ELECTRIFICATION WITH SOLAR POWERED MINI-GRIDS, A CASE STUDY FOR THE ISLAND OF KYTHNOS

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ABSTRACT

A study was prepared regarding the viability and potential of electrifying remote houses and settlements with stand alone PV systems in remote areas. The financial and technical factors that affect the implementation of stand alone PV systems in the Greek islands, and particularly for the island of Kythnos, are presented. The patterns of energy consumption of the users electrified by PV installations made during the European projects JOR3-CT98-0244 and 0215 are going to be presented. A new market for PV and hybrid renewable systems seems to emerge.

1. INTRODUCTION

The implementation of PV systems in the islands of the Aegean Sea and remote locations is proposed, taking into account the existing energy supply status and climatic factors. A review of the nation-wide PV applications, experiences, problems encountered and lessons learned are presented in [1]. Furthermore, reference to barriers for PV market development is given and the prospects created by the deregulation of energy production and distribution are discussed.

The introduction of stand-alone PV systems and mini-grids, up to 100kWp, are ideal for a wide range of applications for property owners located far from the existing electricity grid in the islands. The capital cost of a stand-alone system is about 10 €/Wp. The PV modules could be integrated on south facing roofs or introduced as shadow canopies, providing an aesthetic adaptation to the usually sensitive environment.

Fig. 1. View of a house with a PV canopy installed in Gaidouromantra, Kythnos.

Recent reports, from the Public Power Corporation (PPC), the Hellenic electricity utility [2], indicate that the electrical energy demand increases every year in a way that local weak utility island grids cannot further support it and there is a race to install new generating units before the summer peak period in some of the islands. Other measures that have been planned by PPC, is the continuation of the interconnection via underwater cable of closely located islands in order to strength those grids. PPC will remain the exclusive administrator of the transmission and distribution grids in Greek islands not connected to the mainland network, even after the electricity market liberalization.

2. ELECTRIFICATION IN REMOTE ARES WITH STAND-ALONE PV SYSTEMS

A PV system with the capability to cover the basic needs, such as lighting, small appliances and refrigerators would be sufficient for most users, as the remaining loads could be covered cost effectively by other means. Therefore, hot water can be provided by a solar thermal system, cooking could be covered by wood/charcoal cooking appliances or by propane appliances, as it is more often the case in arid islands. Currently most of the existing stand-alone systems are composed of a few panels (<300Wp) providing DC electricity service. A shift into AC PV systems will add to the cost of the system but on the other hand it will allow the use of standard appliances. The experience so far indicates that most of the existing systems are installed by the users or by non-qualified technicians. The quality of the materials used and the safety measures are usually poor.

The theoretical potential for the application of photovoltaics in non grid-connected houses in Greece is estimated to be about 36 MWp, assuming an average occupation of 3 inhabitants per house and 200Wp per inhabitant. This estimation is based on the 1991 and 2001 census data of the Greek National Statistical Service about non grid-connected permanently and seasonally inhabited houses.

The introduction of PV systems and RES in general, in low population islands and remote regions will promote the development of such locations using environmental friendly technologies, creating a more stable economic environment that will keep the inhabitants in their lands, reversing the alarming abandoning trend. An important issue is power availability and quality, therefore a potential large scale introduction of PV systems in the island autonomous grids will improve the power service and produce electricity at a competitive cost to the diesel generators in the islands.

There are at least 50 such islands in Greece that are inhabited by permanent populations of less than 10.000 people [3] and several hundreds that are not inhabited and have the potential for development in an environmental friendly way. The main activities, that may be maintained in these islands is the eco-tourism, agriculture and fishing.

There are already approximately 500 KWp of grid connected and stand-alone PV systems installed in such islands. During the summer months the population in these islands may be 2 to 5 times higher than the permanent population.

Given the fact that solar energy is available locally with relatively small insolation variations, the use of solar energy has an edge over other renewable energy sources, which are not usually available in islands and arid countries of the third world (such as biomass and hydro power). Even though, most of the islands have a good wind potential, the houses are usually constructed in wind-protected areas for the comfort of the inhabitants. The cost and reliability of small size wind turbines, appropriate for small stand-alone installations, are not very attractive. Furthermore, the aesthetic effect of wind turbines is not always acceptable, whereas PV systems have a high potential for building integration.

3. STAND-ALONE PV SYSTEMS IN KYTHNOS

The PV installations made during the European projects JOR3-CT98-0244 and 0215, were first commissioned in spring 2001. During our visits to the island, the electricity consumption counters of the individual houses and the PV systems production counters were recorded. It was noticed that the period of peak energy consumption were the months of June, July, August and September, as well as at the times of holidays such as Easter.

