Electrification of isolated areas by interconnecting renewable sources (ERD project): lessons learned

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Abstract—**Researchers from Switzerland and Morocco undertook a joint project to develop a technique for producing electrical energy from renewable primary energy sources to supply small networks of isolated consumers. Specific attention was paid to sustainable development issues, namely, the integration of social, environmental, technical and economic components. The project was carried out in the Ouneine Valley (Morocco). The project aimed to implement a technical transfer program and to improve the population's ability to absorb innovations such as rural electrification by isolated micro-grid. The project also comprised a research component aimed at gaining an understanding of the interfaces between the technical and sociological levels.**

I. Introduction

Many developing countries, particularly less developed countries, are notoriously energy-poor, especially in terms of electricity. There is considerable disparity in electricity consumption between countries with a low versus high human development index, as shown by UNDP statistics. Available figures suggest that this gap between poor and affluent countries is not about to be closed. The International Energy Agency estimates that 1.6 billion people still have no access to electricity.

The situation is even more serious in remote rural areas, which are often neglected by electrification projects due to high costs and technical difficulties. « Only 7 percent of dedicated Rural Electrification (RE) projects and energy sector projects have an explicit poverty-reduction objective. Hence, poverty has not become a central concern of RE projects, and there is rarely any explicit consideration either of how the poor will be included or of any poor-specific activities »[1]. This study demonstrates that the issue for poor people is that they don't gain directs benefits of electrification project : « Once electricity arrives in a village, the connection charge is a hurdle that prevents the poor from connecting to the grid, even though the benefits they would derive—and so their WTP—would exceed the cost of supply. »

Yet, for broad segments of their inhabitants, electricity is a high-priority need that would help improve living conditions and bring standards of living closer to that of urban areas.

One the other, goal 7 of the Millennium Development Goals adopted by the 191 Member States of the United Nations aims to "integrate the principles of sustainable development into country policies and programs; reverse loss of environmental resources." [2] As demonstrate by authors, it's an important thing to implement grids which respect environnemental aspects [3].

On the strength of these observations, the École Polytechnique Fédérale de Lausanne (EPFL), together with the Hassan II Institute of Agronomics and Veterinary Science, and the Targa-Aid non-governmental organization decided to jointly develop and implement a technique for producing electrical energy from several renewable primary energy sources (water, solar, wind power, biogas) in order to supply small isolated consumer networks, with the possibility of interconnecting them. This technique was to be tried in the Ouneine Valley in the Upper Atlas area of Morocco.

II. The stakes of decentralized rural electrification

A. A needed increase in income

Among the various parts of Morocco, the mountainous regions have great potential for tourism and economic development, which unfortunately is only too rarely used to advantage. "Today, the mountains are suffering all the ill effects of neglect: overpopulation, isolation, lack of equipment, economic weakness, and social misery." [4]

Taking this important stake into account, the team decided to implement an electrification project in rural mountain area where is living poor people who didn't have access to electricity and who ask it absolutely for improve their quality of life. The Ouneine Valley was choosing, because it is located in the mountainous Upper Atlas region, which is one of the poorest in Morocco. It was affected by problems related to isolation, by an advanced use of natural resources and by the absence of an integrated local development dynamic.

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B. Preserving the mountain environment

At the same time, it is also appropriate to devote some attention to the methods used in managing the natural environment of mountainous areas, because rural populations often are not well served by large energy production networks and tend to implement their own strategies, which compromise their immediate environment. In Morocco, rural populations (45% of the total population) still have very limited access to electricity and gas. Wood is the main energy source used for cooking and heating, representing 90% of a rural household's energy consumption. Cooking and heating stoves consume large amounts of combustible fuels and emit significant quantities of CO_2 and noxious smoke. The CO_2 emissions have severe consequences for the climate, and overuse of wood harms the environment by contributing to desertification.

In this context, the mountains are special ecosystems that should be preserved. "The mountains are an important reservoir for water, energy and biological diversity. Yet mountain ecosystems are undergoing rapid change. There are risks to accelerate soil erosion, landslides, and rapid loss of habitat and genetic diversity." [5].

