Chapter 7

Photovoltaic Water Pumping System in Niger

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Additional information is available at the end of the chapter

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1. Introduction

Solar energy such as photovoltaic is the most promising energy of the non-conventional energy sources which is capable to satisfy the energy needs of the isolated rural areas. It fits perfectly to the decentralization of power generation for the small communities widely dispersed as evidenced the solar pumps whose operation is nowadays proved flawless (World Resources Institute, 1992).

The use of photovoltaic energy to pump water is particularly well suited in the Sahel. This source of energy is free and abundant, but also provides autonomy for many isolated villages of rural areas. The water pumped is stored in the thanks until its use (in the night or during the cloudy days). Locally, there are many companies that manufacture these tanks. These towers do not require special maintenance and are easy to be repair. This chapter presents a study of photovoltaic water pumping in Niger rural areas. We present first the benefits of photovoltaic water pumping; we describe in the second the photovoltaic water pumping system, before present the solar radiation at Niger. Then the sizing of a photovoltaic water pumping system is described and finally, a case study of photovoltaic water pumping is presented before concluding.

2. Benefits of photovoltaic water pumping system

In African countries, many governments are still struggling to meet the basic needs of the population due to lack of availability of electric power system. In rural areas, these needs are summarized in the drinking water, electrification of health centers and irrigation. For lack of resources, these people are resolved to supply water from wells craft of 10 to 100 m and less than 2 m of diameter. Water is the source of life. Its rarity is one of the tragedies of the Sahel. In this area, people have regularly serious problems of drinking water. The water which involves in agricultural and domestic consumption requires dewatering technologies adapted to local conditions. Yet, the solar energy potential is very abundant. The geographical situation of Niger fosters the development and growth of the use of solar energy. Indeed, given the importance of the solar radiation and the duration of sunshine, which excesses eight hours (8 hours) per day throughout the year, some electricity needs can be met by solar energy. This energy source may be beneficial to the most remote areas, especially in water pumping. The use of solar energy can make a meaningful and lasting solution to the drainage in rural areas. The use of photovoltaic solar energy for water pumping is well suited to these regions due to the existence of a potential groundwater quite important especially in desert areas, and a large solar energy potential. Also, this solar energy has the advantage of being clean compared to conventional energy sources which present constraints of remoteness from the mains, fuel transport and periodic maintenance for diesel engines (Jimmy et al 1998, Barlow, 1993). Photovoltaic solar energy may well contribute to meet the energy needs of these populations. Photovoltaic generators are very suitable to relieve the lack of availability of grid. Indeed, with an installation of 1 kW maximum power, we can pump water to heights of about 80 m, or meet irrigation needs of a village (Commission of The European Community, 1985). In addition, these solar generators can be used concomitantly using batteries to power television sets, or for lighting when the pumping system is not loaded (Billerey, 1984).

3. Photovoltaic pumping system

3.1. Description

Photovoltaic pumping system is a standard pump equipped with an electric motor, provided in electrical energy by photovoltaic panels installed on the site (Handbook on Solar Water Pumping, 1984; Fraenkel and al., 1986). This pump is intended to pump water from the basement to make it accessible to users (Fig. 1).

Nowadays, two types of photovoltaic water pumping systems are used: the photovoltaic water pumping with batteries and without batteries. In Niger, it is often used photovoltaic water pumping without batteries, commonly known as "pumping over the sun". Pumping over the sun is simpler and less expensive than with battery system. Instead of batteries, they use a tank to store water until it is used (Fig.2). Hydraulic storage allows overcoming electrical energy storage thus avoiding the use of batteries which have a limited life (6 years compared with 20 to 30 years of photovoltaic panels) and are polluting. However, the method without batteries has some drawbacks and its main fault is to have a flow of water which depends on the average time of the sunlight (A. Hadj, 1999).

