Groundwater Wind Pumping: Study and Simulation of an installation for crop irrigation in the Chott-Mariem area

Sana Ben Mariem[1*]
1 National Research Institute for Rural Engineering, Water and Forestry, INRGREF, University of Carthage, Ariana, Tunisia

Abstract

This work focuses on the study of a wind turbine pumping of groundwater for crops irrigation. We chose the Chott Mariem region of Tunisian Sahel as a favorable region for the implementation of wind pumping groundwater system due to its high wind potential.

The application relates to treate wind pumping with two modes, namely the wind pumping by windmill and the wind pumping by an electrical turbine.

A first part of this work deals with the design of two wind pumping installations, based on the characteristic data of the region (available wind and water source) and the irrigation water requirements of the crops. The second part is concerned with the coupling of all the components of each installation to be modeled under the TRNSYS environment.

The results of the simulation of two systems present the monthly water flows that could be obtained by these systems.

Key words: Wind energy - Windmill - Turbine - Irrigation –TRNSYS.

1. Introduction

Water is a precious and coveted source. Its use increases continuously from year to year, for all areas, namely food, industry and especially agriculture, whose irrigation absorbs more than 70% of the water resources [1].

The increasing consumption of water, coupled with the evaporation of surface water and the reduction of precipitation, leads to an alarming situation. So groundwater seems to be an alternative to this problem. However, the main constraint is to ensure the energy required to pump this groundwater.

Diesel or electric motors have been widely used for pumping water. But as the price of oil and therefore of electricity, had continued to increase, especially in 2008, it is therefore increasingly necessary to find ways of feeding pumping facilities that are less dependent on petroleum products or electricity.

Today, renewable energies, especially wind power, have become one of the main resources for the production of electricity as well as for the mechanical pumping of water.

In Tunisia, the wind potential is considerable and can be largely exploited, especially in the regions of Thela, Bizerte, Elborma, Kélibia, Monastir-Sousse, where the average wind speed can reach 4 m / s.

The Tunisian experience in the use of wind energy comes back to the 1960s, when hundreds of windmills were used in our country for pumping water [2]. Today these machines are totally neglected, the use of wind energy is limited to the production of electricity and the pumping of the water is ensured only by the electric wind turbines.

However, around the world, windmills have been widely used for a long time and to this day, in addition to the considerable Tunisian wind potential, we have chosen to study the wind power pumping of groundwater in Tunisia.

In this work, the two wind pumping techniques of water, electrical and mechanical, are presented.

The objective of this work is to predict the operation of a future pumping wind turbine plant in the Chott Mariem area for crop irrigation using modeling.

The modeling was carried out with the TRNSYS model [3] for simulation of two types of pumping wind turbine systems (electrical and mechanical).

2. Materials and methods

2.1. Study of a pumping wind turbine in the Chott-Mariem area

2.1.1. Presentation of the study area

The region of Chott-Mariem, belongs to the delegation of Akouda, from the governorate of Sousse on the Tunisian Sahel. It is distinguished by a lower semi-arid climate with a mild winter and a hot and dry summer

* Corresponding author
E-mail address: benmeriem.sana@gmail.com

given its eastern boundary with the Mediterranean Sea.

Rainfall varies from year to year, with an annual average of 360 mm / year. The average annual temperature is 19 ° C. It is relatively stable from one year to the next. [4]

The wind data required for this study is provided by the Chott-Mariem local weather station. The winds are regular, with an average speed of 3.9 m / s of frequent north-east direction. The maximum instantaneous speed does not exceed 12 m / s.

2.1.2. Dimensioning of a pumping system

The various steps for the design of a pumping system are [5]. :

- Assessment of water requirements;
- Calculation of the hydraulic energy required and;
- Choice of system components.

Assessment of water requirements

Water requirements for irrigation depend on crop type, irrigation method and meteorological factors (temperature, humidity, wind speed, evapotranspiration) [6].

In view of the cultural suitability of the Chott-Mariem soils and the vocation of farmers, we chose for this study, some vegetable crops such as tomato, chili and potato irrigated with drip. The surface recommended is 1 ha, exploited in soles between the different crops practiced.

Irrigation water requirements for the peak month (May) for 1 ha of crops are estimated at **757** m^3 / ha.

The water requirements of the crops are given in table 1.

Calculation of required hydraulic energy

The irrigation water is supplied from a surface well at the Higher Institute of Agronomy of Chott Mariem. The well is 3 m in diameter, drawn at a dynamic depth of 21.5 m. The water level in the well is 10.20 m.

The quotidian hydraulic energy demand, corresponds to the energy required to raise a daily volume Q (m^3 /d) to a height h (m), taking into account the pressure losses in the pipes.