As demonstrate by authors, it's an important thing to implement grid in rural areas which respect environnemental aspects [6]

C. Suggesting a specific technical response

As a technology and a development tool, electrification must satisfy the three criteria that form an integral part of sustainable development: social equity, environmental protection, and economic efficiency. It's necessary to built basic energy service delivery structures to those currently without access to modern energy, as energy is a prerequisite for sustainable development and for fighting poverty, especially in Africa.

Today, decentralized energy production in developing countries supplied often a single dwelling or a single village. Such production systems are isolated, and for that reason, are uncertain in nature and depend heavily on weather conditions and resource availability. They cannot guarantee reliability or a secure supply. Most of the time, these production facilities are delivered as turnkey systems and are poorly adapted to the region (since they take into account neither the local context, in particular the strengths and weaknesses of the installation site, nor the possibility of ownership by the recipients). In addition, it is extremely difficult to monitor such facilities because they use imported technology with high production costs. Such projects neglect the regional dimension.

Some applications have been successful and others less so, due to the difficulty of taking into account all of the constraints, which can be social (demographic growth, low level of education, scattered dwellings), technological (sophistication of imported equipment, lack of maintenance), environmental (limited energy resources), economic (very low incomes, investments), or political (lack of suitable active program). Thus, it would seem appropriate to suggest an approach able to clearly define how one should implement a decision-support process for choosing the optimal electrification system.

III. OBJECTIVES

The primary objective of the Decentralized Rural Electrification (ERD) project was to develop a technology for the production of electrical energy from several types of renewable primary energy sources (water, solar, wind energy, biogaz) to supply small networks of isolated consumers, with the possibility of interconnecting these networks. It was felt that such a decentralized micro-grid should be compatible with the national network to allow for future connection.

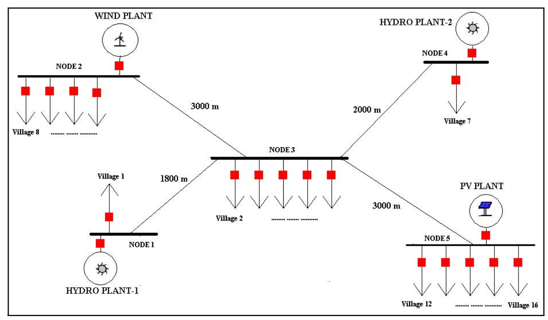

Fig. 1. Initial configuration of the valley micro-grid

Still, the institutions responsible for this research-action project agreed from its inception that the use of decentralized energy production techniques made sense only if it was incorporated into an overall regional development context and helped improve the living conditions and income of the rural populations. For this reason, a consensus was quickly formed with regard to the project's objectives, which were:

- to participate in promoting the sustainable development of the Ouneine Valley by supplying quality electricity to a group of villages by means of a decentralized micro-grid powered by various renewable energy sources, and
- to gain new knowledge and experience in the area of rural electrification on both the technical and sociological levels. The ERD project was seen as a pilot project for isolated areas.

A. Choosing the optimal electrification system

This research-action project concerned the creation of a decentralized electrical micro-grid able to supply several villages, with multi-source production, the advantage of which lies both in equal access for all villages, and their inhabitants, and in the sharing of natural resources. However, the solution had to be the most appropriate one given the existing socioeconomic, environmental and technical constraints.

From a socioeconomic perspective, three issues were noted: the cost of the electricity, such that it corresponds as much as possible to the peoples' ability to contribute; future needs, such that the amount that must be produced to meet demand can be evaluated; and finally, ownership by the residents in such a way as to encourage good management of the infrastructure.

Environmentally speaking, it was agreed to attempt to make the best use of natural resources to produce clean energy, but also to respect the environment and the landscape when installing the micro-grid.

Finally, the technical constraints were:

- to maintain unchanged the irrigation flow and the water distribution in turn,
- to guarantee a sufficient supply of electrical energy over time (control, operational and maintenance facilities, etc.),
- to ensure the adequacy of the electricity produced and distributed with respect to large grids (constant voltage and frequency, no harmonics). In order to achieve this, each unit's control system had to be capable of operating (1) while connected to the relevant decentralized micro-grid, (2) in isolation if necessary, and (3) while connected to the supposedly inflexible national grid.

Finally, to help select the best solution among several production variants, taking all of the constraints into account, it was necessary to develop a specific decision support tool [7]

B. A decision-support tool : the OptElDec software

A specific decision support tool, called OptElDec, has been developed at the EPFL in Lausanne, This software [8] is composed of two layers, a simulation layer and a decision support layer.