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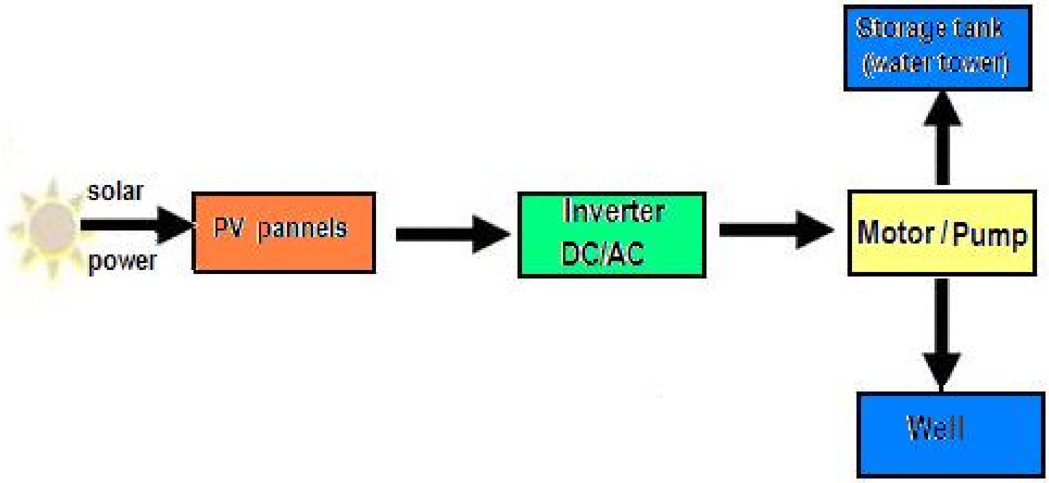

Figure 1. Principe of photovoltaic pumping system.

