DOI: https://doi.org/10.54966/jreen.v27i1.1159 - *Journal of Renewable Energies 27 (2024) 81 – 98*

Journal of Renewable Energies

Revue des Energies Renouvelables

journal home page: https://revue.cder.dz/index.php/rer

Research paper

Design and sizing of a solar thermal power plant with parabolic trough collectors

Sylvain Niyonsaba [a,*], **Jean Bosco Niyonzima** [b]

[a] *Ecole Normale Supérieure du Burundi, Department of Applied Sciences, Electrical Engineering, Boulevard Mwezi Gisabo, B.P.: 6983 Bujumbura, Burundi.*

[b] *Université du Burundi, Centre de Recherche en Infrastructures, Environnement et technologie (CRIET), Chaussée Prince Louis Rwagasore 164, Bujumbura, Burundi.*

ARTICLE INFO

Article history:

Received January 17, 2024

Accepted May 6, 2024

Keywords:

Design,
Solar,
Thermal,
Cylindrical,
Parabolic,
Power plant.

ABSTRACT

This project aims to build a solar thermal power plant to supply the MUTSAMA center. The lack of electricity and the need to increase the efficiency of the MUTSAMA center are the main reasons why we decided to carry out this work. To achieve this, we adopted a strategy of studying the selection of the site and the solar resource, calculating and adapting the parameters of the solar thermal power plant, and choosing the equipment for our production source. To meet the objective, we carried out a modeling and simulation study of the solar thermal power plant using the SAM tool and designed a system for orienting the collectors to the path of the sun using an Arduino Uno R3 board and TinkerCad software. The plant's collectors are parabolic troughs made by Solagenix (SGX-1). The plant is built with two collectors, each formed by twelve modules, and produces a power of 0.5 MW with 12 hours of operation in the absence of sunlight. The results show that the plant can produce a power of 517.17KW, an energy evaluated at 325939KWh for one year with a capacity factor of 8.3%, and gives a maximum power for a period of 10 hours to 16 hours during the day.

1. INTRODUCTION

Electrical energy is important for the social and economic development of the country. The need for a better future is based on the development of electrical energy. The lack of electricity is a major challenge to achieving sustainable development, and it is against this backdrop that the latter requires governments

* *Corresponding author, E-mail address: sylvainniyonsaba@gmail.com*
Tel.: +257 79963971

ISSN: 1112-2242 / EISSN: 2716-8247

and economic production companies to carry out far-reaching reforms in the energy sector (Zibouche and Mekaoui, 2021).

To contribute to the country's development, we want to create a source of electrical energy to facilitate the operation of the MUTSAMA center. After analyzing the area's climatic conditions and the renewable resources it possesses, we chose this solar thermal source to take advantage of the sun and its good storage capacity compared with other energy production systems. Moreover, exploiting renewable energy resources is one of the challenges of this millennium, given that the world is aware of the harmful effects caused by the use of very expensive, non-renewable fuels (Remili and Saadi, 2022).

In our work, we limit ourselves to techniques aimed at customer satisfaction to increase the output of the MUTSAMA center by meeting the need for electrical energy, which is the driving force behind the development of society. It is with this in mind that we want to create a source of solar thermal energy to power the MUTSAMA center. The general objective of this work is to design and propose the construction of a solar thermal power plant to ensure the smooth running of the MUTSAMA center. To deal with the subject and answer the questions raised, we adopted a strategy of studying the selection of the site and the solar resource, calculating and adapting the parameters of the solar thermal power plant, and choosing the equipment for our production source. Our work is carried out using the System Advisor Model tool, SAM for short. This tool is used to model and simulate the results of the solar thermal power plant. In addition, the SAM software is also used to study and analyze the geographical coordinates of the area where we want to install the solar thermal power plant. The MUTSAMA center consumes a power of 103755 W and an energy equal to 835290 Wh/D. As with all other solar thermal power plants, our production system has a sun-tracking system. The collectors are adapted to the sun using electronic circuits based on an Arduino Uno R3 electronic board.