The *simulation layer* allows the simulation in function of time of a given power system including power sources (solar, hydro, wind and diesel power), energy storage elements (batteries, reservoirs), consumers and a power grid.

The *decision support layer* allows comparing different configurations of the power system in terms of up to 3 different criteria which can be weighted independently. For comparing the different configurations, the simulation layer is used by the decision support layer for simulating each configuration.

The structure of the presented tool is modular, facilitating the addition of new elements to the simulation layer. The two main layers, simulation and decision support, are designed in a way that the simulation layer is fully functional without the decision support layer (dashed arrows in Figure 2).

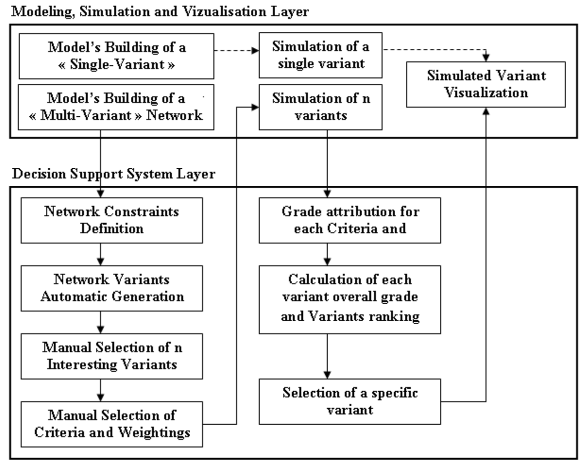

Fig. 2. Opteldec structure

The simulation layer is programmed in Matlab; a graphical user-interface programmed in Java allows easy introduction of the necessary data. The following elements are currently available: passive load (consumer), photovoltaic module, hydro-electric power station including an optional, reservoir, wind power station, biomass power station, diesel generator, battery, rectifier/inverter and simplified grid.

Simulation is very important in order to make a projection in the future and to see how an electrical network will behave depending on its own structure (power stations, priorities, etc.), on meteorological factors (river flows, wind curves, etc.) and human factors (mean consumption, peaks, etc.).

Once simulation is done, two major issues raise. The first one concerns output data interpretation. In complex systems, much information must be gathered inside the model in order to comprehend reality. This is particularly the case for projects as the case study, in which many dimensions as technical, sociological, human and environmental must be considered.

The second issue is that a simulation is just a way to make a "what-if analysis" without giving any information about our candidate power network position or ranking among the whole solution space. One solution to overcome this issue could be to consider a set of candidate power networks, and to build one after another a model for each of them, to carry out a simulation, to save the output data and once all the simulations are made, to compare all the variants. The main drawback of this approach is that it requires a lot of time for building the models, for output data gathering and for the ranking of the solutions. The methodology and the tool introduced in this research tackle simultaneously these two issues. On the one hand, we propose a semi-automatic construction of power network variants based on propositions made by the network designer. On the other hand, we propose a sequential approach for the evaluation of each variant based on Analytic Hierarchy Process (AHP) that allows considering quantitative and qualitative criteria. By using this tool, project managers are able to quickly assess a wide range of network variants regarding various criteria (proposed by engineers, sociologists, consumer associations, environment defenders etc.). Furthermore such a participative approach is the best warranty for project acceptation and sustainability.

Furthermore, it was necessary to consider that in rural electrification projects in developing countries, it is often not possible to satisfy completely the demand in electrical power. It should be planned to disconnect less important loads when the electrical power demand is high and/or the electrical power production is low. Sometimes a diesel generator is installed but should only be used for serving high priority loads (e.g. refrigerator for drugs conservation) when the renewable energy sources cannot cover the demand of these loads. Situations like these need specific operating strategies of the power system. For this purpose a priority system was introduced in OptElDec which allows acting on the operating strategy of the power system. The idea is that the user assigns a priority to each load using priority 1 for the most important loads and priority 6 for the least important. This guarantees that loads with higher priority will always be served first. Additionally the user assigns to each power source a lowest priority to serve. Attributing priority 4 to a hydroelectric power station guarantees that this power station will only be used for serving loads with priority 4 or higher. During the simulation, at every time step the program first serves the highest priority loads using the lowest priority power sources and goes then over to using higher priority sources for lower priority loads until the priority of the remaining loads is lower than the priority of the remaining sources.