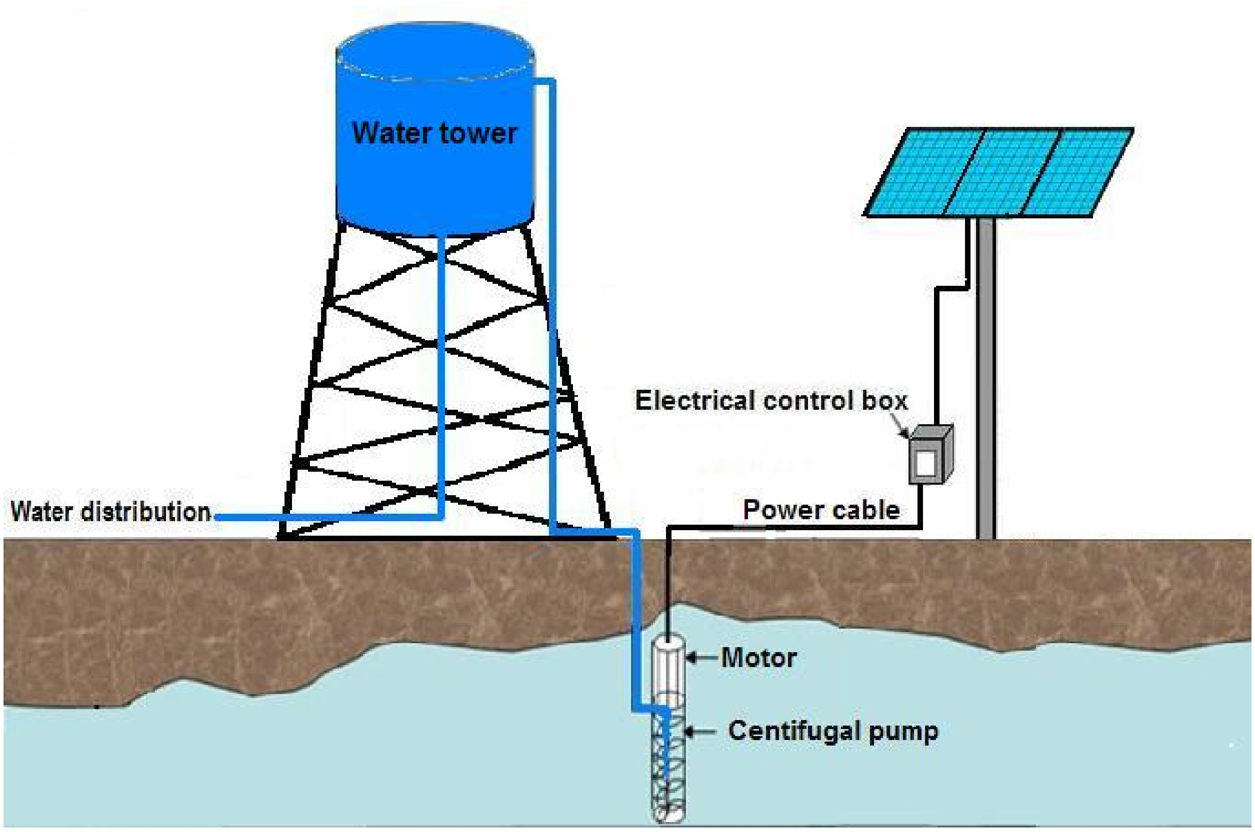

Figure 2. Photovoltaic water pumping without batteries with a tank to store water.

There are two types of pumps to draw water surface: Positive Displacement *Pumps* (volumetric pumps) and centrifugal pumps. Besides to the type of pump, there are two other characteristics at the pumps according to the physical location of the pump in relation to the pumped water: the suction system and stuffer one. They discharge pumps are submerged in water. Their motor is immersed in water with the pump and the discharge pipe placed after the pump can lift water to tens of meters to the storage tank depending to the engine's power. Afterward, the system is connected to a distribution network that delivers water to users.

3.2. Photovoltaic system

To generate the necessary energy to the motor of the pump, solar photovoltaic panels are placed for converting solar energy into electrical energy (Fig.3). As the panels generate a direct current (DC), it is often used DC/AC converter to convert the direct current produced by the solar panels into alternative current (AC) if the motor of the pump is AC. On the other side, if the motor is DC, the device does not need a DC/AC converter. The energy produced by the panels can be used directly or stored. In the case of an application for water pumping, it is more interesting to use the energy to raise the water in a castle that serves as hydraulic energy storage.

To prevent a dysfunction of the pump when it is live on photovoltaic, due to under sizing or over sizing the PV generator, an inverter is used to ensure the proper operation of the PV/ pump system.

Figure 3. Students determining the current-voltage characteristic I = f(V) of solar cell "over the sun" at the University Abdou Moumouni of Niamey (Niger).

4. Solar radiation at Niger

To design a photovoltaic water pumping system, we will need to quantify the available solar energy. Therefore, it is very important to know the solar radiation of the locality. Solar radiation (kW/m^2) is the energy from the sun that reaches the earth. The earth receives a nearly constant

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of solar radiation at its outer atmosphere. The intensity of solar radiation varies with geographic location (Fig.4).

