development for the Gradual Penetration of Photovoltaics into Island Grids”, the basic technological components have been developed and tested (tolerant PV inverter, bi-directional battery inverter and supervisory control).
The data collected from various Greek, Italian and French islands, about their population, installed utility capacity and the cost of electricity production are very important in order to compare with the cost of PV systems introduction. A new model for the calculation of Diesel generator based power production costs is introduced, which considers separately the cost share related to the diesel operation time, allowing therefore to quantify the added value of the “capacity credit” provided by Renewable Energy Systems.

Keywords: Island Grids - 1: Economic Analysis - 2: Utilities - 3

1. INTRODUCTION

This work presents the issues raised and the conclusions for a potential strategy for the gradual introduction of photovoltaic systems into the Greek, Italian and French islands with autonomous grids. During the course of the project JOR3-CT97-0158, titled “PV System Technology Development for the Gradual Penetration of Photovoltaics into Island Grids”, the basic technological components have been developed, and therefore the related technical characteristics and specifications are known. A number Balance of System (BOS) devices were developed:

- a tolerant PV inverter,
- a bi-directional battery inverter able to form and improve the grid performance characteristics [1],
- the supervisory control.

The above devices allow the co-ordinated large scale introduction of PV systems in existing island grids currently powered by diesel generators. Specifically, they allow for a gradual transformation of these grids from purely diesel powered systems to hybrid with increased PV penetration and finally, allowing 100% PV powered grid operation. The technical issues concerning this transformation were therefore specifically addressed by the project and were presented at the 16th European Photovoltaic Solar Energy Conference in Glasgow [2].

Task 6 of the project required that the project partners from Greece, Italy and France provide first indications concerning the implementation strategies in his own country and related markets.
The questions and issues raised are mainly oriented towards the identification, quantification and stimulation of the market potentials for the technologies developed by the project, and include:

- Description of the energy market environment, where the envisaged technologies are most probably going to be applied and implemented.
- A new model for the calculation of Diesel power costs, which considers separate the cost share related to diesel operation time, allowing thereby to quantify the added value of the "capacity credit" provided by renewable energy systems.
- What kind of information is needed to be collected from the islands (i.e. load demand curves/profiles/trends, air photographs of villages, in order to determine roof integration potentials, regulatory barriers, key players and local enterprises, which may be involve and have an economic interest in promoting PV, strategies based on whom and how to contact influential people at the local level, and what kind of information must be given to them to convince them to start promoting and implementing PV projects).
- What kind of non-technical barriers hinder the introduction of the envisaged PV technologies and how can these be counter-acted.
- Island utilities requirements
- The market strategy deemed most convenient to be adopted
- Which are the strong messages, which need to be launched towards governments (national, regional and local), the islands municipalities and utilities.

Today in the Mediterranean, the break-even island community size, where PV systems are cost-effective, is about 500 inhabitants. This may vary due to different economics (utility structure, incentives, taxes, tariffs etc.) between countries and it depends also on the utilization factor of the Gensets, according to the activities on the islands during the year.

On the less populated islands the diesel electricity produced is very expensive (exceeding 0,5 Euro/kWh) and consequently PV power, if combined with the BOS technologies developed by the present project becomes a cost-effective alternative. On islands with more than 500 inhabitants, PV technology will mostly present higher overall costs than diesel powered ones (except in the case that externality costs are also considered).

THE GREEK ISLANDS

The goal in this project is to cover the energy needs of islands (or small communities), with a population less than 2000 people. In Figure 1, the installed generating capacity (data from PPC, 1994) per permanent island inhabitant is presented. Note that in the Greek mainland grid the installed capacity is approximately 1kW/inhabitant.
The large values of installed capacity per inhabitant and the marked difference in energy utilization between winter and summer seasons are due to the touristic character of these islands. Therefore, the consumption pattern of energy use favors the use of solar energy.

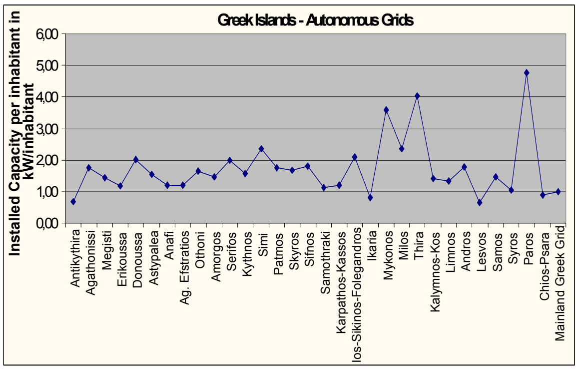

Figure 1: Installed generator capacity (data of PPC, 1994) in the Greek islands per permanent inhabitants (censor 1991) for islands with up to 10.000 permanent residents.

