Study and Design of a Photovoltaic Pumping System in the Madinah Sector at Dogomet Prefecture Dabola (Guinea)

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Abstract. This work concerns the design study of the photovoltaic pumping station of Madinah village in Dogomet - Dabola. It is based essentially on the assessment of the water needs, the calculation of the necessary hydraulic energy, the determination of the available solar energy and the choice of the components of the photovoltaic system and the pump. We have found that for the 1500 inhabitants of the village, the required daily flow is 30 m^3 and it has been determined for the storage of water six (6) tanks of 3 m^3 each brand MILA TANK, for a total volume stored of 18 m^3. The sizing method used made it possible to calculate: the energy required for pumping equal to 7431.81 Wh/day; the corresponding peak power, 2452.74 Wc; the number of modules is 10 with a peak power of 256 Wc each. The calculated hourly flow rate of the chosen pump is 5 m^3/h for an electrical power of 3066 W. The diagram of the entire plant of the pumping station was developed.

Keywords: Photovoltaic, Pumping, Sizing, Manometric Height

Introduction

The global population explosion, industrial development, animal husbandry and the housing sector have resulted in an increasing need for water. The most common solutions were based on the consumption of surface water, which is now increasingly rare due to global warming and pressure from different users. On the other hand, groundwater exists, but at depths, which require more reliable and efficient pumping systems, hence the importance of solar photovoltaic pumping (Jimmy et al., 1998).

Despite the high hydrogeological potential of Guinea and the significant efforts made to exploit it, the rates of access to drinking water in rural and urban areas are still relatively low. The improvement of the living conditions of the populations in the rural areas is linked to the search for adequate solutions to this problem (Yann, 2017). In this context the exploitation of solar energy through solar pumping technology remains one of the solutions for all areas with significant solar radiation (Memoris, 2009). The Madinah sector is moving away from rural areas with no electricity or any form of conventional drinking water supply. The Madinah sector's only source of drinking water is a human powered (mechanical) pump, two improved wells and a few ordinary wells. This study focuses on the study and design of a solar pump in the Madinah sector in Dogomet, Dabola prefecture.

Materials and Methods

Materials

As part of this work, we used the following equipment: the computer, the calculator, the decameter, the centimeter, the string, the ruler or the sight, the bezel or level, Matlab. The village of Madinah is one of the districts of Hamdallaye district in the Rural Commune Dogomet, Dabola prefecture. The Dogomet Created on 31th December 1991, consists of 33 Sectors divided between 10 districts (Figure 1). It has a population of 30730 inhabitants including 17015 women and 13715 men, nearly 85% of this population lives in rural areas and practices agriculture and livestock breeding. The Dogomet RC is located 382 km from Conakry and 50 km from the capital of Dabola. It lies between 11°26' west longitude and 10°42' north latitude, with an average altitude of 639m, and an area of 1440 km^2. Its climate is of Faranah type is characterized by the alternation of two seasons: a dry season from November to April and a rainy season which extends from May to October. The average rainfall varies from 1500 to 1600mm of water per year, with an average temperature of 30°C and a solar irradiation of 467 kWh/m^2/day (Saïdou, 2017).

Today, there are 42 boreholes in the Dogomet Rural District, 2 of which are non-functional and 12 improved wells, most of which dry up in the dry season. These water points are unequally distributed over the area of the municipality. All of these boreholes are only equipped with mechanical (mechanical) pumps. The Madinah sector consists of 150 families, 8 to 10 persons per household with 51.5% women and 48.5% men (Saïdou, 2017). The drilling of Madinah was carried out in 1993 by the National Service of Development of Water Points under the financing of the Guinean State. The picture in Figure 2 gives a view of this borehole.