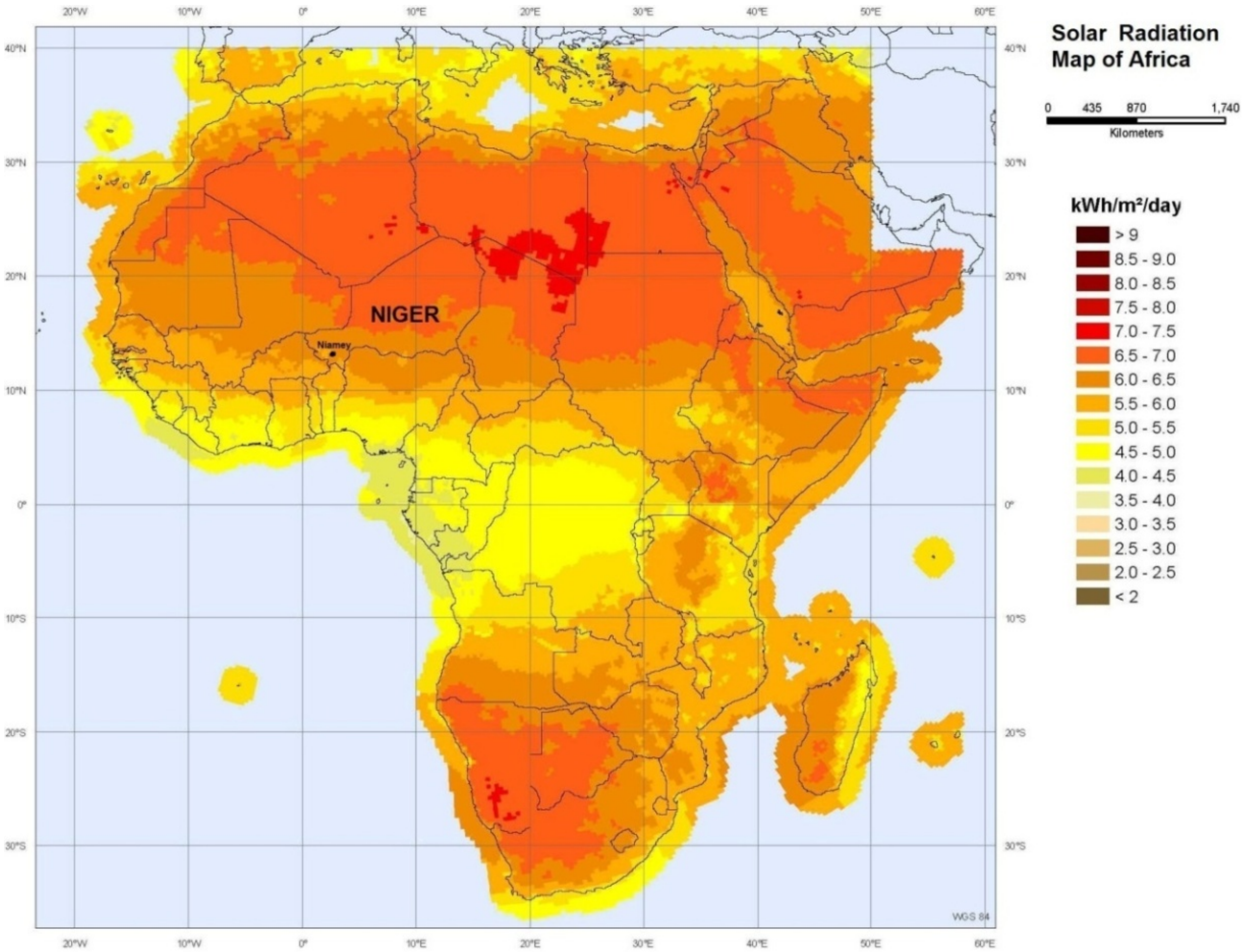

Figure 4. Africa solar radiation map (Source: UNEP, NREL and the Global Environment Facility).

It also varies with the season and time of the day. In Sahel, the solar radiation at the earth's surface is very important (Fig.5).

The most productive hours of sunlight are from 9:00 a.m. to 5:00 p.m. Table 1 gives the daily average time (Hours/day) of the sunlight at Niger (Keita town: Latitude 14.75°N and Longitude 5.76°E).

Month	Jan.	Feb.	Mar.	Ap.	Ma	June	July	**Aug.**	Sept.	Oct.	Nov.	Dec.
Average Time (Hours/day)	9.0	9.3	8.7	8.4	8.8	8.6	8.2	**7.5**	8.1	9.2	9.5	8.9

Table 1. Monthly average time (Hours/days) of the sunlight at Niger (Keita town: Latitude: 14.75°N and Longitude: 5.76°E)

