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

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ABSTRACT: Rural micro grids with Renewable energy generation is becoming the most cost-effective and sustainable option for rural electrification of compact villages in remote areas. This solution, also known as multi user solar grids (MSG), offers the cost effectiveness of SHS's with the additional benefits of reduced operating costs and surge power capacity for productive uses. The impact of the drop in PV prices has been significant since most of the MSG designs are based on 75% to 99% of the generation. At the same time the cost of fossil fuels continues to increase and, therefore, the levelized cost of electricity (LCOE) will be very sensitive to the total final consumption and the renewable energy (RE) fraction. The purpose of the work is to show the need to introduce a cap on the load and to illustrate some of the lessons learned in demonstration projects since the importance of this issue was first identified.

The concept of energy daily allowance introduces certainty in the most uncertain parameter when sizing and simulating RE hybrid micro grids with multiple users and the review of the issues that have influenced its refinement can help planners and designers of rural electrification projects:

- From a market point of view it helps to generate more user acceptance.
- From a financial point of view it reduces load uncertainty and its associated risk regarding collected revenues.
- From a technological stance, it enables components like batteries and inverters to operate within their specified range.
- From a social point of view, it responds to users' needs more accurately and guides them through the management of energy use and energy budget.

1. INTRODUCTION

RE based rural electrification programs tend towards an energy service equivalent to the grid. In addition to the technical quality of the electricity provided, one key issue for the successful implementation is to guarantee each user a minimum amount of energy *EDA* (***E**nergy **D**aily **A**llowance*) within their needs and budget.

Based on research and field experience, the key points are, from a social point of view, the identification of the requirements for user acceptance and, from a technical point of view, the identification of the needs and limitations of energy and power. An intelligent energy allowance scheme should consider also issues like:

- How to cap consumption but create also incentives for energy efficiency and rational use of energy?
- How to encourage consumption of surplus RE generation?
- Can the user store unconsumed energy?
- Is it relevant to try to influence user behaviour as a function of RE plant status?

The identification of these issues during several years of implementation has refined the basic concept of Energy Daily Allowance (EDA) to make it a more intelligent and flexible and introducing communications between the power plant's supervisory control and the individual electricity meters/dispensers of each user in the micro grid.

2. EDA concept

2.1 Individual installations VS multi-users

In rural regions, some users have periods with lower energy consumption (shepherds, outdoor activities, etc). These periods may occur with weekly or seasonal frequency, and to avoid capture losses on individual power systems, it would be desirable to share with a neighbour the use of the energy surplus.

In a multi-user facility, these periods of individual lower usage are distributed between all N users, and the energy provision EDA_{tot} of the overall system may be smaller than the energy EDA_i guarantied for each user i: $EDA_{tot} = F_E \sum_N EDA_i$ where F_E is the energy utilisation factor which is less than one. This allows the plants' designer to reduce the rated PV capacity and the battery size, which leads to reduced investment costs.

Other factors reducing costs are:

- The €/kWp-cost decreases with the size of the plant.
- Reduced maintenance costs of a larger plant than many individual ones.

- Easy to be expanded, when additional energy requirements occur

Another advantage is the possibility to increase the service provided to the user by installing common services in the village, such as public lighting, a public washing machine, or electrical tools for craft manufacture.

Another point concerns the availability of peak power for the users. For a typical individual power system (1 kWp), a continuous power of few hundred of Watt would be sufficient. However, the high start up currents of refrigerators, pumps, etc. represent a high instantaneous power that requires a relatively high inverter power, which is oversized for the average load.

In a multi user grid, the probability, that all users require their guarantied maximum power $P_{i,cont}$ for continuous use at once, is low. This probability is even lower for instantaneous peak power $P_{i,peak}$ for start-up. Hence, the power provision P_{tot} of the overall system may be smaller than the power $P_{i,cont}$ + $P_{i,peak}$ required for each individual user: $P_{tot} = F_{P,cont} \sum_N P_{i,cont} + F_{P,peak} \sum_N P_{i,peak}$

where FP,cont and Fp,peak are less than oneThe inverter size of a multi user system is usually determined by the continuous power demand. Once covered this demand, there is still plenty of peak power available for each user and each single user has more inverter peak power available than he would have in an individual installation.

2.2 Challenges in multi user micro grids

MGSs have specific challenges, which do not occur with single user facilities. One of these is the need to develop the village project as a whole, as all users to be connected have to agree at once to contract the service and the distribution lines costs and layout has to be considered.

The main challenge is the energy distribution between the users. Sharing a common resource without limitations leads to the abuse by individual users as users are often not aware of the energy consumption of the appliances. This entails a reduction of the electric energy service to the whole village if no limits are established. This social aspect has driven to design a clever concept, which ensures the adequate operation of RE micro-grids.

2.3 EDA advantages

The Energy Daily Allowance (EDA) is used as a key design parameter and it is fundamental from a social point of view because it responds to users' needs more accurately and guides them through the management of energy use and budget.