- *Required pumping rate*

Assuming that all the flow is obtained in 5 hours, we therefore have an average hourly flow of the machine of 4.9 m^3/h.

- *Pumping height*

Figure 1 shows schematically a pumping installation in terms of estimating the height of elevation of water.

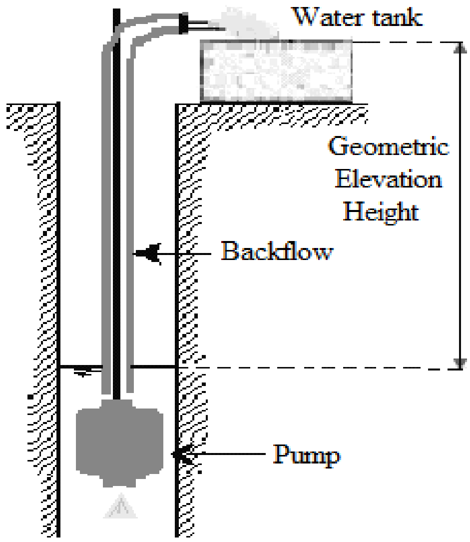


Fig. 1: Estimation of the height of the water elevation.

Table. 1: Gross crop irrigation water requirement (m^3/ha)

Crops / Month	%	S	O	N	D	J	F	M	A	M	J	Jt	A
Potato (O/S)	16.6			52	30	36	-						
Potato (S)	16.6						8	82	223	245			
Tomato (S)	16.6							54	109	203	194	139	
Tomato (E)	16.6					27	65	142	150	124			
Tomato (O/S)	16.6	61	86	97	63	42.5							
Chili	16.6							43	111	185	171		
Total	**100**	**61**	**86**	**149**	**93**	**106**	**73**	**321**	**593**	**757**	**365**	**139**	**-**

* Corresponding author
E-mail address: benmeriem.sana@gmail.com

* The geometric height of the water elevation, Hg is 14 m

The optimum diameter of the discharge line can be found through the Bresse formula:

$$DN = 1{,}5\sqrt{Q} \qquad (1)$$

DN = Nominal diameter in m

Q = Pumping flow in m³/s

This formula results in a diameter of 55 mm. We choose a commercially diameter, DN: 50/60 with pressure losses of 10 mm / m.

* The Total Dynamic Head (TDH) is expressed as follows:

$$TDH = Hg + \Sigma J \qquad (2)$$

∑J: pressure losses Somme

So TDH is equal to 14.14 m.

- *Pump power*

The power of the pump P is calculated by the following formula:

$$P = \frac{Q \times TDH}{75 \times Rt} \qquad (3)$$

Rt: Overall pump efficiency (0.7)

So we have a pumping power of 0.4 hp (300W), meaning 1500 watt hours of energy each day.

Pumping Wind Turbine Selection

For our installation, we can chose a mechanical or electric pumping wind turbine.

Windmill

Containing a set of models of windmills and taking into account the average wind speed, we choose, for this study a windmill composed of the following elements (figure 2) [7] :

- A wheel with 18 blades made of galvanized steel sheet, 3.65 m (12 foots) in diameter. It will be fixed to the shaft by a tightening. The rotational movement of the control shaft is transformed into alternative vertical movement by a crank plate and a connecting rod. The approximate weight of the rotor assembly can be up to 755 Kg.
- A piston pump, of 127 mm diameter, the pump cylinder is made of stainless steel, the piston in bronze, lined with a plastic trim. The strainer valves are also made of bronze, they prevent the defusing if the water runs out. The long and short strokes of the piston are respectively 28.58 and 20.96 cm.
- A four-post tower of 15 m high, with an anti-rust paint, of good quality, protects it from bad weather.

Electric wind turbine

The pumping installation can be equipped with a wind turbine which must satisfy the pumping unit's power requirements, estimated at 300 W.

If we observe the technical characteristics of certain models of small wind turbines, it can be seen from the power curves that this power is produced only for nominal wind speeds of more than 8 m / s. Thus, it is necessary to over-dimension the wind turbine to obtain the required power at the average wind speed of the region.

Thus, the installation will consist of a complete and independent system operating at 220 volts AC, and rated power of approximately 700 W. Its main components are as follows (figure 3) [8]:

- A rotor with three fiberglass blades, 2.5 m in diameter.
- A multiplier (gearbox) used to adjust the rotor speed to that of the alternator.
- An alternator that generates electricity from the rotation of the rotor. The current produced is an alternating current (AC).
- A steel tower keeps the wind turbine at a height of 20 m.
- A pumping unit consists of a 300 W centrifugal pump immersed in the well and operated by an AC electric motor on the surface. The transmission of motion is through a shaft line accommodated in the discharge line.
- A battery is used to store additional electrical energy not used by the pumping unit.
- The capacity of the battery is calculated from the consumption of electric power that is needed every day, it amounts to 1.500 kWh. If the wind will not have the desired speed for a maximum of 3 days, it will be necessary to store the equivalent of 4.5 kWh of power in the battery. So we need a battery with a nominal capacity of 375 ampere-hours.
- Other important components of the system are a rectifier, an inverter and a system

* Corresponding author

E-mail address: benmeriem.sana@gmail.com

for regulating the charge / discharge of the battery.