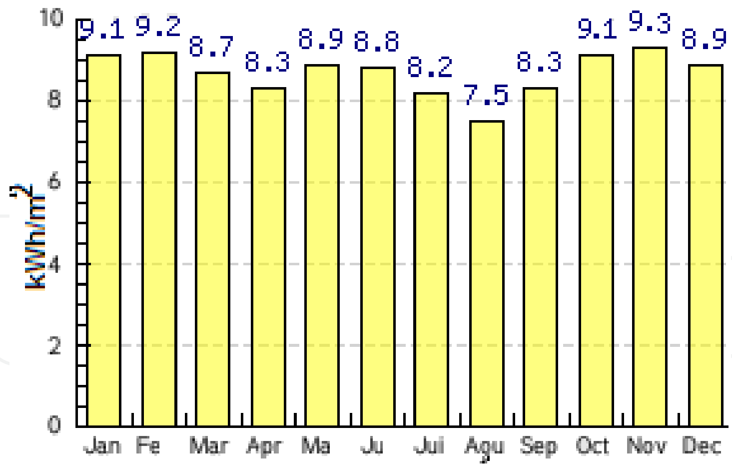

Figure 5. Daily average radiation of sunlight per month at Niger (kWh/m^2.day).

5. Sizing a photovoltaic water pumping system

Photovoltaic water pump sizing is the determination of the power of the solar generator that will provide the desired amount of water (Alonzo, 2003).

The photovoltaic water pump sizing consists of:

- Assessment of daily water needs of the population to know the rate flow required;
- calculation of hydropower helpful;
- determining of the available solar energy;
- determining of the inclination of the photovoltaic generator which can be placed;
- determination of the month sizing (the month in which the ratio between solar radiation and hydropower is minimum);
- sizing of the PV generator (determination of the required electrical energy);

5.1. Assessment of daily water needs of the population

Determining the water needs of the consumption of a population depends mainly of its lifestyle, the environment and climatic conditions of each region. Drinking, cooking, washing and bathing are the main uses of water for human needs. Animals also need water for their survival. The water use is also essential in the field of agriculture.

Depending on the nature of the users (humans, animals) or the use, the amount of water required for each user or usage are:

- **Population (Humans)**
  - 5 liters /day, for survival;
  - 10 liters /day, for the minimum acceptable;

– 30 liters /day, the normal living conditions in Africa;

• **Animals**

– Cattle	40 liters /day;
– Sheep, Goat	4 liters /day;
– Horse	40 liters /day
– Ass	20 liters /day
– Camel	20 liters /day (reserve for 8 days)

• **Irrigation (agriculture)**

– Crops at the village	60 m^3 /day / hectare;
– Rice	100 m^3 /day / hectare;
– Cereals	45 m^3 /day / hectare;
– Sugar cane	65 m^3 /day / hectare;
– Cotton	55 m^3 /day / hectare.

There are three standards for the calculation of water requirements:

1. The standard for the minimum amount for survival.

2. The current target of funding agencies: 20 liters/day/person that does not include livestock and gardening.

3. The minimum amount necessary for economic development: 50 liters/day/person. It includes:

20 liters/day/person, for personal needs;

20 liters / person / day, 0.5 unit of cattle per person;

10 liters / day / person, 2 m^2 for vegetable crops.

In applying the standards 2 and 3, we obtain the following water requirements (Table 2) depending on the size of the village (population).

Population of village (persons)	Standard 2: (20 liters/day/person) (m^3)	Standard 3: (50 liters/day/person) (m^3)
250	5	12.5
500	**10**	**25**
750	15	37.5
1000	20	50
1500	20	75
2000	40	100

Table 2. Water requirements depending on the size of the village (population).

5.2. Determination of hydropower helpful

The average daily load i.e. hydropower helpful (kWh/day) required is expressed by:

$$E_H = \frac{g^*\rho_a{}^*Q_a{}^*TH}{\eta_P{}^*3600} = \frac{C_H{}^*Q_a{}^*TH}{\eta_P} \quad (1)$$

Where, g is acceleration of gravity (9.81 m.s^{-2});

ρ_a is water density (1000 kg/m^3);

Q_a is daily water needs (m^3/day);

TH is the total head (m);

η_P is pump system efficiency

The tank capacity is determined by the daily water needs and the autonomy of the system.