Our system was programmed and simulated using Tinkercad. The system consists of twenty-four modules grouped in two collectors. The solar power plant supplying the MUTSAMA center has a capacity of 0.5 MW and operates for 12 hours in the absence of sunshine. The results show that the power produced by the solar thermal plant is 517.17 kW, an energy evaluated at 325939 kWh for one year with a capacity factor of 8.3 % and gives a maximum power for a period of 10 hours to 16 hours during the day.

Apart from the introduction and conclusion, this study is divided into two main parts. The first part presents the methodological context and the sizing techniques for the solar thermal power plant, specifying the system for orienting the collectors to the path of the sun. The second part presents the results obtained during the sizing of the solar thermal power plant and the results obtained after simulation using SAM software, and finally an analysis of two results found.

2. METHODS AND OBSERVATIONS

SAM software is used to design, simulate, and analyze hypothetical solar thermal power plant plants. The National Renewable Energy Laboratory (NREL) has developed this software to help project managers, engineers, and researchers model different renewable energy systems such as parabolic solar power plants, photovoltaic systems, wind turbines, and geothermal energy applications. In addition, SAM offers cost-effective analysis solutions for systems that facilitate decision-making processes (Bashir and Özbey, 2022).

The SAM software uses two approaches to simulate solar thermal systems: physical and empirical models. The empirical model is based on real-life scenarios from several existing plants. On the other hand, the physical model has more flexibility and allows users to modify the design parameters Hamilton et al. 2020). Therefore, the SAM software is used for the design of the solar thermal power plant and includes several menus such as start a new project, open a project file, open script, and quit as shown in Fig. 1.

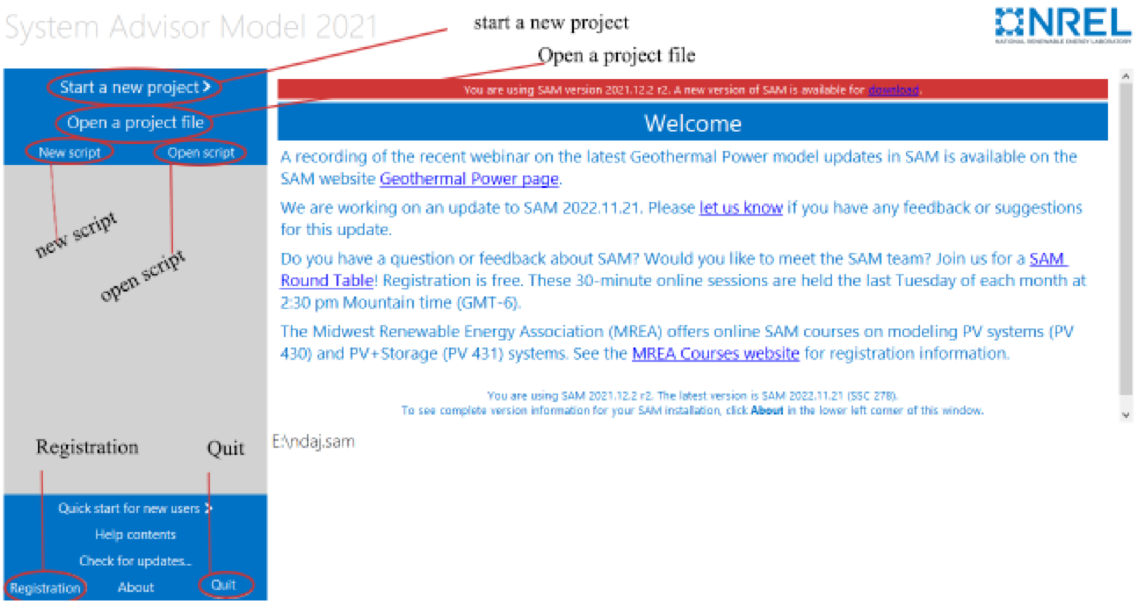

Fig. 1. The SAM software interface.