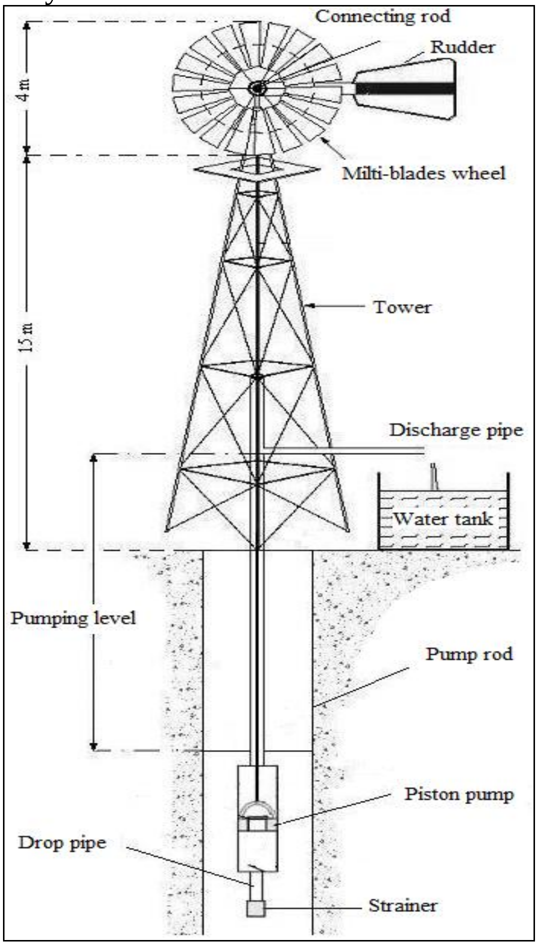


Fig. 2: Windmill pump installation

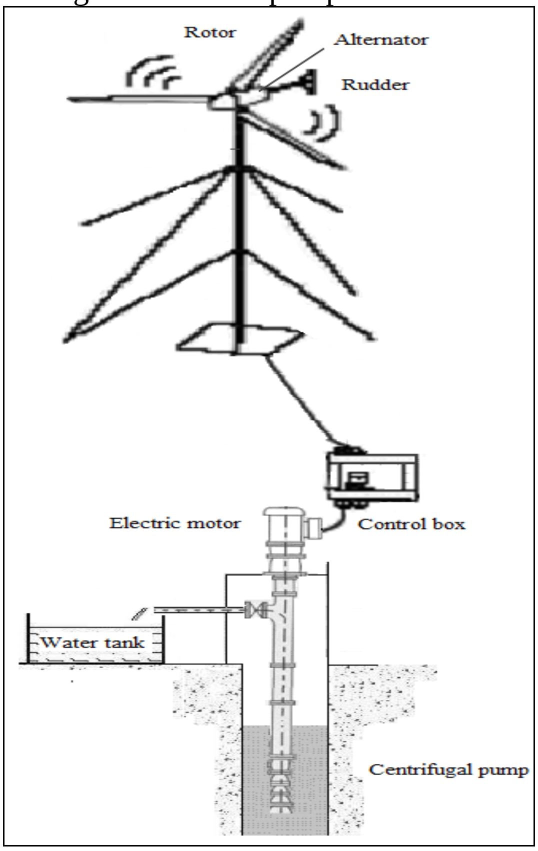


Fig. 3: Electric wind turbine installation

* Corresponding author
E-mail address: benmeriem.sana@gmail.com

2.2. Simulation of wind pumping systems by TRNSYS software

The aim of this study is to realize the design of a mechanical and electrical pumping wind turbine and to model all the components of the system by the TRNSYS software [9].

The principle of the installation is to extract the groundwater using a pump, powered by the power provided by the wind turbine. The water extracted by this pump will therefore, in relation to the power produced by the wind turbine.

First of all, the components for the two types of pumping are selected from the TRNSYS module library.

There is a problem of the non-existence of a type modeling the pump and which presents the relationship between the pumped water flow, the power supplied and the total dynamic head.

There is a type in the TRNSYS library that models the pump but this takes the water flow as input while in this work the water flow is an outlet.

It is therefore necessary to create a new type using the FORTRAN language. This component represents the pump.

