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Comparative studies of two sites for the installation of a photovoltaic solar pumping system for irrigation

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ABSTRACT

This article proposes an approach to assessing the solar potential of a site in order to install a solar pumping system to irrigate a crop field.

The energy provided by solar irradiance as a function of time is analysed in order to understand how it behaves during the sunny period of the day. In addition, this temporal variation makes it possible to summarily assess the behaviour of the system to be installed.

Keywords: Solar Pumping, Solar Energy, Water Flow, Irrigation, Solar Pumping, Legal Time

I. INTRODUCTION

With reference to the objectives of sustainable development, in particular those which concern agriculture and food (actions against hunger), our research work consolidated in this article wishes to provide an approach to the identification and choice of site for the establishment of a pumping system intended to irrigate crop fields in order to improve on the one hand, agricultural yield in tropical zones and on the other hand, to be able to vary several types of crops throughout a year.

Indeed, we carried out comparative studies of two sites in the northern region of Madagascar in order to be able to identify the different parameters which can impact the choice and sizing of such a system.

In addition, our approach focuses on the different spatio-temporal parameters of the sites studied. Consequently, this article is divided into the following parts: the methodology adopted, the results as well as the related discussions and the conclusion.

II. METHODOLOGY

For both sites, we considered several data allowing us to answer the different research questions relating to our work. In this work we are interested in the following information

- The water needs of the sites;
- The solar potential of each site;
- The electrical parameters of the pumping system per site;
- The pumping rate for each site.

The approach adopted in this article is based on three fundamental principles: calculation of illuminance, calculation of flow.

The following two sites were considered:

Table 1: Study sites

Sites	**Longitude**	**Latitude**	**Sunshine [KWh/m^2/day] (worst-case month of the site)**
Ambohitrakongona(Sambava)	50,167	-14,267	5,2
Cap Diego (Antsiranana)	49,2833	-12,2667	4,8

A. illuminance

This approach makes it possible to size photovoltaic solar collectors and subsequently analyze the variation in pumping flow.

Regarding illuminance, we used the following relationships[1]:

✓ The overall illuminance is defined:

$$G^* = \Phi + D^* \qquad (1)$$

✓ Direct illumination is given by the relation:

$$\Phi\,(\beta, \gamma) = I^*[\sin\beta \cos h \cos(a - \gamma) + \sin h \cos\beta] \qquad (2)$$

For a horizontal sensor (β=0), the illumination onlydepends on the height of the sun [4]:

$$\Phi\,(h) = I^* \sin h \qquad (3)$$

Or $\text{Sin}\, h = \cos\varphi \cos\delta \cos\omega - \sin\varphi \sin\delta$ (4)

The diffuse illumination is given by the relation:

$$D^*(\beta) = \left[\frac{1+\cos\beta}{2}\right] D_h^* + \left[\frac{1-\cos\beta}{2}\right] a^* G_h^* \qquad (5)$$

For a horizontal sensor (β=0), the diffuseillumination becomes:

$$\mathbf{D}^*(\beta) = \mathbf{D}_{\mathbf{h}}^* \qquad (6)$$

The declination of the sun is expressed by:

$$\delta = 23,45\ (6)\text{si}\left[\frac{360}{365}\ (q - 81)\right] \qquad (7)$$

- qbeing the date of the yearstartingfromJanuary 1

To determine the hour angle of the sun varies at each moment of the day we used the following relationship:

$$\omega = \frac{360}{24} t_{SV} - 180 \qquad (8)$$

True solar time is determined from the following formula:t_{SV}

$$t_{SV} = t_L - \kappa + 4(L - L_{st}) + \tau \qquad (9)$$

With :

- t_L: legal time expressed in hours
- κ: time zone and season correction coefficient;
- L: longitude of the site;
- L_{st}: standard longitude;
- τ: time correction coefficient

Or

$$\kappa = C_1 + C_2 \qquad (10)$$

With :

- C1:spindle correction coefficient
- C2:seasonal correction coefficient.

$$L_{st} = 15\, n_{fh} \qquad (11)$$

$$\tau = 9{,}87 \sin 2\left[\frac{360}{365}\ (q - 81)\right] -$$
7,53 cos360365 (q−81)−1,5 sin360365 (q−81)(12)

B. Water requirements

Determining water requirements for a given specific consumption depends particularly on lifestyle, environment, demography and climatic conditions of each region [2].