Fig. 2. View of the settlement in Gaidouromantra, Kythnos.

One issue that has surfaced during the initial operation of the settlement systems (mini-grids), it was the competition between some of the house owners as to how much energy each one could and should use on a daily basis. As a first measure of demand side energy management, load controllers (developed by Econnect LTD.) were installed in all houses of the settlement in Gaidouromantra, in Kythnos, Figure 2, one to each individual house consumer. The load controllers were set on frequency sensing mode. In this case, whenever the grid frequency drops below the set threshold of about 49.1 Hertz, which corresponds to a certain percentage of remnant battery capacity, then the controllers cut off the house electric supply and enter a time out period set between 2 and 4 minutes. The selected time out period incorporates a random factor that allows the loads to come back onto the grid in a random sequence, in order not to overload the system.

It is expected that when the house owners will be charged with the pre-agreed tariff for the electricity consumed, then this issue will become less pronounced. Each electrified house will be paying a fixed amount of 30 € per year, while the electricity consumption will be charged for 0,088 € per kWh. The funds collected from the house owners will be used for the maintenance of the systems. In the following months, thanks to the European project DISPOWER (ENK6-CT-2001-00522), the interconnection issues between mini-grids and the island grid will be studied.

The possibility for the large scale introduction of such renewable energy plants is examined for remote locations in the Greek islands and more particularly for Kythnos. A new market for PV and combined renewable systems seems to emerge, with benefits for all the involved parties, i.e. the users, the utilities, the renewable systems industry, the local authorities etc.

3.1 Case study

Taking as a case study the electrification of a farmer by a stand alone PV system, as it was implemented at the location Tripios in Kythnos, through the project PV MODE, JOR3-CT98-0244. The farm is accessed through a harsh unpaved road. The distance from the main paved road to the farm is about 3.5 km. The farmer does not live there but visits the farm everyday for several hours and may stay there occasionally.

The farm has the following activities:

- Watering, usually tomatoes and water melons starting in April-May of each season,
- about 25 bee hives and electric equipment to extract honey,
- watering a small number of fruit bearing trees,
- bringing up about 100 goats and pigs provided with potable water.

Table 1. Loads installed at the farmer's property in Tripios, Kythnos.

Load Description	**Nominal AC load in Watts**
Refrigerator Eskimo brand, volume: 340lt (soft start introduced)	195
2 fluorescent lamps 58W each	120
1 incandescent lamp	60
Radio-cassette player	15
Hot wire device for honey removal	1000
Honey centrifuge motor	1000
Water pump installed in well, Grundfos, SQ7-40, soft start.	1800
Sum of loads in Watts	**4190**

A list of the loads that existed on the farm on a survey made in the spring of 2001, is presented in Table 1. The loads are split in two fused circuit breakers. The water pump is connected through a 10Amp type B fuse-circuit breaker and the rest of the loads to a second 10Amp type

B fuse-circuit breaker. Most of the equipment and the power systems are installed inside a room 9 meters long by 4 meters wide (see Figure 3).

Fig. 3. View of the farmer's house in Tripios, Kythnos.

The PV system is composed of 36 Solarex MSX60 PV modules, each with a nominal power output of 60Wp. The PV modules are connected to a Sunny Boy 2500 grid tied inverter, which in turn is connected to a Sunny Island battery inverter forming the grid (Voltage and Frequency) of the stand alone system (see Figure 4). The battery inverter is connected to a battery bank of 30 Lead-acid liquid electrolyte, 2 Volt cells, with a nominal capacity of 50 kWh.

3.2 Economic Viability of Stand-Alone PV Systems

In order to access the economic viability of such AC PV stand-alone systems with respect to other possible electrification solutions we have to estimate the initial cost of the system, the maintenance and service cost as well as the cost of other possible solutions for electrification. The most important load for the farmer is the water well pump. Until now the farmer was using a water pump that was driven by a small internal combustion benzene engine. His experience with this combination of internal combustion engine and pump was negative. He was complaining about high consumption of benzene, frequent break downs and associated needed repairs that cost money, non-automated operation that meant a time consuming task. In addition, when the farm was visited for the first time, it was noticed that around the small engine there were stains on the ground coming from oil and benzene spillage, which represent environmental and human hazards.
In the following table, an inventory of the PV system components with a short description and their prices are listed. The monitoring equipment and their cost are not included.