2.2.1. Mathematical modeling of the new component "Pump"

To create our new type modeling the pump, it is necessary to determine the equations that govern this type. In this study, we are interested in determining the water flow rate as a function of the power supplied by the wind turbine which is determined as follows:

$$Q = \frac{R_{pump} \times R_{motor} \times P_{turbine}}{\rho \times g \times TDH} \quad (4)$$

In the case of water (1 liter = 1 kg), the following expression can be used:

$$Q = \frac{R_{pump} \times R_{motor} \times P_{turbine}}{TDH} \times 75 \quad (5)$$

ρ, the fluid density (kg / m^3), g the intensity of gravity (N / kg), P the power produced by the wind turbine (Watt),

R_{pump} pump efficiency (%), and R_{motor}, motor efficiency (%) Equation 5 is introduced into the program using the FORTRAN language.

2.2.2. Presentation of the new type

The new type is named TYPE 202 (figure 4) and contains the simulation program of the water pumping group. It contains parameters, inputs and outputs.

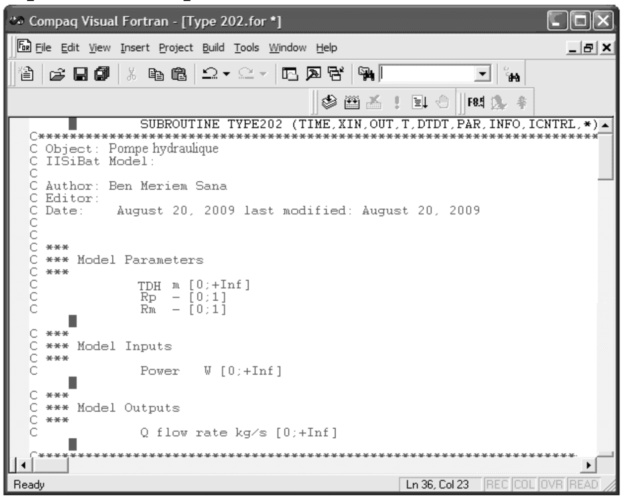


Fig.4: New type 202 in the FORTRAN language

* The parameters (figure. 5) are the independent inputs of the time which do not vary during the simulation:

- R_{pompe}; The efficiency of the pump (%)
- E_{motor}; The motor efficiency (%)
- TDH; The total dynamic head (m)

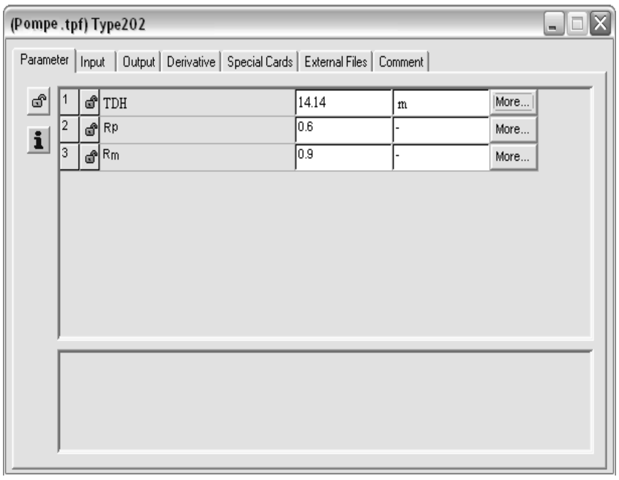


Fig.5: Parameters of the new type 202

* The inputs (figure. 6) are the variable inputs over time:

- P; The power produced by the wind turbine (hp.)

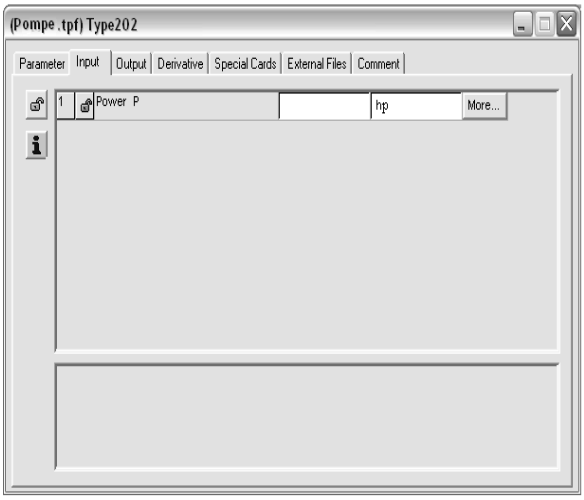


Fig.6: Inputs of the new type 202

* The outputs (figure 7): - Q; The flow of water supplied by the pump (kg / s)