1. Estimated specific consumption

Specific consumption (Csp) is a hypothetical consumption of water per day evaluated according to consumption ratios established by international organizations such as the WHO (World Health Organization) [3].

Table 2 : Specific consumption given by the WHO

Human	5 l/day	Survival
	10 l/day	Minimum admissible
	30 l/day	Normal living conditions in Africa
Irrigation	100 m^3/day/ha	Rice
	60 m^3/day/ha	Market gardening
	45 m^3/day/ha	Seeds
	65 m^3/day/ha	Sugar cane
	55 m^3/day/ha	Cotton
Animals	40 l/day	Beef
	5 l/day	Sheep - Goat
	40 l/day	Horse
	20 l/day	Donkey

2. Assessment of water requirements for irrigation

Irrigation water requirements depend on the type of crop, metrological factors such as temperature, humidity, wind speed, soil evapotranspiration, the season of the year under consideration and the irrigation method [2].

For the purposes of our research, we considered two sites where the population lives mainly from fishing, agriculture and livestock. Since this work involves irrigating cultivated land, the main types of crop we considered were corn, peanuts, cassava, tomatoes and rice.

The same soil-crop characteristics are assumed for both sites. To this end, the following table shows the crops and their total areas:

Table 3 : Crops and their surface areas

Crops	**Surface area [ha]**
Peanuts	3,4
But	2,6
Tomatoes	2
Cassava	2
Rice	1,6
Total land area |ha]	11,6

Consequently, the irrigation water requirements for each site are as follows:

Table 4 : Irrigation water requirements

Crops	**Water requirements [m³/day/ha]**	**Surface area [ha]**	**Total [m³/day]**
Peanuts	35	3,4	119
But	45	2,6	117
Tomatoes	50	2	100
Cassava	60	2	120
Rice	100	1,6	160
Total [m³/day]			616

We need 616 m^3 /day to irrigate each test site: Cap Diego (Diégo Suarez urban district) and Ambohitrakongona (Samabava urban district).

C. Pumping system

1. Hydraulic power requirements

Once we have defined the volume of water required and the characteristics of the water source, we can calculate the average daily and monthly hydraulic energy required using the relationship :

$$\mathbf{E_h = C_H . V . H_{mT}} \qquad (13)$$

With :

- E_h: Hydropower (kWh/d)
- C_H: Hydraulic constant (Kgh/m^2s^3)
- V: Daily water volume (m3/d),
- H_{mT} :Total head (m)

2. Total head H_{mT}

$$H_{mT} = H_g + \frac{P_2 - P_1}{\rho g} + \frac{V_2^2 - V_1^2}{2g} + \Delta H_{Ca} + \Delta H_{Cr} \qquad (14)$$

With :

- H_{Cr} : Total pressure drop across the discharge pipe
- H_{Ca} : Total pressure drop across suction line
- H_g: Geometric height of elevation

In our case, we have chosen a geometric height of 25m.

3. Electrical power requirements

The energy required to lift a given quantity of water to a given height over the course of a day is calculated from the following equation:

$$E_e = \frac{E_h}{\eta} \qquad (15)$$

With :

- E_e : Electricalenergy in (kWh/d)
- η: Pump unit efficiency (0.81)

4. Energy required to pump a daily flow of water

The daily energy to be supplied E_j (Wh / day) to pump a flow Q (m^3) of water per day at an average H_{mT} (m) is :

$$E_j = \frac{C_H . Q . H_{mT}}{\eta_S} \qquad (16)$$

With :

η_S :Pumping system efficiency

The efficiency of the pumping system is given by :

$$\eta_S = \eta . \eta_{tr} . \eta_m . \eta_B \qquad (17)$$

With :

- η_{tr}: Transmission efficiency
- η_m: Motor efficiency
- η_B: Battery efficiency

5. Photovoltaic generator peak power

Having known the daily volume of the storage tank, the equivalent pumping head and the daily irradiation incident on the generator plane, the size of the photovoltaic array is calculated, taking into account the efficiency of the pump unit.