2.1 Site selection and solar resource

The geographical coordinates and irradiance are determined using the System Advisor Model tool, SAM single, and are grouped in the table in Table 1.

Table 1. Geographical coordinates.

Characteristics	Value
Longitude	29.703°C
Latitude	-3.861 °C
Altitude	1892m
Global radiation	5.79 kWh/m^2
Diffuse radiation	1.35 kWh/m^2
Ambient temperature	42 °C

2.2 Calculating the parameters of the solar thermal power plant

The essential geometric characteristics of the reflector are focal length, aperture width, and length. The focal length is the distance between the top of the reflector and the focal point. The aperture width (w) refers to the distance between the collector and the rim (Moya, 2012). Concentration is the ratio of reflector size to receiver size and is calculated by equation (1) (Bashir and Özbey, 2022).

$$C = \frac{\mathrm{W} - D_0}{\pi \times \mathrm{D}_0} \tag{1}$$

With D_0 : Outside diameter of the absorber tube in m

W: Opening width (m)

The fluid mass flow rate is calculated by Eq. (2) (Amin et al. 2015).

$$\dot{m} = \frac{\pi \times D_i \times V_f}{4} \tag{2}$$

With $\dot{m}$: mass flow rate in kg/s, D_i: Inside diameter of absorber tube in m, V_f: Fluid velocity in m/s

The internal transfer coefficient h_f is given by the following Eqs. (3) and (4) (Bashir and Özbey, 2022):

$$R_e = \frac{V_f \times D_i}{\nu} \tag{3}$$

With ν: Kinematic viscosity in m^2/s

$$N_u = \frac{h_f \times D_i}{K_f} \tag{4}$$

With K_f : Thermal conductivity W/m.K , h_f : the local heat transfer coefficient in $W/m^2.K$,

Nu=3.66 for Re <=2000 And $Nu=0.0243*Re^{0.8}*Pr^{0.4}$ For Re>2000

The collector efficiency factor is given by the relationship in Eq. (5) (Rawani et al. 2017):

$$\acute{F} = \frac{1}{U_L\left[\frac{1}{U_L} + \frac{D_0}{D_i \times h_f}\right]} \tag{5}$$

With D_0 : Outer diameter of absorber tube in m, D_i : Inside diameter of absorber tube in m,

U_L : is the heat loss coefficient in $W/m^2.K$

The collector heat removal factor Fr is calculated using Eqs. (6) (Rawani et al. 2017; Ghodbane et al. 2015) :

$$Fr = \frac{\dot{m} \times C_P}{\pi \times D_0 \times L \times U_L}\left[1 - \exp\left\{\frac{\acute{F} \times \pi \times D_0 \times L \times U_L}{C_P \times \dot{m}}\right\}\right] \tag{6}$$

With $\acute{F}$: is the collector efficiency factor, C_P : is the heat capacity of the fluid in [J.kg-1. K-1], L: Length in m. The absorbed flux is represented by Eq. (7) (Rawani et al. 2017):

$$S = I_b \times R_b \times \rho \times \gamma \times (\tau\alpha)_b + I_b \times R_b \times (\tau\alpha)_b \times \left(\frac{D_0}{W - D_0}\right) \tag{7}$$