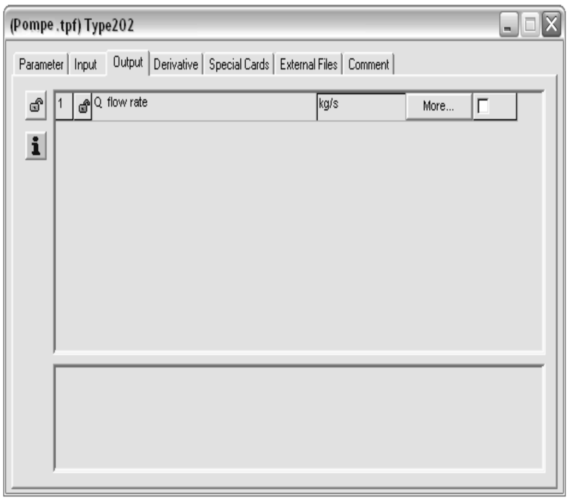


Fig.7: Outputs of the new type 202

2.2.3. Assembly diagram

After creating the new type, it was added to the standard TRNSYS components [10]. . These types are linked together by connections capable of communicating the information from one type to another, the following circuits are then obtained, as shown in figures 8 and 9.

Standard components of Schematic assembly of installation

* Wind Turbine (**type 90**): Type 90 is a mathematical model for a wind energy conversion system (WECS).The model calculates the power output of a WECS based on a power versus wind speed characteristic. The impact of air density changes and wind speed increases with height is also modeled.

* Corresponding author
E-mail address: benmeriem.sana@gmail.com

* Weather data reading and processing (**type 109-TMY2**): This component serves the main purpose of reading weather data at regular time intervals from a data file, converting it to a desired system of units. The model also calculates several useful terms including the mains water temperature, the effective sky temperature, and the heating and cooling season forcing functions.

* Water Draw (**type 14b**): This type represents the source of water (well) to provide the amount of water needed for crop irrigation. The code of Type14 is entirely general, this version of the component uses units of kg/hr to be more readily useful for creating water draw forcing functions.

* Vertical cylinder (**type 60**): This type models a stratified liquid storage tank. It gives the possibility of varying the different parameters characterizing the storage tank, such as the storage volume, the number of water inlets and outlets, etc.

* Online Plotter (**type 65**): The online graphics component is used to display selected system variables while the simulation is progressing. This component is highly recommended and widely used since it provides valuable variable information and allows users to immediately see if the system is not performing as desired.

* Pump (The new **type 202**): This type models the water pumping group.

Mechanical wind turbine components

The wind energy conversion system converts the kinetic energy of the wind into a mechanical rotational energy, which will be used directly to operate a piston pump. Therefore, a unit representing the piston pump must be added to the standard components.

Electrical wind Turbine Components

The mechanical energy produced by the WECS is converted into electrical energy, so it is necessary to add electrical components that are necessary for the electric pumping system. From the TRNSYS library, the following were used:

* Power conditioning (**type 175)**: It is a mathematical model for a power conditioning unit. The model is based on empirical efficiency curves for electrical converters (DC/DC) or inverters (DC/AC or AC/DC). In this instance of Type175, it is assumed that the available input power is known. Corresponding output power is calculated.

* Electrical storage (**type 47): ** This model of a lead-acid storage battery operates in conjunction power conditioning components. It specifies how the battery state of charge varies over time, given the rate of charge or discharge.

* Regulator/Inverter (**type 48**): This type models both the regulator and inverter. The regulator, distributes DC power from the turbine to and from a battery (in systems with energy storage) and to the inverter. If the battery is fully charged or needs only a taper charge, excess power is either dumped or not collected by turning off parts of the array. The inverter converts the DC power to AC and sends it to the load and/or feeds it back to the utility.

