IMPLEMENTATION OF A PV RURAL MICRO GRID IN THE ISLAND OF SANTO ANTÃO (CAPE VERDE) WITH AN INDIVIDUAL ENERGY ALLOWANCE SCHEME FOR DEMAND CONTROL

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ABSTRACT: In February 2 012, entered into service Cape Verde's first rural micro grid with 100% renewable energy generation. This project was carried out within the framework of the "Energy Facility" ACP-EU program. Permanent electricity access had been strongly requested by the local stakeholders and community of the village to cover basic energy needs such as lighting, communication, community services and ice production for fish conservation.
The objective of the project was the electrification of the village of Monte Trigo (600 people) in Santo Antão Island, with a Multiuser Solar micro-Grid (MSG).
The project was implemented in 2 011, and is currently in the post commissioning follow-up period. A key aspect of the project has been to ensure the long-term sustainability of the electricity service. In addition to the description of the plant and the operation and management scheme, this article underlines the importance of the Energy Daily Allowance (EDA) concept from social, technical and economic perspectives. In conclusion the article intends to highlight the validity of both the technical solution and management model.
Keywords: Rural electrification, Energy Daily Allowance, Dispenser Meter.

1 PROJECT SITE LOCATION

Monte Trigo is a remote village located in the south-west coast of the island of Santo Antao in Cape Verde. It has latitude of 17 º 01'N, longitude 25 ° 19'W, see Figure 1. Access to Monte Trigo is by boat only, a journey which takes about one hour from the village of Tarrafal, the nearest centre.

The main economic activity in the community is fishing and trade with nearby villages.

Energy demand includes 60 out of 80 households, 1 school, 1 kindergarten, 1 medical centre, a connection point for telecommunications and TV, 1 hostel for tourists and visitors and some small commercial shops.

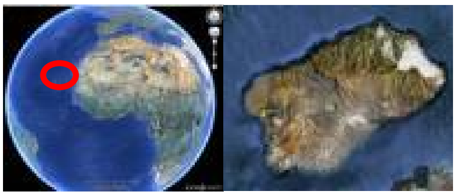

Figure 1: Site location for Monte Trigo MSG project *(photo: APP)*

2 DESCRIPTION OF THE INSTALLATION

The facility implemented in this project is a Multiuser Solar micro Grid (MSG) based on "near" 100% photovoltaic production. The pre existing diesel generator of 20 kVA now works only as a backup.

The plant was designed to produce enough energy at any given time of the year for a rated aggregate demand estimated at 90 kWh / day. The PV power plant is based on a double DC-bus 48 Vdc configuration and MPPT charge controller; a 27,3 kWp PV generator; a storage capacity of approximately 370 kWh in two batteries, that can provide at least four days of autonomy at the rated demand; and two dual inverters, with a rated power of 8 000 kVA (30') each, to convert the DC into 230V, 50Hz AC for distribution 24 h/day to users through an 800 m LV distribution grid. Table I summarizes the main characteristics of the installation.

The system is controlled by a supervisory unit which has the main function of optimizing the state of charge of the two batteries by: controlling the PV charge controllers; induce the interconnection between the two inverters if necessary; and influencing demand by interacting with the electricity dispensers/meters through a broadcast function.. The diagram of the installation is shown in Figure 2.

The PV generator was mounted on a wooden pergola that provides shade to the village's schoolyard, see Figure 6. This solution was agreed upon between the direct beneficiaries and local stakeholders, has given very good visibility to the energy source and provided added value shading the school yard in a hot climate. The beneficiary population was engaged from the beginning in decisions regarding the design and also playing an active role during the installation period.