Greek Island Power Supply

For many autonomous systems (over 80) installed in the Greek islands, new generation capacity will be needed in the next few years. These systems consist mainly of diesel units and have relatively high operational costs, due to the high price and transfer costs associated to the fuel used. Since the solar and wind potential in most of these islands is high, the economic viability of photovoltaics and wind generators has to be investigated as an expansion alternative. However, the penetration of renewable energy sources (mainly photovoltaic and wind generators) has proved to be an attractive alternative in the aspect of reducing both the operational cost and pollution issues such as the air/water emissions and noise.
Preliminary studies for many small (low in population) Greek islands show that the penetration of solar energy into small electric power grids can be economically viable for small systems with up to around 2000 kW installed generating capacity. In figure 2, notice that the annual average energy production cost decreases as the installed generating capacity in the islands increases.
Wind energy generators are today competitive in several large Greek islands, depending on type of oil used in the existing diesel generators, installation cost, etc.

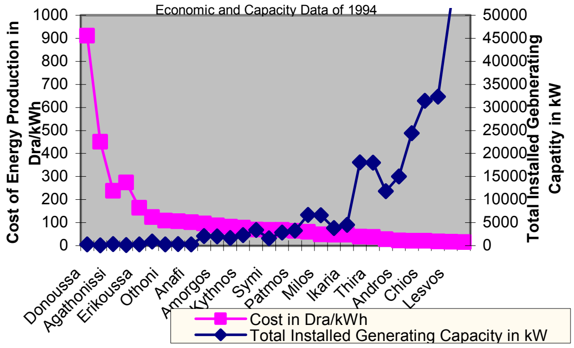

Figure 2: Installed generator capacity in the Greek islands and cost of energy production per island.

Issues such as system reliability, easy maintenance and aesthetic integration are also important in the islands. Yet, the most important issue is system expandability as the load demand is increasing at an average rate of 8.5% per year for the past ten years. The load increase is even higher for small islands. Conventional (diesel) systems are easily expandable and the existing technical personnel in the island electric power production plants is familiar to these systems and knows how to maintain them RES systems have to display at least similar attributes.

The best strategy for the introduction of RES in Greek islands is:
First, to pinpoint the electricity needs that can be easier satisfied by RES rather that diesel. Secondly, to solve the technical problems, that prevent RES system expandability, adaptability and their integration in conventional island power supplies. Finally, demonstrate that RES systems have at least the same virtues as conventional ones and should be the power source of choice when the price is right.
One of the first questions raised during this project has been whether to design a hybrid system for a large, a medium or a small island. Depending on the answer we have to face different technical problems, and of course, we may end up to different solutions. One important issue during the economic evaluation of RES for large Greek islands is the perspective of electrical interconnection to the mainland Greece. Even if the interconnection never occurs, the investor has to account for this possibility and compare the electricity cost in the Greek mainland grid. Therefore, it seems more appropriate to address the introduction of RES in smaller islands with fewer possibilities to be interconnected with the Greek mainland grid.

THE ITALIAN ISLANDS, "ISOLE MINORI"

Presently, the Italian islands not connected to the continental electricity grid, are powered by expensive and environment unfriendly diesel generators used to feed the local (island) grid. While in the past the diesel generator represented the only viable power supply solution for such islands, today PV technology may offer a convenient alternative, especially where tourism plays an important role for the island economy.
The Italian islands are therefore expected to reach earlier than most continental areas in Italy those conditions where

PV becomes cost-effective and more convenient than conventional power. Nevertheless, the practical implementation of PV technology on Italian islands has remained far below expectations.
The two largest Italian islands, namely Sicily and Sardinia, were deemed of little interest for the present investigation, since the actual energy and water supply conditions do not differ substantially from the typical situation to be found also on the continental mainland. Accordingly the project team decided to exclude these two major islands from the present investigation, and to focus instead work onto the so-called “Isole minori” (minor Italian islands).
The Italian “isole minori” are more or less distributed along the coastlines of the Italian mainland, Sardinia and Sicily. Only on the Adriatic sea, between the Venice lagoon islands and the Tremiti islands in the south (near the Gargano peninsula) there is a relatively long stretch of open sea without any islands. Except the Venice lagoon islands, which suffer for their northern latitude, all other Italian islands present arid climate with abundant solar resource of approx. 4,5 kWh/m^{2}day annual average (1600 kWh/m^{2}yr).