Peak power is determined using the following simplified formula [5.10].

$$P_c = \frac{E_j}{0{,}6G*} \qquad (18)$$

where G* is global solar radiation

6. Number of modules

The number of modules can be determined from the following relationship:

$$N_m = \frac{P_C}{P_m} \qquad (19)$$

With :

- P_C : Generator peak power
- P_m : Module power or nominal power of a panel

The number of modules connected in series will be :

$$N_{mS} = \frac{U_S}{U_G} \qquad (20)$$

The number of modules connected in parallel :

$$N_{mP} = \frac{P_C}{P_m \cdot N_{mS}} \qquad (21)$$

Where:

- $N_{mS}$and N_{mP} are the number of modules in series and parallel, respectively
- U_G : the module's nominal voltage in volts
- U_S : the operating voltage

Correcting the number of panels gives :

$$N = N_{mS}\, N_{mP} \qquad (22)$$

7. Determining battery capacity

The capacity of a battery cell is the amount of electricity a charged cell can deliver during the discharge period, expressed in ampere-hours or Watt-hours .

The capacity of an accumulator is determined by the following relationship:

$$C_{réelle} = \frac{N_j \; E_j}{DOD \cdot \eta_{bat} \; U_B} \qquad (23)$$

With

- Nj : Varies according to geographical location and application from 4 days to 1 month (number of days of autonomy)
- Ej : Average consumption
- U_B: Battery terminal voltage
- DOD : Depth of discharge
- η_{bat}:Energy efficiency of batteries

It is noted that the percentage of deep discharge (D_p) varies between 70 and 80%. We must then ensure that the daily discharge (D_j) is of the order of 10 to 20%, i.e. minimum N_j equals 5 days.

8. Determining the number of batteries

The number and arrangement of batteries are determined by the following relationships:

Batteries connected in series :

$$N_{BS} = \frac{U_S}{U_B} \qquad (24)$$

Batteries connected in parallel :

$$N_{BP} = \frac{C_{réelle}}{C_C} \qquad (25)$$

Where:

- N_{BS} and N_{BP} are respectively the number of batteries connected in series and in parallel
- U_S : The operating voltage
- C_C : Capacity to choose from (in Ah) "Battery manufacturers offer batteries with capacities that vary by fairly large leaps.

Parallel connection of several batteries increases capacity.The storage conservation condition is translated by :

$$E_J < C_{réelle} \cdot U_B \qquad (26)$$

9. Hydraulic power

Hydraulic power is the pump's useful power.

$$P_U = P_h = \rho . g . Q . H_{mT} \qquad (27)$$

With :

- P_U : Power imparted to the liquid as it passes through the pump.
- Q: Daily flow

10. Mechanical power absorbed by the pump

This is the power measured on the pump coupling or power on the pump shaft [7].

$$P_a = \frac{P_U}{\eta} = \frac{\rho g Q \, H_{mT}}{\eta} \qquad (28)$$

11. Pump motor power consumption

The power supplied by the motor is given by :

$$P_m = \frac{\rho . g . Q . H_{mT}}{\eta . \eta_m . \eta_{tr}} \qquad (29)$$

With :

- η_m : Motor efficiency
- η_{tr} : Transmission efficiency
- P_m: Engine power

12. Pump sizing

Pump selection is based on the following two factors:

- ✓ Total head H_{mT}
- ✓ Hourly throughput Q_h

a. Hourly flow rate Q_h

$$Q_h = \frac{V}{h} \qquad (30)$$

Where:

h: Maximum sunshine hours at 1000 w /m^2

$$h = \frac{E_{sol}}{1000} \qquad (31)$$

E_{sol} : Daily solar energy

III. RESULTS AND DISCUSSIONS

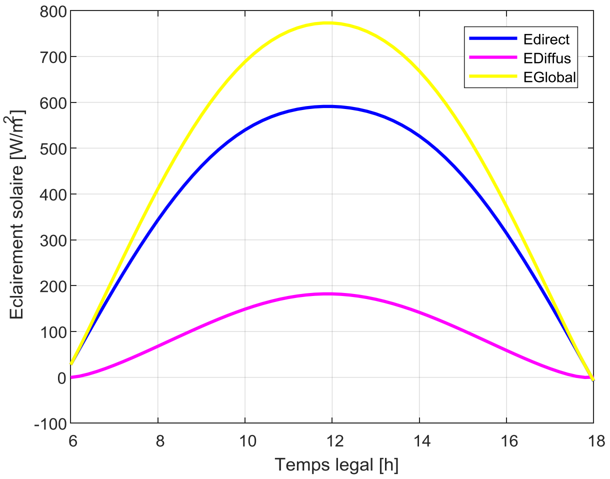

Figure 1:Irradiation of cap diego

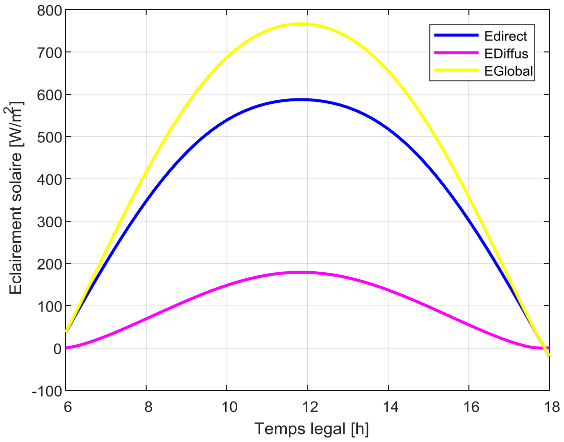

Figure 2 : Irradiation of Ambohitrakongona

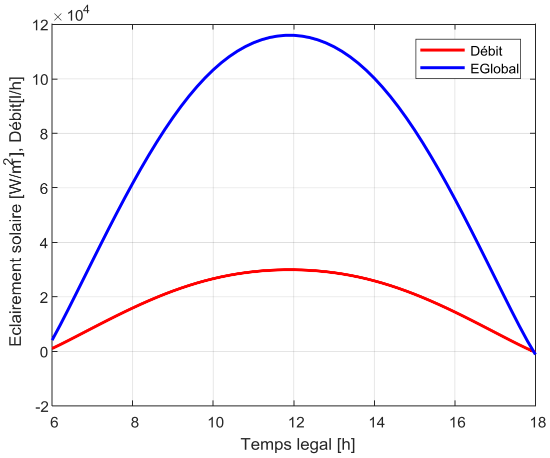

Figure 3:Variation of the flow rate as a function of irradiation and legal time at the level of Cap Diego

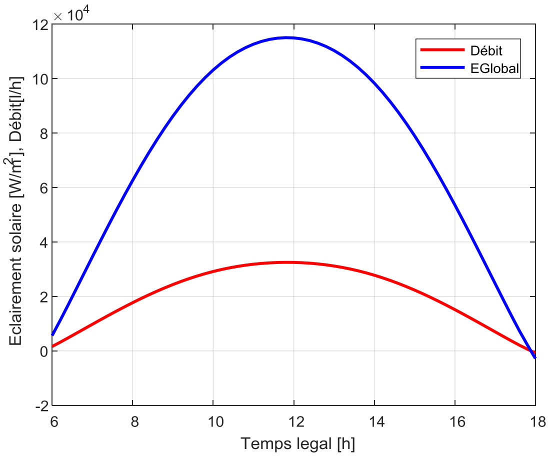

Figure 4:Variation of the flow rate as a function of irradiation and legal time at the level of Ambohitrakongona

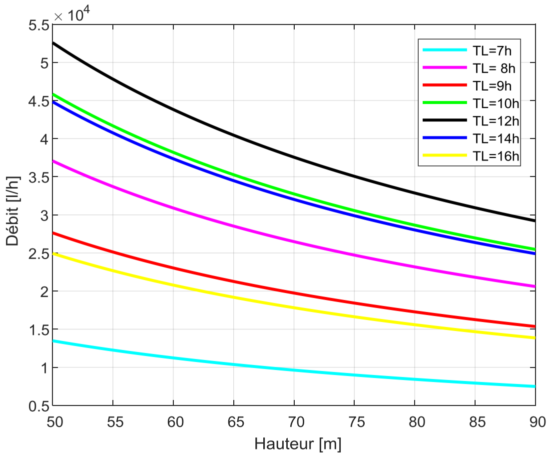

Figure 5 : Variation of the flow rate as a function of the head and the legal time at the level of Cap Diego (day)