MSG MONTE TRIGO	
GENERAL SPECIFICATIONS	
Owner	Municipality of Santo Antâo
Operator	APP
Quality of the service	24 h/day, 230 VAC single phase
Number of connections (initial/planned)	61 / 80
Type of Tariff	Energy Daily Allowance (EDA)
Aggregate contracted de EDA (kWh/day)	90
Rated RE Production (kWh/day – $H_{p)}$	85 a 5,2
INDIVIDUAL LOADS (ENERGY DAILY ALLOWANCE)	
Households (EDA=825 Wh/day)	20
Households (EDA=1 100 Wh/day)	18
Households/Shops (EDA=1 650 Wh/day)	14
Households/Shops (2 200 Wh/dia)	6
School (EDA=1 650 Wh/día)	1
ICE maker machine (~ 4.200 Wh/day)- deferrable	1
PV GENERATOR	
Photovoltaic Capacity (STC)	27 300 W
Module Type	ATERSA 130 W_{STC}, 36 cells silicone mono crystalline
Number of modules	210
Inclination / orientation	15º / +20º S
BATTERY CHARGE CONTROLLER	
Rated power	12 x 2 000 W
Converter type	Maximum power point tracker (MPPT)
Recharge algorithm	3 stage with adaptative voltage
BACK UP GENSET	
Rated Capacity	20 kVA 3 phase
Fuel	Gasoil
BATTERY	
Technology	Lead-acid vented deep discharge cicle
Number of cells (voltage)	2 batteries of 24 cells (2V ea.) (48V)
Model	Exide OPzS Solar 3 850 Ah
Total capacity (C_{100}) (kWh)	370
Autonomy	4 days at rated demand
INVERTER	
Voltage in/out	48 V_{CC} / 230 V_{AC} single phase
Rated Power (30')	2 X 8 000 W
Harmonic Distortion	< 2,5%
DATA LOGGING	
Type of data	Energy, voltage, temperature, solar radiation, etc.
ELECTRICITY DISPENSER METER	
Voltage	230 V_{AC} 50 Hz
Model	CIRCUTOR Electricity Dispenser BII
Cut off power	Setting according to tariff at (500 W,1000 W, etc)
Algorithm	Energy Daily Allowance (EDA) configurable
DISTRIBUTION and STREET LIGHTS FEEDER	
Length (m)	800
Number of lamps	20
Type	70 W hps / 2 level electronic ballast

Table I: MSG project characteristics Monte Trigo, Santo Antao (*Source: TTA*)

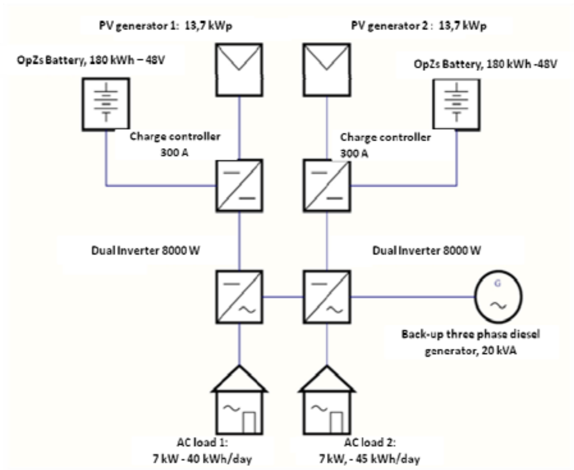

Figure 2: General scheme of the MSG Monte Trigo *(Source: TTA)*

3 NEED OF DEMAND MANAGEMENT

One of the specific challenges of rural micro grids is the need to plan and develop the village project as a whole, since a majority of users should agree to contract the service to justify the distribution feeder line costs

But the main challenges are the risk of uncertainty of the demand in the design phase and the energy distribution between users during operation to avoid blackouts in case of individual abuse. Limits have to be pre-established and agreed.

These specific management challenges have lead to the design of a concept to ensure the adequate operation and demand-side-management (DSM) of RE micro grids.

3.1 Energy daily allowance concept

The concept of Energy Daily Allowance (EDA) has been developed by TTA in the past 20 years of experience in rural electrification projects, and was introduced and adapted to the local conditions in the Monte Trigo project.

A clear definition of the energy needs (present and future) of the village is a key point in the design phase. The EDA concept has been used in several rural electrification projects in different contexts throughout the world and it has been well accepted because it responds to users' needs accurately, guides them through the management of energy use and also establishes a fixed monthly energy budget.