5.3. Determining of the available solar energy

The method used is based on the determination of daily mean values of solar radiation available and hydropower necessary.

5.4. Determining of the inclination of the photovoltaic generator which can be placed

The inclination β to the horizontal plane of the photovoltaic panels (PV) must be to maximize the relationship between solar radiation and hydropower necessary. We have chosen 15°N, the latitude of the locality (Keita town: Latitude 14.75°N).

5.5. Determination of the month sizing

The sizing month will be the worst month, i.e., the month that the ratio between solar radiance and hydraulic energy required is minimal. In our case it is the month of August is the month of sizing. In august the average time is 6.5 hours/day.

5.6. Sizing of the PV generator

As the system works all year round, the field is tilted at an angle equal to the latitude of 15 ° N. It was in August that the average number of hours of sunshine is the lowest maximum: 6.5 hours/day. Assuming a 25% loss due to the temperature and dust, the required electrical energy is given by:

$$W_{PV} = \frac{E_H}{Radiance^*(1 - loss)} \quad (2)$$

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6. Case study

A study on the photovoltaic water pumping system in a village at 30 km of Keita (Niger) to meet the water needs of the five hundred (500) persons gave the following summarized results.

Figure 6. Photovoltaic water pumping station with a volumetric pump at Niger.

a. Assessment of daily the water needs: Using the Standard 3: (50 liters/day/person), the water needs rises to 25 m^3/day.

b. The average daily load i.e. hydropower helpful (kWh/day) required is given by this expression :

$$E_H = \frac{g^*\rho_a^*Q_a^*TH}{\eta_P^*3\,600} = \frac{C_H{}_*Q_a^*TH}{\eta_P}$$

With g= 9.81 $m.s^{-2}$

ρ_a= 1000 kg/m^3

Q_a= 25 m^3/day

TH = 52 m

η_P= 50 %

It provides: E_H =7 085 Wh

c. The available solar energy:

d. Daily average radiation of sunlight varies from 7.5 to 9.3 kWh/m^2/day.

To make sure to do a good sizing, we choose the minimum value of average radiance: 7.5 kWh/m2/day.

The inclination to the horizontal plane of the photovoltaic panels is: $\beta = 15° N$.

e. The sizing month is: August, 6.5 hours/day.

f. Sizing of the PV generator

Assuming a 25% loss due to the temperature and dust, the required electrical energy is given by this expression:

$$W_{PV} = \frac{E_H}{Radiance*(1 - loss)}$$

$$W_{PV} = 1260 \text{ Wc}$$

The operating point of our photovoltaic field is set at 120 volts due to the characteristics of the inverter. The photovoltaic field will be composed of 10 multiple modules in series. Generator power is 1260 Wc, the rate current is 10.50 A. With photovoltaic panels which have 3.5 A, we will have 3 modules in parallel.

The table 3 shows the summary of case study.

Month of sizing	Radiance (kWh/m^2)	Time of sunlight (H)	Loss (%)	E_H (kWh)	W_{PV} (Wc)	Voltage (V)	Current (A)	Configuration of panels
August	7.5	7.5	20	7 085	1260	120	3.5	10 X 3

Table 3. Summary of case study

7. Conclusion

The use of solar energy in Niger, particularly photovoltaic energy, for water pumping is well suited in this arid and semi-arid area due to the existence in this region of an underground water potential, and a large solar energy potential more than 6 kWh/m^2.

Photovoltaic generators are coupled directly to the pump with a DC/AC converter. Storing water in the tanks avoids additional costs accumulator used to store electrical energy. The case study clearly shows the advantage of photovoltaic pumping system compared to conventional energy one which has many constraints of distance to the power grid, of transportation of fuel, and of periodic maintenance of the engines. The cost of one cubic meter (1 m^3) of water pumped by the PV system is more advantageous than others systems. This pumping system constitutes a solution for the water supply of these sparsely populated, remote and isolated areas (Thomas, 1987). With the falling prices of solar panels, this source of energy must be popularized and integrated in the development strategy of these countries.

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