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A NEW APPROACH FOR SIZING ISOLATED POWER PLANTS: CASE OF DIANA REGION - MADAGASCAR

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ABSTRACT

The northern region of Madagascar has strong potential in terms of renewable energy sources. We can particularly mention the sun and the wind. The sunshine rate is estimated at over 3000h annually and the average wind speed in several places can go up to 10 m/s at 50 m height. This being said, several parameters such as existing technologies, locally sold equipment and especially the way of use of the local population as well as regional atypical climatic conditions (Varatraza, high heat) are very little considered decision criteria in the choice of power source configurations according to the desired power levels.

So, this contribution offers an original approach of choice of power sources adapted to the North-East zone of Madagascar and more particularly, the Region of Diana. This work deals particularly with the state of the art of the most popular systems in the world and in the country, supported by a critical analysis upstream, before the presentation of a multi-criteria matrix of choice of configurations, highlighting the particularities of the studied area.

INTRODUCTION

Many countries in sub-Saharan Africa have partnered with private sector players to eradicate the low access to electricity in this region [1], [2]. For Madagascar, the state decided to put an end to JIRAMA’s (Jiro sy rano Malagasy), Madagascar’s water and electricity company, monopoly in early 2000, and to release and open up the electricity market to private operators in clear political and regulatory frameworks [1], [3], [4].

The difficulties encountered by private operators are generally techno-economic problems [2], [5], but sometimes also of socio-cultural origins, especially in rural areas. Problems of sociocultural origins are not taken into account by optimization-based design [6], [7], [8], since the data collected during the preliminary survey are for information only [9], [10]. This article focuses on the size of many of data from the multicriteria analysis method.

Firstly, we will talk about an isolated power plant, followed by its optimization-based sizing method. And then comes a proposal for a new approach using a decision matrix.

ISOLATED POWER PLANT

Background of electricity in rural areas in Madagascar

The rate of access to electricity service was estimated at 15% of the Malagasy population, including 4.75% in rural areas and 51% in urban areas [11], [12].

To overcome this low rate of access to electricity, especially in rural areas, the state, through the Ministry of Energy, set up the Rural Electrification Development Agency (ADER) which has for the role of coordinating rural electrification operations [13]. As a result, it oversees JIRAMA or private operators who have obtained licenses and / or concessions to give electrical services in the areas concerned [3].

JIRAMA is simply an extension of these networks in rural areas. On the other hand, private operators use isolated power plants. In this way, they make sure the production and distribution of electrical energy on non-interconnected distribution networks to a transmission system [3].

Types of isolated power plants

Isolated power plants produce electricity by generally transforming locally available energy, such as hydropower, solar power, wind energy, biomass energy, and so on.

The tropical climate of the northern region of Madagascar allows it to help from solar and wind energy sources. In addition to these two sources of energy, private operators also exploit thermal energy from a generator as the following table summarizes [9], [10].

Table 1 isolated electric power plants operated in the DIANA region

Isolated power plants	PV	EO	GE	SB
Type 1	X			X
Type 2		X		X
Type 3			X	
Type 4	X	X		X
Type 5	X		X	X
Type 6	X	X	X	
Type 7	X	X	X	X

With : PV: Photovoltaic EO: Eolien GE: Generator SB: Storage Battery

Classical design of an isolated power station

Manual sizing

Iterative method:

It consists on determining the necessary power of a source of energy to satisfy the energy demanded by a load. If this source of energy is lower than the demand, this method makes it possible to supplement the rest by a complementary generator [7], [8]. Take such as an energy mix between a PV generator and a wind turbine. The energy demanded at the wind turbine will be defined as follows:

$$E_{eol} = E_{batt} \frac{k}{\eta_{conv}} \quad (1)$$

With:
k = k1 + k2,
k_1: performance of the battery charge,
k_2: battery charger performance (regulator),
η_{conv}: converter output,
E_{batt} = Echarge - Epv: reserve battery power (in kWh),
E_{eol}: energy demanded at the wind turbine (in kWh).

Linear programming method

This method determines the ideal configuration of the two generators (eg solar and wind generators) that satisfy the energy demand of any load [7], [8], [14], [15].
The linear optimization problem is presented by the following objective function:

$$C = C_{wt}A_{wt} + C_{pv}A_{pv} \qquad (2)$$

With:
C: minimum economic cost (in MGA),
C_{wt}, C_{pv}: economic cost factors for one m^2 of area swept by the wind turbine and one m^2 of photovoltaic panels (in MGA/m^2),
A_{wt}, A_{pv}: effective area of a wind turbine and a photovoltaic generator (in m^2).