To ensure all users reliable service, the EDA makes the DSM more intelligent and flexible by limiting the power (kW) and also the energy available to each user (kWh/day) to an agreed maximum yet allowing some flexibility in the form of *virtual individual storage.*

The review of the issues that have influenced its refinement can help planners and designers of rural electrification projects in different aspects:

- Market: it helps to generate more user acceptance increasing reliability.
- Management: it facilitates fee collection
- Financial: it guarantees a fixed revenue stream
- Technological: batteries and inverters operate within their specified range and promote efficient and rational use of energy is encouraged.
- Social: it guides users through the management of energy use and energy budget. It allows for automatic management of deferrable productive uses such as an ice-making facility, water pumping, etc.

3.2 The energy dispenser / meter

The implementation of the EDA concept is done through a special type of electronic meter called an electricity dispenser that permanently interacts with the user to show the available energy level and a signal to encourage or discourage consumption according to the plant's condition.

The *electricity dispenser/meter* is installed at each house. It contains an embedded operation algorithm, which has been optimized through the experience in rural electrification programs and was tailored to this project.

Figure 3: Energy Dispenser Meter (*Source: TTA*)

The operation principles are:

- Limitation of power with disconnection.
- Limitation of the available energy (EDA) based on the contracted tariff, with disconnection.
- Measurement of the total energy consumed.
- Interface with user through LED pilots and display.
- Response of the operation algorithm to the plants' state of charge of the battery and RE generation status.
- Auxiliary smart switch for deferrable loads.

3.2.1 Concept

The concept of EDA serves as a DSM tool, introducing instant interaction between the power plant's supervisory control equipment and the individual electricity dispensers/meters of each user in the micro grid.

The dispenser/meter has an embedded algorithm that operates in a similar way to the water tank depicted in the following diagrams. The water consumption represents the electricity consumption; the water flow is the electric power and the tank is the energy storage. The water level inside the tank represents the user's available electricity.

The remaining energy for the user (in units) at any time is displayed in the dispenser/meter. The "water tank" has a storage capacity of 6 EDA. The EDA is a fixed number of units determined by an agreed tariff. The tank is trickle filled constantly at the rated rate, and empties when energy is consumed.

BALANCED CONSUMPTION: When the user consumes, the level of remaining energy decreases. If consumption is "balanced" with the supply, the level of the remaining energy in the tank remains constant.

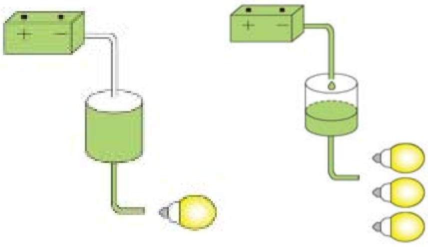

Figure 4: Energy balanced consumption (*Source: TTA*)

LOW CONSUMPTION: When consumption is lower, the tank gradually fills up at the rated rate until the level of 3 EDAs and from 3 to the maximum of 6 the fill up rate is 0,5 the rated value. This feature has been designed to "reward" users that save energy providing extra stored energy can then be consumed in future days.

HIGH CONSUMPTION: When consumption is higher, the tank is emptied (a) and, if consumption remains high, the dispenser/meter, after warning the user at energy <10% EDA and, will disconnect the consumption (b). This interruption is short because the tank is permanently being filled and after a few minutes service will resume as shown in Figure5.

a) b)

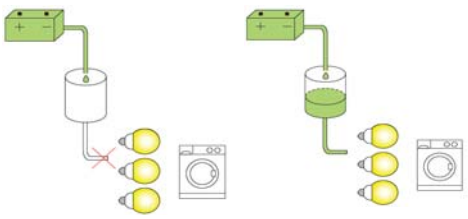

Figure 5: Energy high consumption *(Source: TTA)*

3.2.2 Special Functions

On very sunny days users are encouraged to make use of the surplus cheap generation at no extra cost. This condition is broadcasted by the plant's supervisory control through a Modbus signal and the main special function of the dispenser is to guide the final users through load management using the display and the LED.