In this equation, I_b direct radiation in W/m^2, R_b : global radiation in W/m^2, ρ : specular reflectivity of the concentrator surface, $(\tau\alpha)_b$: average value of the transmission absorption product, γ: Interception factor, the fraction of radiation intercepted by the absorber tube, and S: The absorbed flux in W. The useful heat gain rate Q_u is determined by Eq. (8) (Rawani et al. 2017):

$$Q_u = Fr(w - D_0)L\left[S - \frac{U_L}{C}(T_{fi} - T_a)\right] \tag{8}$$

In this equation, T_a represents the ambient temperature [K or °C], T_{fi} : The fluid inlet temperature, [K or °C], Fr: The heat dissipation factor, Q_u: Useful heat gain in W. The outlet temperature is calculated by the following Eq. (9) (Ghodbane et al. 2015; Irshad et al. 2018):

$$T_{fs} = T_{fi} + \frac{Q_u}{\dot{m} \times C_P} \tag{9}$$

With T_{fs} : Fluid outlet temperature in °C. The rate of heat loss is determined by Eqs. (10) and (11) (Rawani et al. 2017):

$$q_L = (W - D_0) \times L \times S \times Q_u \tag{10}$$

$$q_L = \pi \times D_0 \times L \times U_L \times (T_{Pm} - T_a) \tag{11}$$

Where T_{Pm} : The temperature between the tube and the reflector in [K or °C], T_a : The ambient temperature in [K or °C], q_L : The loss rate in W. The temperature between the reflector and the absorber tube T_{Pm} is calculated by Eq. (12).

$$T_{Pm} = T_a + \frac{q_L}{\pi \times D_0 \times L \times U_L} \tag{12}$$

The temperature value of the glass lid T_C is calculated by Eq. (13) (Rawani et al. 2017):

$$T_m = \frac{T_{Pm} + T_C}{2} \tag{13}$$

With T_m : The average temperature. Instantaneous Efficiency η_i is given by equation (14).

$$\eta_i = \frac{Fr(W - D_0) \times L\left[S - \frac{U_L}{C}(T_{fi} - T_a)\right]}{I_b \times R_b \times W \times L} \tag{14}$$

The temperature of the fluid leaving the exchanger T_{fs} is also given by the following Eq. (15) (Rawani et al. 2017; Ghodbane et al. 2015):

$$T_{fs} = T_{fi} + \frac{Fr(W - D_0) \times L(S - \frac{U_L}{C}(T_{fi} - T_a)}{\dot{m} \times C_P} \tag{15}$$

The pressure at the outlet of the concentrator p_2 is given by Eq. (16) :

$$p_2 = p_1 \times \left(\frac{T_1}{T_2}\right)^{\frac{1-\gamma}{\gamma}} \tag{16}$$

In this equation, the temperature T_1 is at the inlet to the collectors in °C, the pressure p_1 at the inlet to the manifolds in Pa and temperature T_2 is at the outlet of the collectors in °C. The temperature T_4 was calculated using Eq. (17).

$$T_4 = T_3 \times \left(\frac{p_3}{p_4}\right)^{\frac{1-\gamma}{\gamma}} \tag{17}$$

With T_3 is the temperature at the turbine inlet in °C, p_3 is the pressure at the turbine inlet in Pa, and $p_4$is the pressure at the turbine outlet in Pa and T_4 is the temperature at the turbine outlet in °C. The pressure at the pump outlet p_2 is calculated using the following equation (18):

$$p_2 = p_1 \times \left(\frac{V_1}{V_2}\right)^{\gamma} \tag{18}$$

With V_1 : The volume of the tank filled with the fluid in m^3 ; V_2 : The volume of the fluid in m3; p_1 : Pump inlet pressure in Pa ; p_2: The pressure at the pump outlet in Pa. The pump's electrical power is calculated by Eq. (19):

$$P_{el} = \frac{P_h}{\eta} \tag{19}$$

Where P_{el} is the electrical power in watts, η is the pump efficiency and P_h is the hydraulic power. The power of an exchanger is calculated as a function of K, S and Δ_{Tm} can be written as follows using Eq. (20) (Bourret):

$$P = K \times S \times \Delta T_m \tag{20}$$

In this equation, Δ_{Tm} is the average temperature difference between the two fluids in °C, S is the exchange surface in m^2, and K is the overall heat exchange coefficient in W/°C/m2.