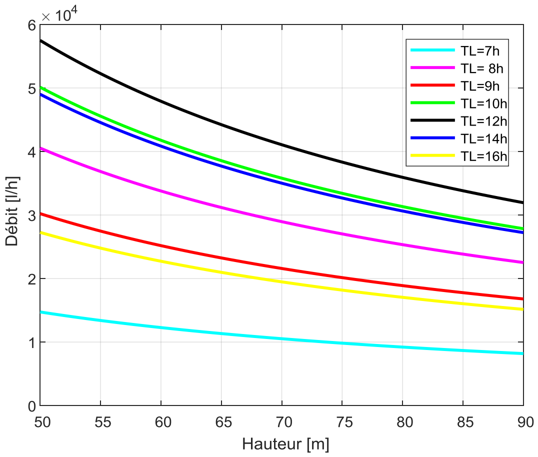

Figure 6 : Variation of flow as a function of head and legal time of Ambohitrakongona (day)

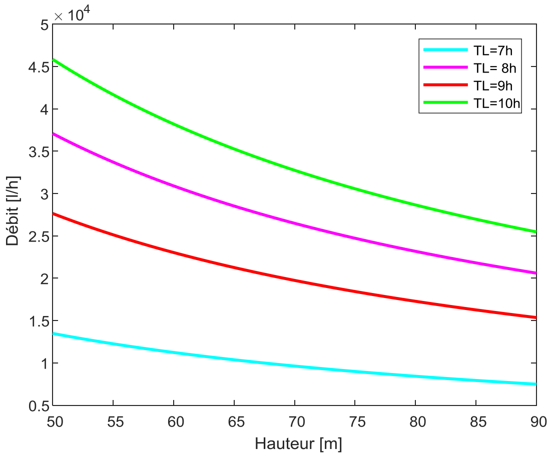

Figure 7 : Variation of flow rate as a function of pressure head and legal time at Cap Diego level (morning))

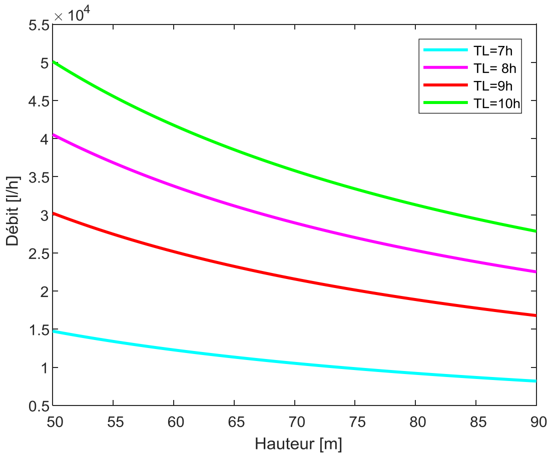

Figure 8 : Variation of flow according to the head and legal time of Ambohitrakongona (morning)

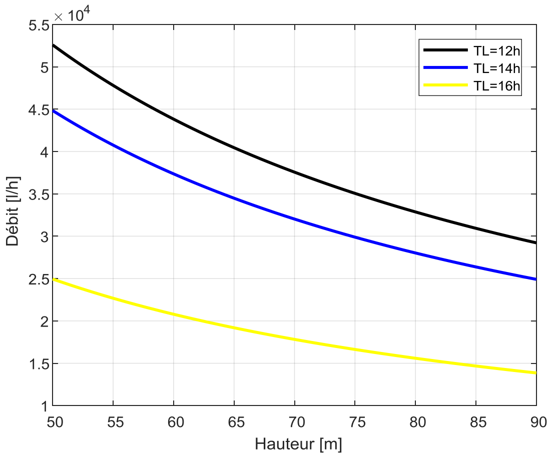

Figure 9 : Variation of flow as a function of head and legal time at Cap Diego level(afternoon)