Dynamic sizing

Nowadays, there are several software for sizing and simulation of isolated power plants, among which we can mention: HOMER, PV Syst, RETSCreen, etc. These programs aim to optimize an autonomous or hybrid system with different optimization strategies [7], [8], [16].
Take such as the HOMER software that is able to size and optimize an autonomous or hybrid system such as wind, PV, micro-hydro generator, network, fuel cell, and batteries. HOMER performs simulations for all possible configurations of the system to check if they are possible. He then estimates the cost of installation and operation of the system and proposes a list of configurations, classified according to the cost of their life cycles [16], [5], [17].

Disadvantages of the classic approach

Conventional sizing (manual or with software) is based solely on the principles of lower cost and technological profitability. It cannot take into account the non-commensurable criteria. And the results do not necessarily meet the needs of subscribers [6].
Indeed, a simple “cost-benefit” analysis shows very quickly its limits and its inadequacy with the number of subscribers who decrease throughout the operation of isolated power plants. Multi-criteria methods make it possible to overcome the weaknesses of conventional sizing.

Example of study

The Nanoe company electrifies 4 to 6 households forming a nano-network in the Ambanja and Ambilobe zones. After the sensitization and the household level survey, the company proceeds with the estimate and proposes installation costs for the interested parties. Some affected households are already retreating in this process, whose reasons may be of sociocultural origins such as the fear of being electrified for the first time in their lives, the failure of the electrical service providers who are already there before, etc... And also, some households that are already subscribers stand out. The origin of this detachment can also because of sociocultural origins.

For example, the household does not have the money to pay their bills, but it offers an exchange of the price of the electricity bill to equal agricultural products.

Multicriteria analysis

In addition to the results of conventional design, multicriteria analysis implements a matrix of choice of multicriteria configuration taking into account incommensurable criteria.

Methodological bases

To find the most suitable solution for the choice of isolated power plants, 4 steps must be followed to create a multicriterion problem:

List the potential actions

In addition to the technology of the equipment to be installed (technical part) and the costs related to the installation (economic part), the lifestyle of the subscribers will also take into account (socio-cultural part).

List the criteria to be considered

These criteria are technical criteria Ct_k, economic criteria Ce_l and sociocultural criteria Cs_{cm}. Where the indices k, l, and m vary from 1 to $nc_{t,e,sc}$ ($nc_{t,e,sc}$: number of technical, economic and sociocultural criteria). Technical criteria include the energy source deposit, sizing method, subscriber load curves, energy efficiency, etc. The economic criteria include installation costs, the time of return on investment, the cost of selling electricity, etc. And sociocultural criteria bring together the standard of living of future subscribers, their income-generating activity, their preference for the source of electrical energy, their belief, the way in which bills are paid,
and so on.

Establish the performance table

In this table, have the different configurations of isolated power plants, the potential actions and the different criteria related thereto. As an example, we took those that are more used in the DIANA region, which are:

$$\begin{aligned} &\text{Type 1} = PV + SB, \\ &\text{Type 3} = GE, \\ &\text{Type 4} = PV + EO + SB, \\ &\text{Type 7} = PV + EO + GE + SB. \end{aligned} \quad (3)$$

Table 2 Matrix of choice of multicriteria configuration

Plants tc_j	**Technic**			**Economic**			**Sociocultural**		
	Ct_1	…	Ct_{nc}	Ce_1	…	Ce_{nc}	Csc_1	…	Csc_{nc}
Type 1									
Type 3									
Type 4									
Type 7									

With:
tc_j: type of isolated plant,
Ct_i: technical criteria,
Ce_j: economic criteria,
Csc_j: Sociocultural criteria,
nc: number of criteria.

Aggregate performance

A weighting coefficient α_i is assigned to each criterion C_i. Its value is between 0 and 1, which depends on the judgment of the planner.

Calculation method

Each type of isolated power station tc_j is evaluated according to the weighting coefficients α_i assigned to each criterion C_i of the different potential actions.

$$tc_j = \sum_{k=1}^{nc_t}\left(\alpha t_k^j Ct_k^j\right) + \sum_{l=1}^{nc_e}\left(\alpha e_l^j Ce_m^j\right) + \sum_{m=1}^{nc_{sc}}\left(\alpha sc_m^j Csc_m^j\right) \quad (4)$$

So, the ideal plant based on the Multicriteria Analysis is the one that received the greatest sum of the weighting coefficient.

$$C_{opt} = \max_{j=1}^{nc_t} tc_j \quad (5)$$

With
C_{opt}: optimal center,
nc_t: total number of criteria.

CONCLUSIONS

The optimization of mathematical problems well posed based on the technical and economic criteria of an isolated power plant gives an ideal result but does not take into account the way of life of the subscribers. These limits are manifested by the decrease in the number of subscribers during the operation of the plant.

Unlike conventional sizing, multicriteria analysis makes it possible to integrate any type of criteria, incommensurable or not. These rules make it possible to arrive at a judicious choice compromise, according to the experience of the man of study which is determining in the weighting of the different criteria. However, this approach depends on the technical means available, the type and amount of information that is provided or collected after an investigation, and the type of outcome desired.

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