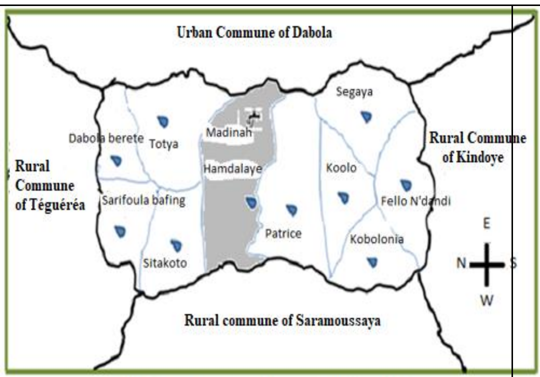

Figure 1 : Map of sub prefecture of Dogomet

LEGEND
: District headquarters
: District limit
: Rural limit
: Drilling Madinah

Figure 2 : Drilling Madinah

Methods

There are two (2) sizing methods for a photovoltaic pumping system, namely: the analytical method and the graphical method (Mohamed, 2015). For this study, we used the analytical method which is essentially based on the assessment of water requirements, electrical energy, available solar energy and system components.

Solar photovoltaic pumping systems. The solar pumping system consists of capturing solar energy via photovoltaic panels to produce electricity that supplies an electric pump to ensure water drainage. Most often used in rural areas not served by the electricity grid, solar energy has for several years already been an alternative to the energy produced by means of a (thermal) generator to operate the pumping systems (Louazene et al., 2013). These photovoltaic pumping systems are generally of two types, depending on whether they work with or without a battery.

The photovoltaic pumping system with batteries, has the advantage of guaranteeing the stability of equipment supply with a regular flow of water (possibility of pumping when the sun is absent). Also, the stored energy can be used for other subsequent needs. Its major disadvantage is that it has several components that negatively affect the reliability and overall cost of the system. Batteries introduce some degree of efficiency loss from about 10% to 15% of energy production.

The photovoltaic pumping system without batteries or pumping system over the sun, requires storage of water in tanks, the water pumped during the day is stored for use at any time. This technique makes it possible to have a simpler, more reliable, less expensive and low maintenance photovoltaic system. The water storage capacity can vary from one to several days according to the models (Jimmy et al., 1998). Thus, this technique (system without batteries) was chosen for this study.

A solar pumping system generally consists of: photovoltaic generator, motor pump, electronic converters (inverters), water storage tank, electrical wiring, hydraulic infrastructure, water purification system and water network distribution (Louazene. et al., 2013). Figure 3 shows the simplified block diagram of a photovoltaic pumping system.

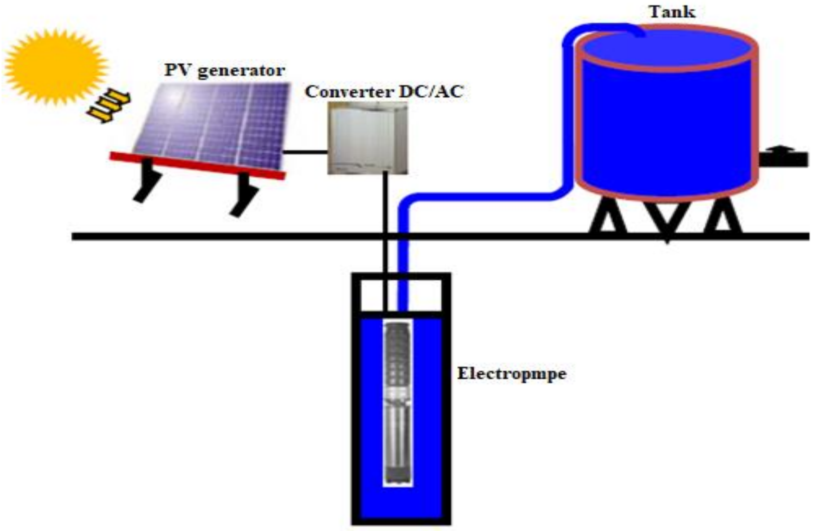

Figure 3. Scheme of a photovoltaic pumping system

The photovoltaic generator or photovoltaic power plant is the series and parallel association of several modules according to the energy needs. It also has a metal structure to support the whole.

The submersible electric pump unit is an assembly of a centrifugal or volumetric pump and an electric induction motor whose common function is to move a liquid from one point to another.

The pump is a device for sucking and repressing a fluid. There are two main types of pumps (centrifugal and volumetric) (Louazene et al., 2013).

Electric motors are electromechanical devices that allow the conversion of electrical energy into mechanical energy, they are of two types, direct current and alternating current. The control and control electronics consist of a DC/DC converter or chopper and a DC/AC converter or inverter (Mamady, 2015). The storage tanks can be built locally, their capacities vary according to the water needs. These tanks require little maintenance. The hydraulic infrastructure (piping) conducts water from its source (often a well or borehole) to the storage tank. The water purification system must meet the standards in force, to ensure its sanitary quality.