Regardless of specific location and archipelago, generally speaking, the Italian “isole minori” may roughly be classified for the purpose of this report as follows:

1. Islands of larger population (beyond 5000 resident inhabitants) of basically stable number over the year, and where local economy, although strongly affected by tourism, still conserves other economic activities. Typical examples for such islands are Ischia and Procida (inhabited to a large extent by commuters working in the city of Naples), Elba, Lipari, La Maddalena (offering logistic support to the known US navy base), but also Pantelleria located roughly half way between Sicily and southern Tunisia.
2. On the other extreme there are the islands oriented exclusively towards tourism economy. Typical examples are Vulcano, Panarea, Giannutri, Ustica etc. - Here the seasonal variation in number of inhabitants becomes enormous (summer population grows 5-10 and even more times in comparison to winter-population), provoking same enormous differences in consumptions of, power, water and any other resources (also the environment) available on the island.
3. Smaller islands resisting modern tourism economy, which still try to conserve their traditional cultural heritage and life-style. The best example for this kind of island community appears to be Marettimo, the most distant island belonging to the Aegadi archipelago located before the west coast of Sicily right in front of Tunisia, where the local still intact fisher community maintains its ancient way-of-life dominated by fishery and sailor traditions.
4. Prison islands (Gorgona and Pianosa belonging to the Tuscany archipelago. Generally the non-prisoners living on these prison islands are either some few fishermen or else people working for services related more or less to the prison. Asinara, a former maximum security prison island located at the north-west corner of Sardinia, has to be considered separate, since only recently it has been transformed into a totally protected and not inhabited national park subject to rigid regulations.

All the other not mentioned islands present development situations somewhere in between the presented first three extremes. The assessment work focussed particularly onto all those islands, which have an autonomous power supply (grid) system powered by diesel generators.
The diesel capacities installed on the “isole minori” are presented per inhabitant by the following figure 3, which clearly makes evident, that the generation capacities on islands are much higher (per inhabitant) than on the Italian mainland. At a first glance this may appear astonishing, if we consider that there is little or no industry on the islands and, if any, industries are present only on the larger islands presenting the lowest values closest to national (mainland) average).

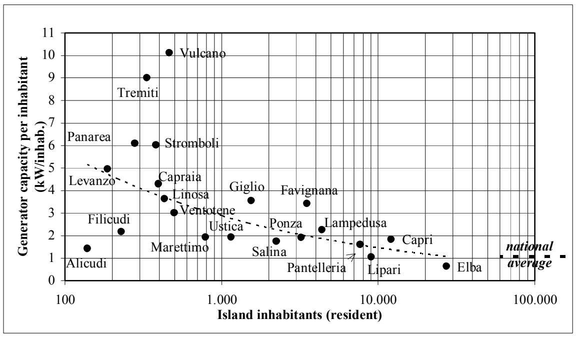

Figure 3: Generator capacities installed on Italian islands (1991)

The wide variation range among smaller islands allows to distinguish between strongly touristified islands (Vulcano, Giglio, Tremiti) on the one (high) extreme, and on the other (low) extreme very recently electrified smallest islands like Alicudi and Filicudi, where local population has not yet become used to the benefits of electricity and have not yet learned to exploit it fully.
The low capacity factor observed (ratio between annual electricity sales and the overall 100% [theoretical] generating capability over 8760 h/yr) in the less populated islands illustrates clearly that the power supply systems serving larger island communities exploit much better installed generator capacities, whereas smaller island communities are unable to utilise in an effective way, the installed capacity which is oversized in order to be able to cope with sudden peaks in load demand. As known, load peaks are statistically much more severe in a small grid with few connected subscribers than in a large grid, where different user habits smoothen the load curve by compensating each other. This phenomenon may be considered to affect significantly (and very negatively) the costs of diesel power on smaller and smallest islands, which makes these islands particularly promising candidates for PV applications, namely Alicudi, Levanzo, Filicudi, Panarea and Stromboli island.
Unfortunately it was not possible to obtain data concerning effective costs of diesel power on Italian islands since local operators (especially local utilities) were reluctant to provide information, especially of economic type. As a result, relevant data had to be gathered indirectly.
Actually, instead of the cost figures, figure 4 presents the estimated revenues of local island utilities calculated by adding to the subsidy paid by the “Cassa Conguagli” (Compensation Fund established by the Italian Ministry of Industry) a typical tariff amount expected to be paid by the

average consumer on islands. This tariff amount was estimated around 320 Lire/kWh = 0,16 Euro/kWh.