The PV system cost per Watt peak installed, is approximately 11 €. This is not an usually high cost for an AC stand alone system. The battery inverter is able to provide constant AC power up to 3.3 kW.

The system started operating during the first week of February 2001. When the farmer was visited on the 30th of May 2001, that is after a period of 4 months (the system was down for about 2 weeks during this period for modifications) the following indications were registered on the installed counters:

- PV module AC energy production : 493 kWh
- AC energy consumption : 179 kWh
- Water pumped with the Grundfos electric pump : 107 cubic meters

Table 2. Investment cost for the Farmer's PV system

Component description	**Cost in € with 18% VAT**
36 Solarex MSX 60Wp PV modules	9400
1 Sunny Boy 2500	2000
1 Sunny Island	3500
Battery bank, 30 X 2Volt cells of 800Ah with metallic base	4500
1 airlift pump for the batteries	400
Electrical board, wires etc.	1000
PV module support structure installed	1000
Estimated installation cost	2500
Total system cost	**24300**

Fig. 4. A view of the PV system power electronic hardware located inside the farmer's house.

The consumption of electricity was less than initially designed for this system, because mainly the water pump was not used as often as expected. The reason for that is the lack of water in the well. During the winters of 2000 and 2001the amount of rain fallen on the island was limited and a shortage of water was evident in many of the islands' wells. The situation was reversed during the last two winter seasons (2002 and 2003) and the ground water availability is not an issue for the time being.
The PV system was designed to be able to provide enough energy to be able to pump out of the well about 20 cubic meters per day during the summer season. That was the amount of water pumped daily by the farmer the previous summer season, when there was no shortage of water. In the spring of 2001, the farmer installed a watering network that feeds the plants with water drops, in order to reduce the water consumption for vegetable watering. Before the PV system installation, the water was let to run and fill the whole area between the plants.
It is obvious that the introduction of PV stand-alone systems has to be complemented by energy and water saving measures, because this way the system cost can be

significantly lowered, as it is demonstrated by the case of the farmer.

Fig. 5. A simplified version of the medium voltage network supplying the island of Kythnos.

On the other hand, if the farmer was to be connected to the island electricity grid, Figure 5, he would have to cover the following costs: the extension of the medium voltage grid of the island by about 3 km, following a rough unpaved road to the farm, a transformer would be required to reduce the 15 KV voltage to 230 V and a one time connection charge usual for all utility connections, that covers the cost of electricity counter and the connection cost from the last utility pole to the house.

The grid extension work cost, projecting from recent grid extensions on the island, is about 12 k€ per kilometre plus the cost for one low voltage utility pole which costs about 880 €. The cost of a 50 kW transformer, usually used in such cases, is about 4.4 K€. The one time connection cost from the last utility pole is about 290 €, see Table 3.

By comparing the investment cost, of about 24 k€ into a PV system, to the cost of electricity grid extension of 41k€, (without counting the electricity consumption cost), it is obvious that the economics of the PV system are more favourable, even if we change two sets of batteries and other electronic equipment during the course of the system's lifetime.

Although, it is easy to make a general statement about the distance beyond which an investment in a PV system is favourable, it is not a simple task, because it depends in many parameters, such as:

- if an extension of the medium voltage grid is needed (for a radius up to 500m distance from the last transformer MV to LV, a grid extension may not be required),
- the accessibility of the electrified location,
- the electricity consumption and power demand of the user etc.
- the quality of the PV system components and therefore the replacement costs during the system's lifetime

Table 3. Investment cost for utility grid extension and connection

Description	Cost in € with 18% VAT
3 km Medium voltage grid extension	36000
Medium/Low voltage transformer	4400
Low voltage pole	880
One time connection charge by utility	290
TOTAL investment	**41570**

There is also another case, which is encountered quite often in remote locations, that is the fact that electrification from the public grid is not permitted if a house is not built according to the legal procedure required by the Greek state. In that case, the electrification by renewable energy sources, such as PV, is the only autonomous solution, considering that the use of a small benzene generator is not desirable due to:

- frequent maintenance and replacement parts costs,
- the fuel transportation and spillage issues,
- noise and exhaust gas pollution affecting the immediate environment of the user.

4. CONCLUSION

It is concluded that, to a first approximation, a PV stand-alone system is cost effective if the distance to access the electrified location is more than 1000 meters away from the medium voltage grid. Photovoltaic systems are technologically mature and economically feasible, without any subsidy, to provide a reliable solution for electricity supply in existing or in planned stand-alone installations at places far from the electricity grid.

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