Maintenance and maintenance. The photovoltaic solar pumping system requires minimal and essential maintenance and maintenance (Yann, 2017). Two types of maintenance (quarterly and annual) are carried out as part of the operation of installed equipment. The purpose of the quarterly maintenance is to verify the correct operation of the equipment and to take measures leading to a better functioning. This interview mainly consists of visual control actions and light measurements (Multon et al., 2004). The annual interview consists of a more in-depth interview. It covers actions carried out during the quarterly interviews but also in-depth measurement actions allowing a more precise assessment of the equipment's operating status (Alhassane, 2013)

Dimensioning of the photovoltaic pumping system. The sizing of a photovoltaic pumping system is based on the determination of these different components (Hadj et al., 2005).

Water requirements: Starting from the norm which defines the minimum quantity necessary for a socio-economic development per individual which is 20 liters per day, one needs the water of the population of Madinah calculated by the equation 1.

$$B_w = b_{w/pd} . N_{fl} . n_{p/f} \quad (1)$$

With: B_w: Water need; : $b_{w/pd}$ = 20 l/pd : Water requirement per person per day; N_{fl} = 150 : Number of family of the locality; : np/f = 10 : Number of people per family

Water storage: six (6) tanks of 3 m^3 each of brand MILA TANK were chosen, for a total stored volume of 18m3 which corresponds to 60% of the useful volume.

Evaluation of the electrical energy requirement: the electrical energy required for the pumping was calculated according to the following parameters: the required water flow (Q), the total head (HMT), the total efficiency of the pump set and the hydraulic constant (Jimmy et al., 1998). The necessary electrical energy is determined by equation 2.

$$E_{elec} = \frac{E_h}{\eta_{gm}} = \frac{C_h.Q.HMT}{\eta_{gm}} \quad [kWh/j] \quad \text{and} \quad C_h = \frac{g.\rho}{3600} \quad (2)$$

With: C_h = 2.725 kg.s.h/m^3: Hydraulic constant; : Q : Volume of water or flow required in m^3/day; g = 9.81 m/s^2 : Gravity acceleration; ρ : Density of water in kg/m^3.

It was selected for this study an AC motor (AC current) whose efficiency of the pump is 55% and the efficiency of the motor is 80% at the nominal operating point, with an overall efficiency of the pump unit of η_{mp} = 44%.

Total head: The H_{MT} of a pump is the pressure difference in meters of water column between the suction and discharge ports. This height is calculated by equation 3.

$$H_{MT} = H_g + P_{chf} \quad (3)$$

with: H_g : Geometric height between the water table and the plan of use; P_{chf} : Loss of charge; the drilling depth or dynamic level is 37 m; the storage tanks will be placed on a concrete support high: 1.5 m above the ground.

Photovoltaic field: the analytical method of dimensioning the photovoltaic field to consist in determining: the peak power, the number of modules, their mode of connection, the power of the inverter to choose and the section of the cables.

The peak power (P_C) of the photovoltaic generator is calculated by equation 4.

$$P_c = \frac{E_{elec}}{E_{avsu}.\eta_{pv}} . 1\ kW/m^2 \quad (4)$$

With: $\eta_{pv} = 65\%$: Efficiency of the photovoltaic system; $E_{avsu} = 4{,}67\ kWh/d$: Average sunning of the site.

The number of modules (N_m) of the PV plant is given by equation 5:

$$N_m = \frac{P_c}{P_m} \quad (5)$$

With: P_c : Generator peak power in [Wc]; P_m : Power of the PV module [Wc]. The type of module chosen has a power of 256Wc, Pyramid Brand, Crystalline Si-Poly Model ZCS-265P-24V Manufactured by ZhonqchaoSolar 2012.

Connection of modules: The number of modules connected in series (N_{ms}) and in parallel (N_{mp}) are calculated respectively by equations 6 and 7.

$$N_{ms} = \frac{U_{ch}}{U_m} \quad ; \quad N_{mp} = \frac{N_m}{N_{ms}} \quad (6 - 7)$$

Or: $U_{ch} = 48$: Nominal voltage of the load the inverter; U_m : Rated voltage of the module in V.