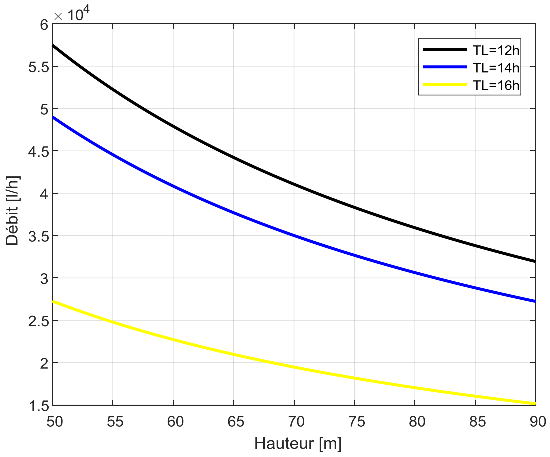

Figure 10 : Variation of flow according to the head and legal time of Ambohitrakongona (morning)

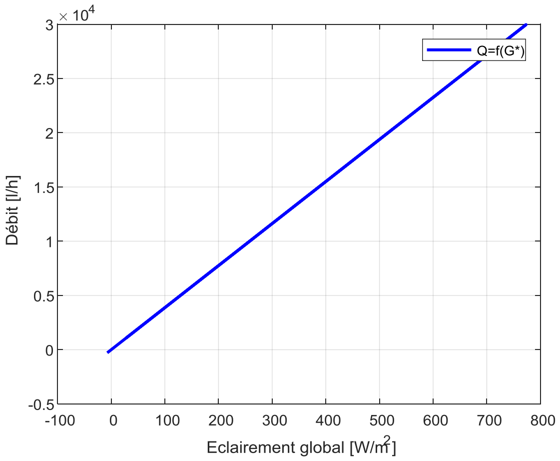

Figure 11:Variation of flow depending on global illumination of Cape Diego

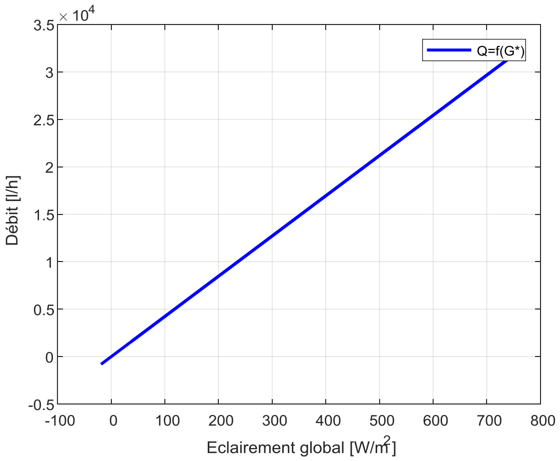

Figure 12 : Variation of flow depending on the overall illumination of Ambohitrakongona

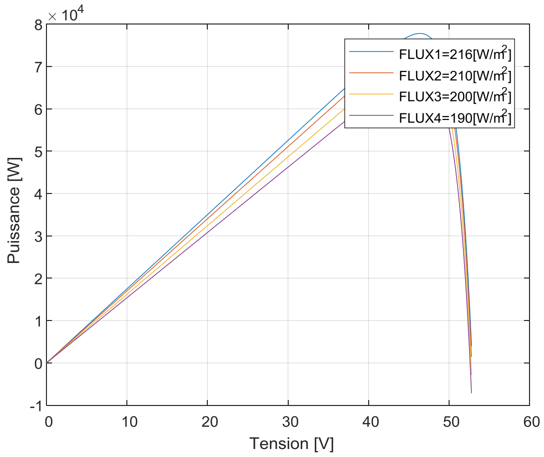

Figure 13 : Variation of power as a function of overall illumination of Cap Diego

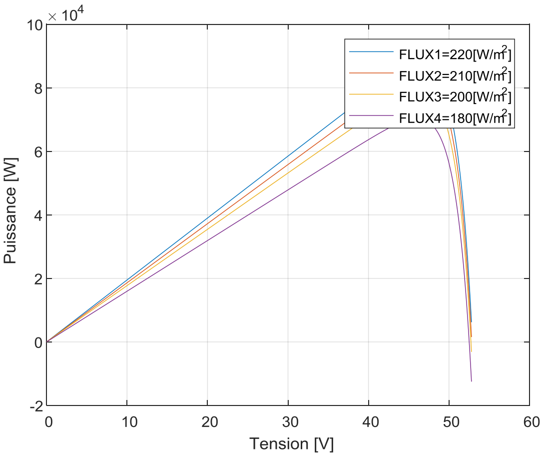

Figure 14 : Variation of power as a function of overall illumination of Ambohitrakongona