* Corresponding author
E-mail address: benmeriem.sana@gmail.com

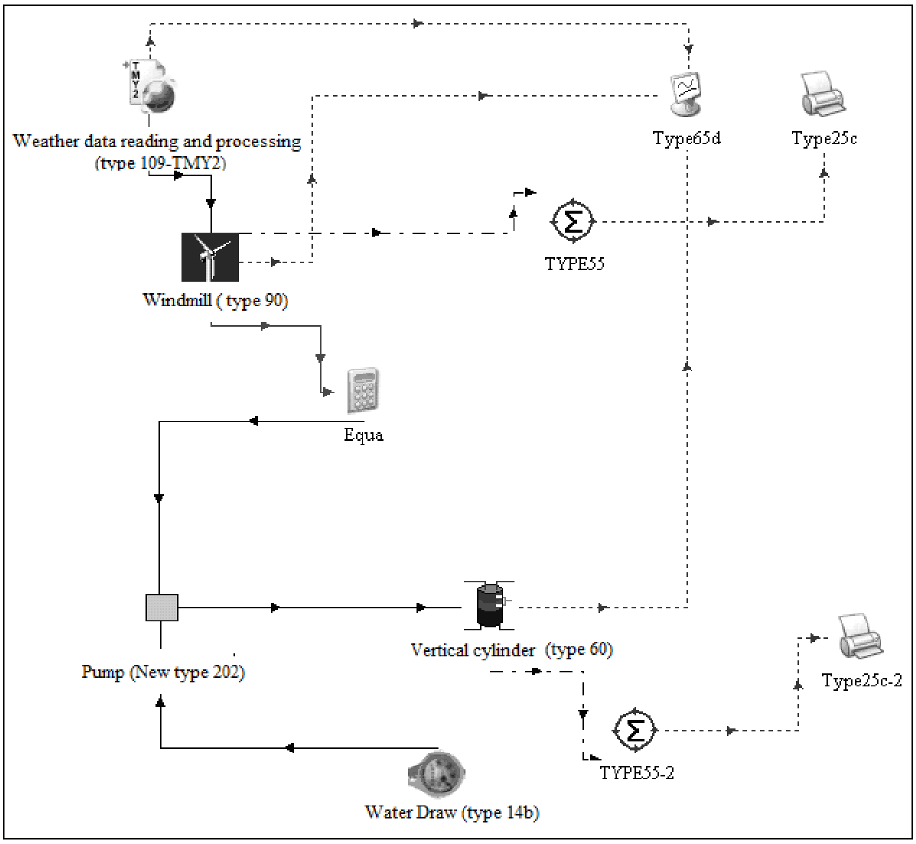


Fig.8: Schematic assembly of mechanical wind pump installation

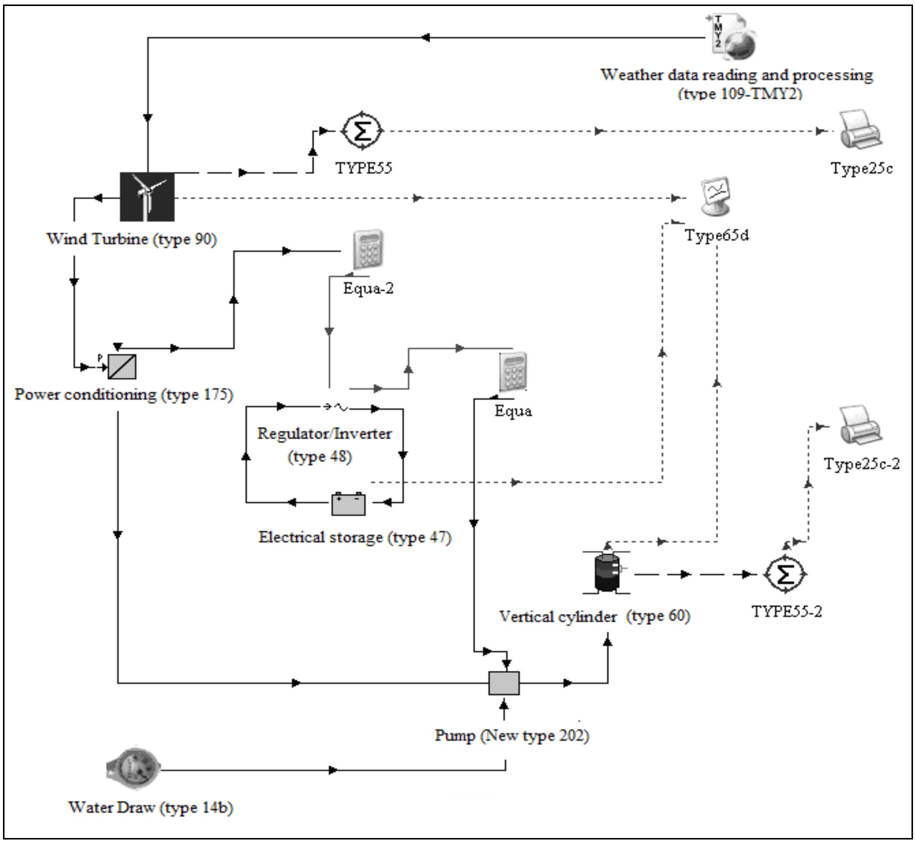


Fig.9: Schematic assembly of the electric wind pump installation

* Corresponding author
E-mail address: benmeriem.sana@gmail.com

3. Results of the simulation

The wind strikes the rotor of the wind turbine which transforms it into a power to operate the pumping group. Indeed, the power produced varies greatly over time. This variation is a function of the frequent variation in wind speed and the technical characteristics of each type of wind turbine.

Figure 10 shows the results of power production by the two types of wind turbines.