Inverter: The power of the inverter used is calculated by equation 8.

$$P_{inv} = \frac{P_{ci}}{\eta_{inv}} \quad (8)$$

Where: P_{ond} is the power of the inverter; η_{inv} = 90% is the efficiency of the inverter.

System Wiring: The choice of cables to consist in the calculation of their sections in order to limit the voltage drops between the various components of the system. For a 48V circuit, as ours the maximum allowable voltage drop between the generator and the converter is 2% and between the converter and the input of the pump set is 3% (Jimmy et al., 1998). The sections of these cables were calculated by equation 9.

$$S = \frac{2\times\delta\times L\times I}{\Delta U\times U} \quad (9)$$

Or: S: Cable section in mm^2; $\delta = 1.6.10^{-8}\Omega m$: Resistivity of copper; L: Cable length in m; ΔU = 2% to 3%: Voltage drop; U = 24V: Voltage of a panel; I = P/U: Intensity of current in A.

The characteristics of the cable connecting the panels and the converter: the distance between the two elements is 4 m, the cable is aluminum (ρ = 1.6 10-8 Ω.m); the voltage of each panel (U = 24 V), ΔU = 2%; intensity I = 11.042 A. The distance between the converter and the pump set is 40 m, the characteristics of the cable that connects them are: ΔU = 3% and I = 48V.

The choice of the pump set depends on the following parameters: pump hourly output and electric power of the pump set (Alhassane, 2013).

The hourly flow rate of the pump Q_h [m^3/h] was calculated by equation 10 (Hadj et al., 2005).

$$Q_h = \frac{Q}{t} \quad (10)$$

Where Q is the daily flow and t = 6 hours is the average sunshine time;

Hydraulic power: Is the power necessary to convey the flow (Q) of water to the HMT, it was calculated by the equation (Yann P., 2004).

$$P_h = P_c \times \eta_{gm} \quad (11)$$

With: P_h: Hydraulic power in W; η_{gm} : Efficiency of the pump set; P_c: Peak power of the photovoltaic generator

Mechanical power: the type of motor chosen must guarantee a yield of about 80%, thus, the mechanical power was calculated by the equation 12 (Multon et al., 2004).

$$P_m = \frac{P_h}{\eta_m} \quad (12)$$

With: P_m: Mechanical power of the pump in W and η_m = 80%: Efficiency of the motor.

Electric Power or Active Power: Allows motor operation, it was calculated by Equation 13.

$$P_{elec} = \frac{P_m}{\eta_{gm}} \quad (13)$$

With: P_{elec} the electric power and η_{gm} = 44% the efficiency of the pump set (44%).

Hydraulic piping: The diameters of water pumping pipes that minimize installation costs are calculated using the Bresse equation (Rapport de stage de Fin d'Etudes Supérieures, 2013).

$$D = K\sqrt{Q} \quad (14)$$

With: D: pipe diameter in m; K = 0.75 to 1.40: coefficient; Q: hourly flow rate of the pump in m^3/s.

Schematic of the system installation. The diagram of the installation of the solar pumping station is given in Figure 4.