C. A local participatory approach

A participatory approach is essential for development projects, with the goal of making the technical changes sustainable. As noted by Bassand, Galland and Joye (1992), "introducing science and technology into society is not a simple matter of grafting knowledge, expertise, practices and techniques onto a social fabric that is not ready for them. We do not have science and technology on one side, and society on the other. On the contrary, the first two must become deeply rooted in the latter, and whether or not they can blossom depends on realities that are simultaneously material, social, economic, cultural, historical and political." Likewise, technology is "inextricably tied to culture (values, signs and symbols, knowledge), social and political organization, and the natural surroundings." [9]

The participatory approach and assumption of ownership by the local population are essential points that were included in the project design and implementation as well as the operation and future management of the equipment.

For this purpose, three levels of public involvement were distinguished during the project's implementation:

- identification, through public surveys, of the short- and long-term economic usefulness, as well as the societal demand. This involved evaluating public receptiveness to ensure the project's social feasibility as regards,
- incorporation of local knowledge that could be combined with the scientific aspects and new technologies,
- participation in the costs, construction and management of the network.

It should be clearly noted that the participatory process was not without glitches, rough spots and dead stops. It required long periods of dialogue and mediation, which sometimes led to a radical shift in the direction of project implementation. As described in a report by the High Council of French International Cooperation (HCCI), "participation can be an asset for finding innovative solutions to the contradictions that crop up between the various development objectives. Dialogue is planned into cooperative mechanisms. But is it possible? It can bring out conflicts, hence the usefulness of mediation and support tools during the emergence of powers and opposition powers. Unrealistic expectations, the political context, the lack of representativeness of the partners, and the risk of exploitation are frequent complications. An effective participatory process will take criticism and suggestions into account, will allow to some degree for a 'right to make mistakes,' and for a possible reversal and redirection of ways of working, and even of strategic objectives and the logical framework." [10]

D. Blending technology and society: adapting the project to social standards

The ERD project was conceived as a multidimensional, interdisciplinary project able to blend technical and social components. Of particular interest were the interactions between technical and social standards.

A technical standard is a set of customary rules, or technical instructions, concerning the characteristics of a product or method, prescribed with the goal of ensuring that certain methods of operation, safety standards and pollution levels are observed. For the ERD project, these technical standards were introduced with the arrival of the electricity produced, using a new methodology adapted to the local context.

As for the social standards, Jean Maisoneuve equates them with behavioral models, concluding that these two notions describe "the type of conduct widely exhibited within a given group, the non-observance of which is accompanied by more or less explicit sanctions, and which the members of the group accept more or less consciously and completely.” [11]

The arrival and development of the project, and the production and implementation of technical standards generated by this electrification project led to disruptions that required technical and social mediation. The interactions that arise in practice between technical, social and institutional data must be acknowledged in order to implement a research-action project that takes into account the complexity of the local society, technical uncertainties, and conflicting values.

For example, the use of water as an energy source has significant consequences in an area where it is subject to quotas. Thus, the construction of a system for producing electricity from hydroelectric turbines leads to a streamlining of the agricultural water supply. This is an important economic and social issue because it influences crop yields. The division of water has been established for generations and is a customary law. As a result, an arrangement for this change in “standards” has to be made with the landowners in order to guarantee that farmers will have the same water resources as before.

Therefore, in implementing such projects, it is appropriate to pin down the psychological, social, economic and political factors that interact with the selection, development, and spread of technologies. This makes it possible to observe how the two normative systems of standards are sometimes in opposition and at other times complementary.

E. Institutional stakes

Right from its design and startup phase, the ERD project met a demand from the Ouneine Valley’s isolated rural population. It was all the more warranted because the Moroccan National Electrical Agency (ONE) was not planning to electrify the area any time soon. The area’s low population density and isolation had led the supplier to give more economically profitable areas higher priority for electrification.

Therefore, the project led to the development of some local technical standards that responded to residents’ wishes and made sense overall in terms of sustainable local development. The project used a clean, autonomous energy source to create an electrical network that carefully took advantage of the valley’s natural potential.