The power produced by the wind turbine is higher than that produced by the wind turbine, it does not exceed 750 W for the mechanical wind turbine and for the wind turbine it does not exceed 700 W.

The variation in the output of the power will influence the volumes of water pumped. And to allow comparison of the volumes of water produced by the two wind pumping systems, it was considered that the wind turbine runs without a battery and that all the power is used to operate the pumping unit.

Figure 11 shows the volumes of water supplied by the two wind pumping systems.

Theoretically, the volumes of water produced will be higher, but during the creation of type 202 (the pump), a power margin has been required, outside of which the pump cannot operate, for safety conditions of the pump.

It can be seen from figure 11 that the volumes of water produced by the electric turbine are greater than those produced by the mechanical wind. Moreover, these volumes are well above the gross irrigation water requirements.

So, excess water can be stored in a storage tank or we can increase the area of crops to irrigate. It is also possible to increase the water height elevation by installing the water tank on a tower to take advantage of the irrigation by gravity.

For the electric turbine, the volumes of water produced are also higher than the gross irrigation water requirements, except for the months of April and May, the volumes of water produced are insufficient due to the lack of power. The water deficit will therefore be covered from the volumes of water stored during the previous months.

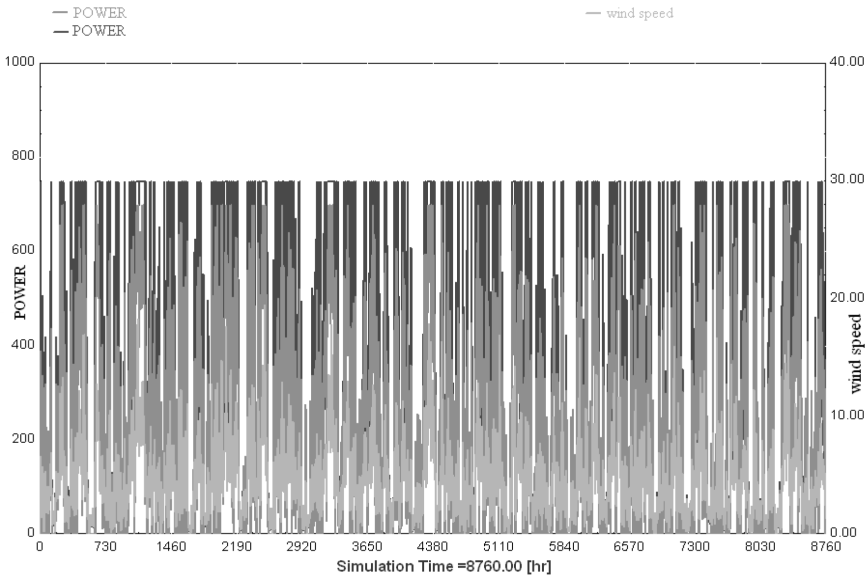
On the other hand, the electric turbine operates with a battery that stores the excess power not used by the pumping unit and which will be used during periods of power shortage. In this case, the stored energy will be used and not the stored water.

Thus, it can be concluded that the two wind-pumping systems, either mechanical or electrical, provide all irrigation water requirements for our study. It is interesting then to compare the price of water production for each system.

The real cost of water cubic meter can be calculated taking into account the lifetime of the turbine (15 to 20 years), installation costs (capital costs and operating and maintenance costs) and the volumes of water produced each year.

For the mechanical turbine the water cubic meter costs about 0.055 DT, while for the electric turbine it costs 0.097 DT.