The unit has four different modes which encourage user load management (modes depend on the battery state of charge and PV current generation). The four modes are indicated in the Table II.

Mode	**Description**	**Energy to Unit Factor**	**Activation**
Normal	EDA and power follow the rated values	1	Energy flow into "store" has the rated value
Bonus	Consumed energy Price is lower	0,5	The PV generation is throttled.
Restriction	Consumed energy Price is higher than normal mode one	2	Battery state of charge is low
Power Limitation	Maximum Power limit reduced	0,8	Inverter Power exceeds maximum configured values

Table II: Dispenser operating modes (*Source: TTA*)

Figure 6: PV Pergola installed at the village´s schoolyard (*Photo: TTA*)

4 OPERATION AND MAINTENANCE

Operation and maintenance activities are organized in order to involve local users as well as the operator of the service. The roles are final users, local caretaker and fee collector, and specialized technicians from the operator APP.

The final users are the first component of a successful and durable service. The objective is not only to support them in maintaining their home installation, but also to make their electricity consumption behaviour and habits more efficient. Practical demonstrations were also performed, directly involving the users, who responded enthusiastically (see Figures 8 and 9). Figure 10 shows how DSM has influenced the aggregate load profile.

Figure 7: Training of local caretaker (*Photo: TTA*)

Figure 8: Training session for final (*Photo: TTA*)

Figure 9: User charging her tariff *(Photo: TTA)*

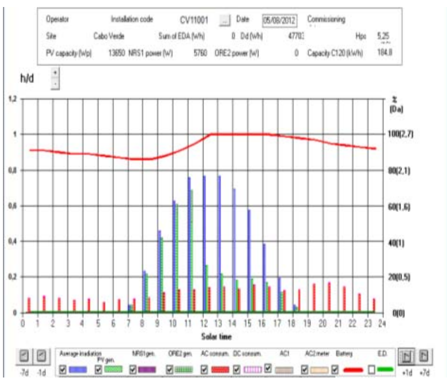

Figure 10: Changing consuming habits after 6 months of service operation *(Source: TTA)*

5 TARIFFS AND ECONOMIC SUSTAINABILITY

The EDA concept implies flat tariffs and commitment on both sides and allows financial forecast with less uncertainty. Electricity rates were calculated to cover the costs of O&M and partial recovery of the initial investment whilst being within the willingness to pay of users. (See Table III). Even if local consensus was easily reached, the process for approval and adoption of the recommended tariffs is taking a long time under legal point of view since it needs a formal approval by the ARE (Agencia de Regolaçao Economica).

Category	EDA (Wh)	Power Limit (kW)	Max. "store" Capacity (EDA)	Monthly Fee (€)
T0301	825	0,55	6	8,51
T0401	1 100	0,55	6	10,85
T0602	1 650	1,1	6	15,84
T0802	2 200	1,1	6	20,81
T1203	3 300	1,65	6	30,47

Table III: Rates currently offered in Monte Trigo *(Source: TTA)*

The initial investment was 290,000 €. The fuel + oil savings are 10,500 € per year[1] while the planned income with the recommended tariff is € 14,000 per year. As depicted in Figure 11, the economic results show a positive cumulative Net Present Value (NPV) in the 20 year project horizon considered.

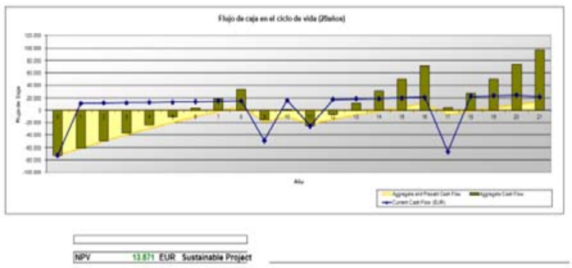

Figure 11: Cash Flow forecast for 20 years life cycle with recommended tariff fees *(Source: TTA)*

6 FIRST PERFORMANCE ASSESSMENT

Figure 12 shows how, four months after start up, the consumption habits of users, are perfectly aligned with the PV generation and battery capacity and the level of battery charge (red line) is typically between 80 and 100%. The PR has been in the range of 40 to 75% which is high for autonomous plants.