After its senior staff visited the Ouneine Valley, ONE’s strategy quickly changed. Responding to the local stimulus resulting from the ERD electrification project, and recognizing that the project had developed an alternative approach, ONE undertook to install medium- and high-voltage lines in the valley.

Initially, this turn of events completely upset the project dynamic. When ONE established its network, it attempted to impose its own technical standards as well as new rules that would apply both to the standardization of the electrical facilities and to the management of the network (especially concerning charges, since the cost per kWh is set by law at the national level).

After two years of negotiations, Targa-Aid, the Swiss Agency for Development and Cooperation, and ONE managed to strike a partnership agreement defining the latter’s position with regard to the valley and the ERD project. This agreement specified the relationships between the various partners. It allowed for a better coordination of activities and a continuation of the project experiment outside of any pressure from the national network. [12]

So the work of the ERD project, which was trying to develop more appropriate technical standards, was nearly brought to a standstill by a national authority claiming institutional and technical legitimacy. Aside from the purely institutional question, the issue of defining standards came up. One of these entities was offering a technical innovation that clashed with a national institution cloaked in a legitimacy that was difficult to challenge. So the question arose whether one could legitimately adopt technical solutions that meet local needs, yet differ from national standards.

In the end, these disagreements helped draw attention to the fact that alternative methods and technical standards that meet local needs can be used.

This example, which illustrates the great difficulty of adapting to innovations, is unfortunately not specific to ONE, but is relevant to most institutions considered to be the state’s operators in rural development. So it would be advisable to continue to try different pilot approaches to find models that might be reproduced on a large scale to limit costs.

IV. . CONCLUSION

The research ERD action project has attained its general objectives in each village selected for the network connections. The required infrastructure, as well as the managing structures, was successfully established through participatory processes. Finally, in the frame of the project, 9 villages (a rural administrative division equivalent to about 300 households) are equipped with two interconnected hydroelectric power plants: the first one with a synchronous machine and the second with an asynchronous generator. These two stations may operate in 3 modes: each generator alone as decentralized production, both in parallel isolated from the main grid, or linked to the national network.

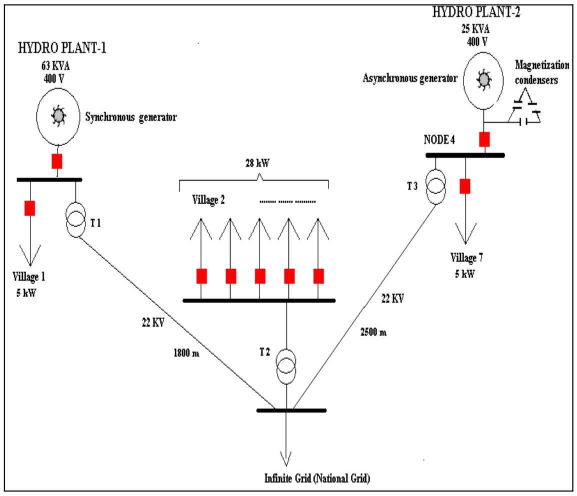

Fig 3, Valley Micro-grid scheme

In social terms, it is clear that electrification tends to improve the people's living conditions notably. Modern lighting is a comfort that people do not want to give up once they have become accustomed to having it, even when the available power is very low.

The success of this project is directly determined by the multiplicity of its components in relation to sustainable development: integration of human, social, technical, economic and environmental aspects. This research-action project enabled us to develop a sustainable technical approach for the electrification of isolated rural areas.Three elements (social, environmental and economic) had to be taken into account: (i) consideration for the unique characteristics of the local society, which needs to be involved in the establishment of technical infrastructure, as well as its maintenance and sustainable management; (ii) adaptation of the technology to the local environmental conditions: the planning and implementation of the project were based on exhaustive studies of the local environmental potential in order to produce clean, renewable energy and ensure a quality supply, and (iii) consideration of local needs and household economic situations in determining the scale of the equipment, so as to produce affordable energy.

For this researchers needs to adopt some new approach with global approach and local application. To achieve this aim, and try to share the developing technical with cultural and social hybridations, technical and social intermediations are necessary. This research project provided the opportunity to develop a new approach, addressing global challenges (such as global warming) while tailoring the application to local needs. To attain the project goals, it was necessary to take into account cultural and social characteristics specific to an isolated territory in a developing country. To this end, an approach valorizing technical and social mediations was adopted.

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