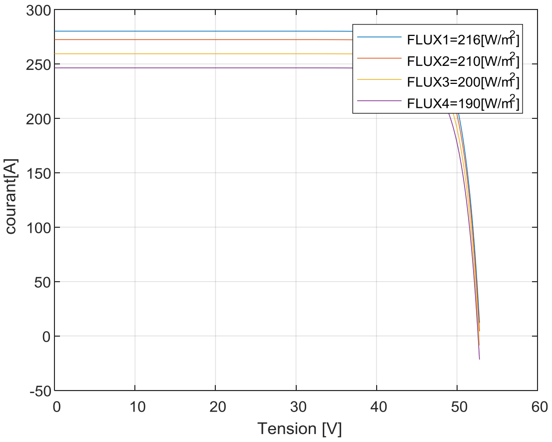

Figure 15 : Variation of current as a function of the overall illumination of Cap Diégo.

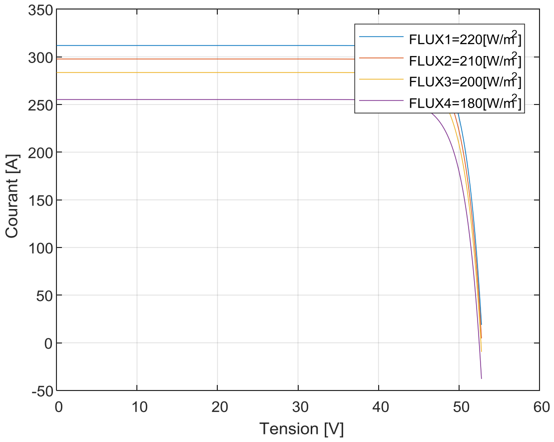

Figure 16: Variation of current as a function of overall illumination of Ambahitrakongona

Considering that we have the same value of crop area to irrigate and that the water requirements at the two study sites are identical (E_j=233.65 [kWh/d]), the above graphs allow us to state that the solar pumping system is different from one site to another.

The choice of pumping system depends on the irradiation of the site and the pump head. In other words, the pumping rate varies from one site to another.

We found a peak power value of 74,88 kWc for Cap Diego and 81,12 kWc for Ambahitrakongona.

If we consider the mechanical part, the pump for Cap Diego has an absorbed power of 16,48 kW, while that for Ambohitrakongona is 18,02 kW.

If we linearize the curves above, we have a curve of flow variation as a function of overall illumination:

The flow rate - H_{MT} curves normally have a stable evolution, that is to say the total head, H_{MT} decreases when the flow rate of a pump increases. The flow rate of a pump also varies depending on the legal time, that is to say the flow rate and TL increases until midday, then decreases during the afternoon.

IV. CONCLUSION

This article has made it possible to identify criteria for choosing, sizing and optimizing the operation of a photovoltaic pumping system to successfully carry out its technical feasibility study.

The central parameter is the flow. This thus leads to the approximate sizing of the water storage capacity. The elements determining the choice of a motor pump depend on several important factors: the type of pump desired, the type of motor, the power required for pumping, the total head of the installation, the water flow rate, etc. .

The analysis is almost identical for the choice and sizing of solar panels: their manufacturer characteristics of voltage and power vary from one model to another.

Finally, the positioning, determination of the peak power of the solar panels as well as the surface area necessary for the proper functioning of the pump can be calculated. These require some knowledge of the geographical parameters of the site as well as its sunshine.

The results obtained by simulation presented in this study show that the head of the photovoltaic pumping system operating over the sun depends on the geometric head and the pressure losses at the suction and discharge level.

The daily quantity of water pumped depends on:

- the peak power of the solar panel,
- the efficiency of the photovoltaic pumping system,
- global illumination,
- the total head.

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