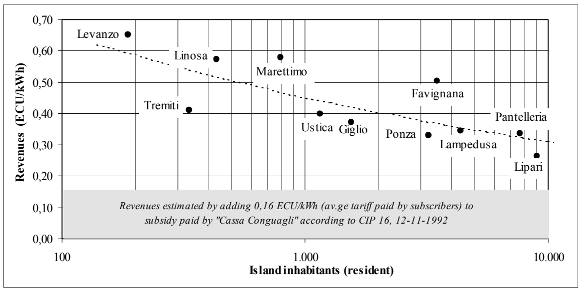

Figure 4: Revenues of local utilities on Italian islands for conventional power (1992)

Needless to say, that such subsidy mechanism favouring conventional energy acts as a strong barrier against PV and renewables in general: on the one side, as already mentioned, they induce islanders to boost their consumptions (making the PV alternative become larger and more expensive), on the other they freeze the existing (conventional) energy system on islands and hinder the introduction of innovations. Especially on smaller islands, the same money spent today to subsidise conventional power would be sufficient to provide for the funding required to replace conventional (diesel) power by PV technology.
Note For comparison: The typical cost of PV power ranges around 1000 Lire/kWh (0,50 Euro/kWh), while wind-power (where available) may be even lower than 200 Lire/kWh (0,10 Euro/kWh).

FRENCH ISLANDS

The renewable energy sources have received new support in several European countries. The French framework changed in the last months, and permits a more offensive and sustainable penetration of renewable energy sources. The new law adopted in February 2000 about the electricity service modernisation and development with the one adopted in June 1999 on the territory management enhance this target. Of course, the older laws on energy saving and rational use of energy are always up to date.
All this legislation will be completed in order to reach the objectives of gas emission reduction given by the European White Paper strategy and the government future action.
Currently the main aspects are:

- Partial market liberalisation with purchase obligation by the utility (up to 12 MW) in order to insure the selling and sustain the market before the total market opening.
- Pay back tariff: 0.63 FRF/kWh for the photovoltaic grid connected, with an expected increasing in a few months.
- Fiscal incitement to RES implementation

EDF (Electricité de France), the French public utility is involved in the French islands like in the main classical grid; the particularity concerns the overseas territories where local producers and distributors are also present.
The electricity production cost in the French islands is double than the main country cost. So the French utility EDF has losses up to 2.4 billions of French francs in 1998 thanks to the tariff obligations.
With the electricity low selling price, the take off of renewable energy sources is difficult without specific financial supports (subsidies, non taxation). The "price flag" is absent, even if the electricity consumption increases in the overseas departments (+ 8% per year since 1996).
We assist to the development of fossil plants with carbon emission more important than in the main country (680 g of carbon per kWh against 183 g of carbon per kWh on the continent).
The French islands could be the most interesting application field for renewable energy sources implementation but incitement actions must be elaborated, proposed actions are described at the end of this report.
Thanks to a wide autonomy, the overseas territories have each of them a specific regulation with private or public utilities; the regulation is conducted by the local government.

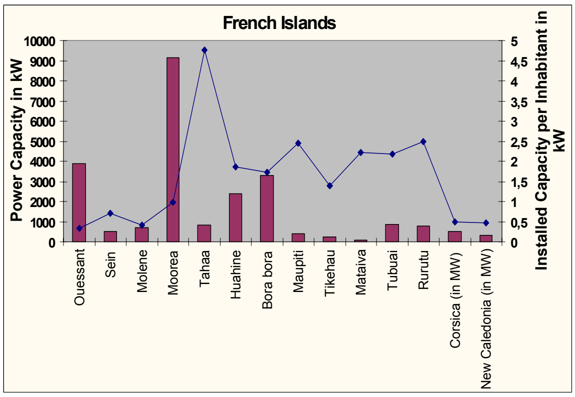

Figure 5: Installed capacity and capacity per inhabitant in various French islands.

Figure 5, presents information about various French islands, where the trends observed in Greek and Italian islands are further confirmed.
Two main actions are on going for the strategy penetration in this field in order to support this action:

- The French government and the national agency for environment (ADEME) signed a specific contract and commitment for 2000 to 2006. The main objective is to reduce gas emission (1.2 millions tonne avoided) thanks to renewable energy sources. Among the key actions, one is specifically dedicated to the French islands (Corsica plus overseas islands) with a budget of 14 M Euro. For photovoltaic the main tasks are: +375 GWh / year produced by renewable energies 500 sites equipped with renewable energies (stand alone and grid connected).
- A big assistance for RES in French island (with department status) is the law on pay back tariffs.