[1] The "saved" fuel is based on the previous scenario which only operated four hours per day. To operate the old diesel system for 24hours/day would be much more expensive.

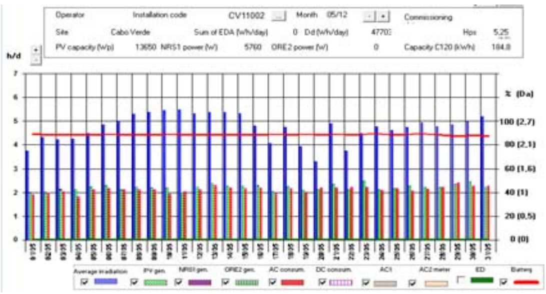

Figure 12: Main performance indicators of the micro grid (May 2012) *(Source: TTA)*
Blue bar: reference yield [h/day] Green bar: PV yield [h/day] Red Bar: final yield [h/day], Red line: remaining battery charge [%][days].

The Monte Trigans are very satisfied with the new service, which indicates the positive outcome of the project. The village's habits adapted very easily to their new quality of life and what it brought. This is demonstrated by two fundamental events:

- On-time payments by 100% of users during the first 6 month of service.
- Changes are already improving the life of this community: the 20 users that initially did not sign up have requested connection to the grid, 10 users have already bought their first refrigerators, and local workers brought a welding machine from a nearby village to repair a structure.
- Users have become accustomed and value the EDA concept, and have shaped their electricity consumption behaviour accordingly (Figure 13).

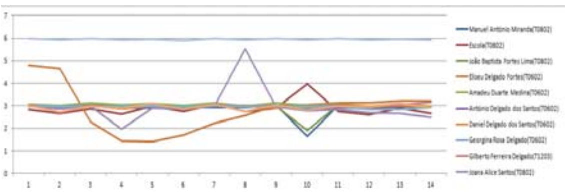

Figure 13: Normalized EDA availability for a sample of 10 users: Note that the "store" level is maintained typically at the 3 EDA level. *(Source: TTA)*

Figure 14: The electricity service in Monte Trigo started in February 2012 *(Source: APP)*

7 CONCLUSIONS

The demonstrated technical solution and organizational model can provide a reference for large scale deployment in similar conditions.

This new experience of TTA´s MSG concept confirm the technical solution strength, the appropriateness of the business model adopted in these environments and the fundamental role of the Energy Daily Allowance in the sustainability of the service and its management.

In particular it worth to underline the following conclusions:

- The EDA concept is fundamental to minimize the uncertainty of the economic analysis and results proposed in Figure 11, i.e. the economic sustainability of the service.
- The importance of the EDA concept in order to optimize users' consuming habits has been shown in Figure 10 and 13. After few months of service operation, the users already adapted their consume, according to energy availability.
- The project experience confirms again how the Energy Dispenser Meter and so the Energy Daily Allowance strategy, ensure that the state of charge of the batteries (always around 90% of charge during the first months) as well as the operation power output of the inverters are always inside the optimum rated range.

All these aspects surely are reflected on the economic analysis presented. In particular it has been seen how is it possible to partially recover the initial investment applying electricity fees in line with payment affordability.

8 REFERENCES

[1] 2012. Graillot, M. Briganti, M. Solano-Peralta and X.Vallvé. "15 years of field experience with the "DAILY ENERGY ALLOWANCE" CONCEPT as the basis for load control and guide for social behaviour in rural micro grids".
6th European PV-Hybrid and Mini-Grid Conference. Chambéry (France), April 2012.
[2] 2011. William HONG, (hong.g.aa@m.titech.ac.jp)
"Else, an eventual return to conventional energy: Impacts and Fate of an Off-Grid Rural Electrification Project in an Island in the Philippines"