Furthermore from a technological stance, it enables components like batteries and inverters to operate within their specified range.

Also, thanks to the introduction of the EDA, it is possible to realize long term simulations and show easily the variation of LCOE for representative combinations of technical solutions and loads.

Finally this concept allows the reduction of the risks for the financial sustainability of the project. Indeed an accurate financial planning during the life cycle is feasible.

In order to implement the EDA, a new electronic device has been developed, in association with an industrial partner and taking into account 15 years of field experience.

3. THE ENERGY DISPENSER / METER

3.1 Introduction

The e*nergy dispenser/meter* is an advanced electronic meter, which is installed in the house of each user. It contains an operation algorithm, which has been developed from TTA's experience in rural electrification programs. The operation principles are:

- Limitation of the available energy based on the tariff contracted, with disconnection.
- Measurement of the total energy consumed; memory with long duration.
- Limitation of power with disconnection.
- Indicators and user advice.
- Adaptation of operation algorithm to the plants' state of charge of the battery: The bonus mode and restriction mode encourages adequate user load management.

The concept of EDA is central in the dispenser meter concept. It makes the demand control more intelligent and flexible, introducing communications between the power plant's supervisory control and the individual electricity dispensers/meters of each user in the micro grid.

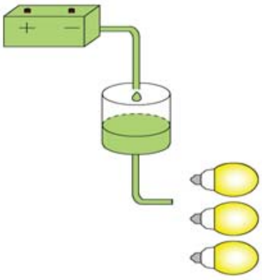
Fig 1: Energy dispenser/meter

3.2 Concept

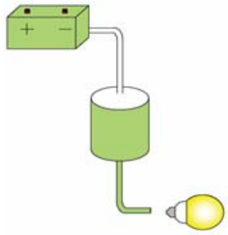
A good way to understand the dispenser/meter functioning is the analogy with the water tank shown in the following diagrams. The water consumption represents the power consumption; the water flow is the electric power and the tank is the energy reserve. The water level inside the tank represents the user energy available.

The EDA for the user (in units) at any time of the day is shown on the screen of the dispenser/meter. We can imagine this energy as the water tank of the diagrams. The tank has the storage capacity for 3 daily EDA. The daily EDA is fixed by the agreed tariff. The tank is updated every second, according to the increased fixed by the tariff, and decreases according to the energy consumed.

BALANCED CONSUMPTION: When the user consumes, the level of the available energy decreases. If energy consumption is "balanced" with the energy provided by the dispenser/meter, the level of the available energy in the tank remains constant.

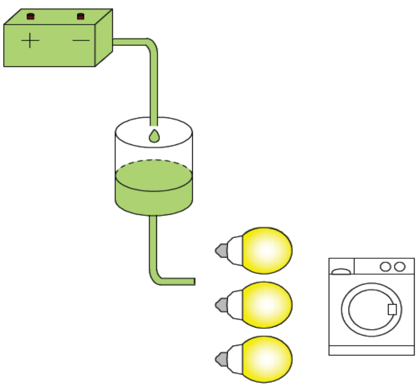


LOW CONSUMPTION: When consumption is low, the quantity of energy "charged" in the tank is greater than the one coming out, so the EDA level fills the tank. If the user continues with low consumption, after filling the tank, the dispenser will begin to fill an additional part of the tank. This "extra" tank also has a capacity of 3 times the daily EDA and it is designed to "reward" users who have spent little energy in the last period.



HIGH CONSUMPTION: When consumption is very high, the tank is emptied (a) and, if consumption remains high, the dispenser/meter, after entering in a RESERVE condition (tank with energy <10% EDA) and warning the user, will disconnect the consumption (b).

a.



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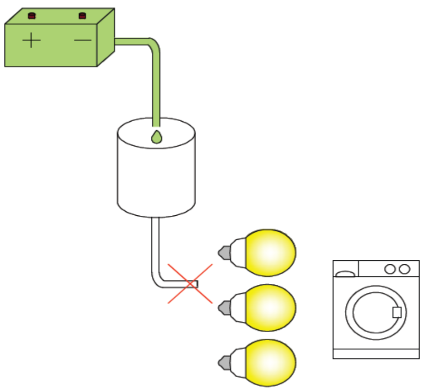

When this happens, the user must turn off their electricity consumption, at least for a few minutes to allow the dispenser/meter start filling the tank again and allow the dispenser/meter to be ready again to deliver energy.

3.3 Main functions

The dispenser continuously measures the power and energy consumed. The programmed tariff determines the maximum power energy available. This available energy is increasing virtually according to the rate contracted when there is no consumption and is stored in an individual user key called TEDI. This FEDI can be removed and used in another *energy dispenser / meter* if desired. It also contains all the information about the energy available and the total energy consumed.