With these tools the strategy for photovoltaic system technology development into French island grids (and stand alone system) is on a good way and will be a good example for the main country.

NEW MODEL FOR DIESEL ENERGY COSTS

A new model for the calculation of Diesel generator based power production costs is introduced, which considers separately the cost share related to the diesel operation time, allowing therefore to quantify the added value of the "capacity credit" provided by Renewable Energy Systems.
Although estimated on the basis of the outcomes of the Italian island investigation, the following cost model and resulting figures comply basically also with the results of the corresponding investigations made by the other partners of this project on smaller islands in Greece and in France (French Polynesia).
The model makes a clear distinction between:

- The fixed cost share, which cannot be saved by PV (or other renewables), and which stems basically from the transmission and distribution grid costs (including related investments O&M + local operator/manpower costs) + administration, billing, payment collection and overheads
- The cost share proportional to produced energy (basically costs of fuel and related handling and transportation from continent), which usually is saved by grid connected RE systems (which therefor are typically called "fuel-savers")
- Diesel operation time related costs, which can be saved if the PV (or other RE) contribution allows for effective stopping of individual diesel units (the so-called "capacity credit" since applicable to any kind of thermal power generation capacity)

It is common knowledge that investment amortisation, wear and tear, as well as maintenance of a diesel generator depend primarily on the number of running hours (whether a diesel generator is running idle (at zero-load), or producing its full power, this doesn't change substantially the scheduled routine maintenance (and refurbishing) plan which, in any professional power plant environment, will generally be scheduled according to the reading of the operation hour counter of the individual diesel unit.

The interesting aspects of this last mentioned cost share are:

- The smaller the installed capacity on an island, the much larger the "capacity credit" share (and related possible savings) become
- Utilities do not trust/appreciate the capacity credit of RE contributions (since unreliable due to the uncertain and not controllable primary energy source: the sun or the wind), but they do trust battery storage systems. And that is where the battery storage + bi-directional inverter (the AC storage system) makes the (very substantial) difference.

Figure 6, presents a graphic illustration of the model results as presented above. The installed diesel capacity is presented (horizontally) in logarithmic scale in order to embrace a wide range of possible sizes, ranging from very small diesel gen-sets (10kW) up to larger diesel power plants (3000kW = 3 MW). The AC energy storage system (consisting of battery storage + bi-directional inverter) allows to save, in addition to cost share (2), also cost share (3), i.e. to exploit effectively the related "capacity credit" by allowing to stop temporarily individual diesel generators and to reduce thereby their operating hours.

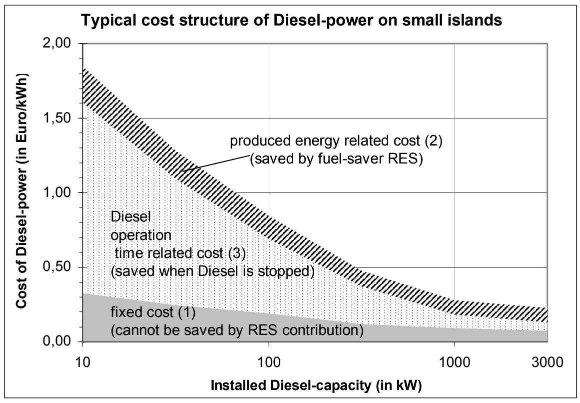

Figure 6: Modeling of the the costs of electricity produced by Diesel engines with respect to the installed capacity in small islands.

Cost share (3) depends strongly on diesel plant size: the larger the diesel plant, the smaller this cost share (reason why conventional utilities are little familiar with this cost share), the smaller the diesel plant, the larger is this cost share (reason why on small islands, and in small diesel gen-set applications, especially in developing countries, it becomes prevailing).
On the other hand, for "fair" cost comparisons, it needs also to be considered that the AC storage system (the CEBS - Central Energy Buffer System developed by ANIT) adds an additional cost of approximately 0,10-0,15 Euro/kWh to each kWh being stored and returned to consumption, mainly because the battery needs to be replaced periodically (every 3-5 years), and the related cost needs to be recovered over the limited lifetime of the battery).

CONCLUSIONS

The break-even point for an island community size, where PV systems are cost-effective, is about 500 inhabitants. This may vary due to different economics between countries and it depends also on the utilization factor of the Gensets, according to the activities on the islands during the year. Any isolated community (small village or other), presently electrified by diesel, located either on an island or simply at a distance from the nearest electric network, too far to allow for a cost-effective cable-connection, represents potentially a market for the PV technology developed under this project.

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