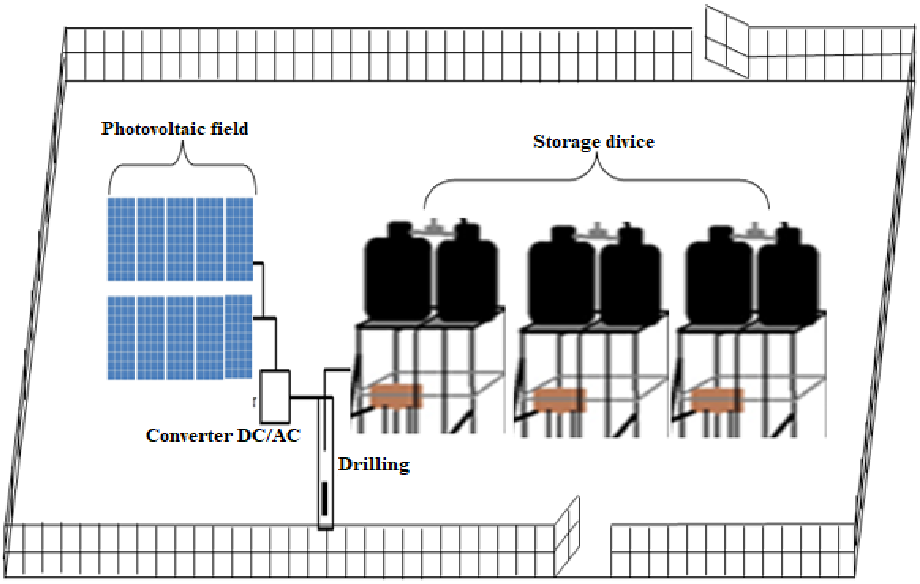

Figure 4. Scheme of installation pumping system

Results and Discussion

The sizing results of the Madinah photovoltaic pumping station are shown in Table 1.

Table 1. Sizing results of the PV pumping system

Nº	Settings	Symbols	Values	Units
1	Daily flow	Q	30	m^3/day
2	Total Manometric Height	H_{MT}	40	m
3	Daily energy required	E_{elec}	7431.81	Wh/day
4	Peak power	P_c	2452	Wc
5	Number of modules	N_m	10	-
6	Number of serial modules	N_{ms}	2	-
7	Number of modules in parallel	N_{mp}	5	-
8	Power of the inverter	P_{ond}	2752	W
9	Cable connecting panel-converter	S (L = 4m)	4	mm^2
10	Cable connecting converter motor pump	S (L = 40m)	16	mm^2
11	Hourly rate	Q_h	5	m^3/h
12	Hydraulic power	P_h	1079	W
13	Mechanical power	P_m	1349	W
14	Hydraulic power	P_{elect}	3066	W
15	Pipe diameter	D	5	Mm
16	Water tanks (6 tanks)	Re	18	m^3

The design of the photovoltaic pumping station in the village of Madinah is characterized by a daily water requirement of 30 m^3, with a total head of 40 m (HMT). This value is consistent with the HMT of several boreholes in Guinea averaging 30 m to 120 m (Memoris, 2009). The daily electrical energy required to meet these water needs is 7431.81Wh or about 7.5 kWh, the rated peak power corresponding to this energy is 2452 Wc. This peak power is calculated as a function of the most adverse daily solar irradiation at Dabola in August (kWh/m^2) (Yann, 2017). The type of module chosen has a power of 256 Wc, pyramid brand, crystalline Si-poly Model ZCS-265P-24V Manufactured by Zhonqchao Solar 2012. This type is the most used today, because of its performance and its ranges of varied power rating (5 to 1000 Wc) and an average life of 20 years (Hadj, et al., 2005).

Thus, based on these characteristics, the number of panels calculated is ten (10), the mode of connection of these panels is two (2) in series and five (5) in parallel, the set gives a short voltage. 48V circuit. The power of the calculated inverter is 2,752 W. This is how a 3000 W power inverter was selected. The calculated pump flow rate is 5 m^3/h, which corresponds respectively to the hydraulic power and the mechanical power. and electric (1079 W, 1349 W, and 3066 W).

The motor pump brand chosen in accordance with these characteristics is the PANELLI centrifugal type with a 60% efficiency, which is well suited for total pressure ranges ranging from 32 m to 80 m (Louazene et al., 2013). The cable section between the panels and the converter (4 m long) is 4mm^2; between the converter and the pump set (40 m long) is 16 mm^2. Using the pressure drop diagram, the diameter of the water pipes equal to 50 mm has been determined (Multon et al., 2004). To minimize these losses, we have installed the tanks as close as possible and connect them most directly to the pump.

Conclusion

This research focused on the study and sizing of a photovoltaic pumping system for the Madinah site of the Dogomet sub-prefecture, Dabola prefecture. The studied system is the water supply says: "over the sun". We have shown that the Madinah site has a favorable climate for the exploitation of photovoltaic energy, with sunshine of more than 4.65 $kWh/m^2/day$. A detailed study of all the components of the pumping system was carried out. The dimensioning gave the following results: the water requirement, the energy requirement, the peak power, the number of modules, the connection mode, the power of the inverter, the sections of the cables, the hourly flow of the pump its power electric and the diameter of the water pipes. The study of the economic analysis of the solar pumping station, which has not been addressed in this work, will be the subject of another research topic.

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