The main functions of the dispenser are:

- Control of the EDA per each user, based on the tariff contracted
- Disconnection when the energy reserve is used up.
- Measurement of the total energy consumed; memory with autonomy of long duration.
- Power limiter with disconnection.
- Guided load management (through display and LED)**:** Three different counting modes incentivating user load management (modes depend on the battery state of charge):
    - **Normal mode**
    - **Bonus mode** (battery full charged and PV generation ongoing)
    - **Restriction mode** (battery undercharged)
- LCD display.
- LED communicator for user´s guiding for energy management

As said the Dispenser meter contributes also to the correct equipment usage and to force them to operate within their specified range.

4. EXPERIENCE ON MANAGEMENT

4.1 User acceptance

An evaluation of the acceptance of this technology shows a high degree of satisfaction among the users, essential for success. The main reason they mentioned is the adequate regulation of the energy distribution, which avoids conflicts between the users. Most of them adapted their consumption behaviour very well so that they don't feel really limited. The following figures show the satisfaction of the users in a community in Morocco using a PV hybrid micro-grid:

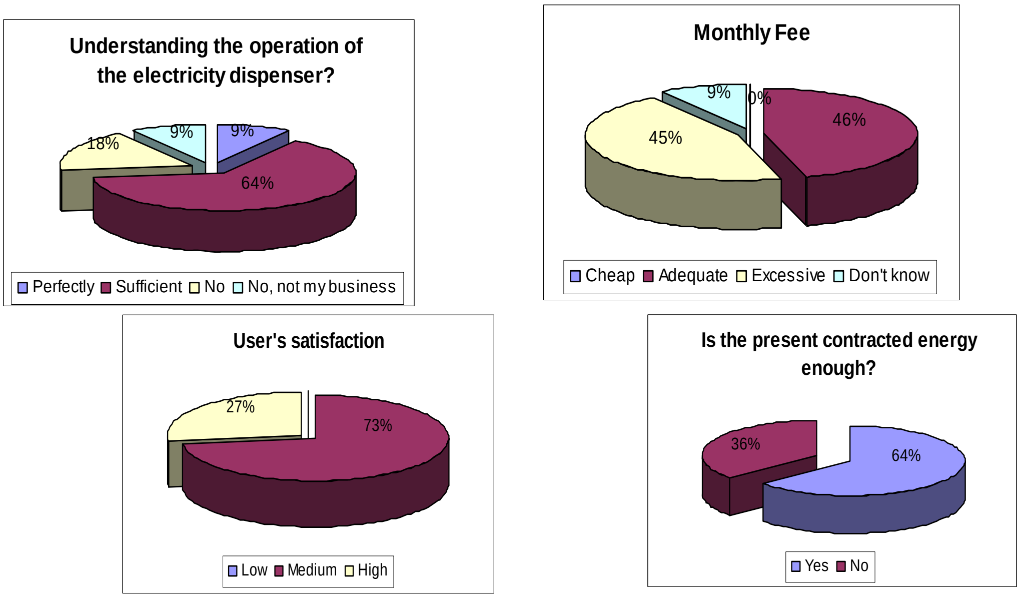

Figure 2: Satisfaction study in Akkhane, Morocco

4.2 Different user behaviours

Another interesting observation that could be done after many years of project implementation and monitoring is the different behaviour of each user in front of this new technology. The main conclusions are the following:

- There is a broad majority of users consuming only part of the energy contracted. They have stored energy in the regular and emergency reserve.
- There are other users, which have adapted their energy consumption to the state of the PV plant. For example, users achieved a higher consumption than the contracted energy, and still has energy stored.
- Another type of user is the one that consumes energy without taking care of the limitations.

4.3 User training seminars

At the beginning, users had to understand the concepts of the energy reserve and the emergency reserve. Also the different modes (bonus / normal / restriction) produced question marks in the faces of the users. It was clearly necessary to explain the operation principle of the PV plant, but also the concepts of energy and power. A user, who does not understand the reason of the energy and power limitation, will be always complaining. He has to know what energy is, why there is the need of energy efficient appliances, and the basic principles how a PV plant works. All this knowledge is useful for the understanding of the *energy dispenser / meter*, especially the differences of the bonus and restriction mode. So, training actions have to go hand in hand with the technical system implementation. We have to draw the same conclusion as for individual stand alone PV systems:

Only a trained user can be a satisfied user.

5. CONCLUSIONS

Multi user systems for the electrification of rural villages have specific advantages compared to individual systems. The centralisation of the system allows for reduced investment and maintenance costs, but also for increased performance and better service. Such systems favour the installation of common electrical appliances such as public lighting or special machines.

The main problem of multi users systems is the energy distribution between the users. This problem, leading to failures of village electrification projects with PV, is now addressed by a simple electronic device installed in each household. After 15 years of operation in the field in many Rural Electrification Programmes, studies have shown that the users accept the energy dispenser/meter device and the concept of EDA. However, for a satisfying operation, it is necessary that the users do understand the operation of the PV system and the energy dispenser.

The EDA concept and the associated tariff concept are an advantage from the social point of view but also technical and economical. Fees are within user's willingness to pay and the monthly collection has been very successful in part thanks clear transaction mechanisms based on flat fees. The degree of satisfaction is high and demand increase is slow.