* Corresponding author
E-mail address: benmeriem.sana@gmail.com



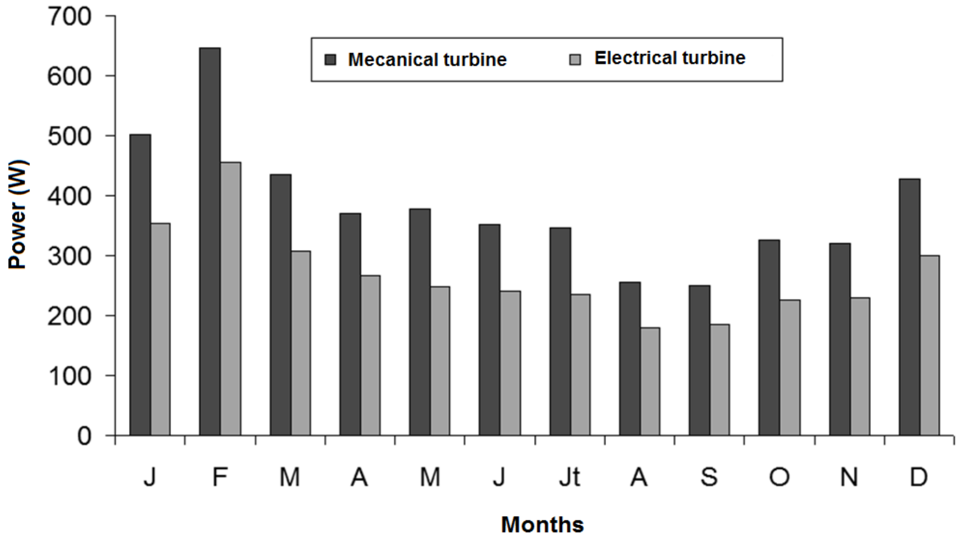


Fig. 10: Power produced by the two types of wind turbines

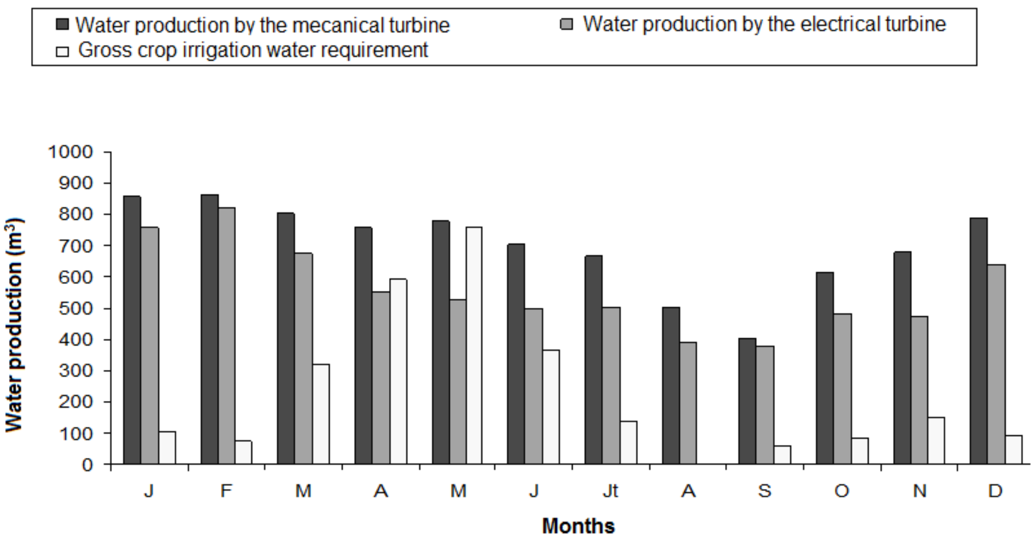


Fig. 11: Monthly water production by the two types of wind turbines

* Corresponding author

E-mail address: benmeriem.sana@gmail.com

4. Conclusion

In this work, we presented the study of a wind pump installation to irrigate one hectare of vegetable crops located in the Chott Mariem region of the Tunisian Sahel. The different elements of the systems were presented. Pumping is ensured by two modes, mechanical and electrical.

These two machines were simulated by the TRNSYS software in order to predict their behaviors. The application of the TRNSYS software prompted the creation of a new component, in FORTRAN language.

The results of the simulation of two wind pumping systems under the conditions of the Chott Mariem region showed the different water flow rate that could be obtained by these systems.

From these results, it was concluded that the mechanical turbine offers a higher power and allows water flow rate higher than those supplied by an electrical turbine.

An estimate of the cost of water production has shown that the cost of water cubic meter produced by the mechanical turbine is lower than that produced by the electrical turbine. This allows us to favor the installation of the mechanical system.

These results encourage reflecting on the importance of mechanical turbines for pumping water, although these machines suffer from a negative image among the actors concerned in our country and have long since been abandoned.

References

[1] United Nations Educational Scientific and Cultural Organization 2001. Securing the Food Supply. Paris: UNESCO.

[2] Agence Nationale pour la Maîtrise de l'Energie, 2003. Étude Stratégique, 1996. Bilan des réalisations, 163.

[3] TRNSYS v.16, A transient system simulation program. Solar Energy Laboratory, University of Wisconsin-Madison, 2004.

[4] Elamouri M. et Ben Amara F., 2007. Wind energy potential in Tunisia. Renewable Energy 33, 758–768.

[5] Cemagref, Irrigation. Guide pratique. Les stations de pompage individuelles pour l'irrigation. 309.

[6] FAO. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements. By: Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. FAO Irrigation and Drainage Paper No. 56. Rome.

[7] http://www.bornay.com/en/productos.html

[8] http://www.ecolabenergies.fr

[9] TRNSYS 16, a TRaNsient system Simulation program, Volume 1, Getting Started. 7.

[10] TRNSYS 16 a TRaNsient system Simulation program Volume 2, Using the Simulation Studio. 19-25.

* Corresponding author

E-mail address: benmeriem.sana@gmail.com