Fluid flow in heat exchangers and a heat condenser can occur depending on the type of heat exchanger and condenser. There are two types of fluid flow:

- counter-current flow
- co-current flow

For counter-current flow, the average temperature difference between the two fluids is given by Eq. (21) (Bakha et al. 2021) (Bakha et al. 2021):

$$\Delta T_m = \frac{\Delta T_S - \Delta T_E}{\ln\left(\frac{\Delta T_S}{\Delta T_E}\right)} \tag{21}$$

With $\Delta T_S = TC_E - Tf_S$ and $\Delta T_E = TC_S - Tf_E$, ΔT_S is the temperature difference at the outlet in °C ; ΔT_E is the temperature difference at the inlet in °C ; TC_E is the hot inlet temperature in °C, TC_S is the hot outlet temperature in °C, Tf_E is the cold inlet temperature in °C and Tf_S is the outlet cold temperature in °C.

For a co-current flow, the average temperature difference between the two fluids is given by Eq. (22).

$$\Delta T_m = \frac{\Delta T_E - \Delta T_S}{\ln\left(\frac{\Delta T_E}{\Delta T_S}\right)} \tag{22}$$

With $\Delta T_E = TC_E - Tf_E$ and $\Delta T_S = TC_S - Tf_S$

The heat exchange coefficient is calculated using Eq. (23):

$$\frac{1}{K} = \frac{1}{h_1} + \frac{1}{h_2} + \frac{e}{\lambda} + R \tag{23}$$

With $h_1$and h_2 are local heat transfer coefficients in W/m^2.K; λ : Thermal conductivity of a material in W/m.K and R : The thermal resistance of a material in m^2 °C/W.

The surface area of the exchangers is therefore given by Eq. (24):

$$A = \frac{\emptyset}{U \times \Delta T_m} \tag{24}$$

With: U = overall heat transfer coefficient (W/m². °C); A: surface area in m^2, ΔT_m The average temperature difference between the two fluids in °C; $\emptyset$: Flux in watts.

The thermal power is given by equation (25):

$$Q = m \times C_P \times \Delta T_m \tag{25}$$

2.3 Choice of equipment

Generally speaking, a parabolic trough-concentrating solar thermal power plant consists of solar collectors, a storage system, and a power block (Mills, 2018). The storage system is divided into two parts, one of which is called the cold tank and is intended for storing cold fluid, and the other is called the hot tank and is intended for storing heat. The power block consists of the turbine, condenser, and generator. The heat exchanger can be found on the power block or the storage system, depending on the type of storage used. Figure 2 shows the complete diagram of the solar thermal power plant with all the equipment.

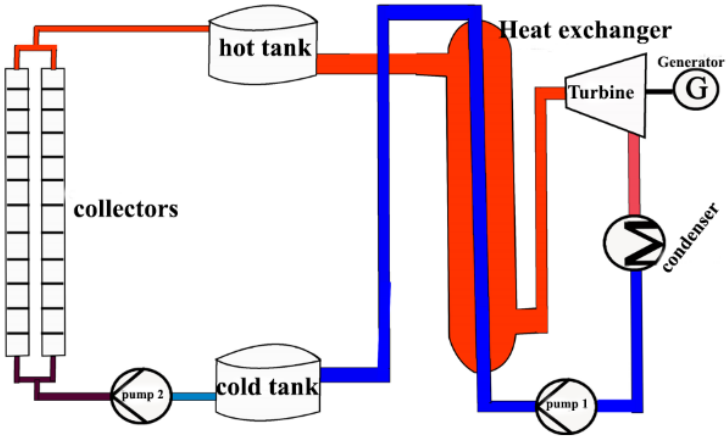

Fig. 2. Schematic diagram of the solar thermal power plant

3. DESIGN AND SIZING OF A PARABOLIC TROUGH SOLAR THERMAL POWER PLANT

The design of a parabolic trough solar thermal power plant is influenced by the technical characteristics of the selected collectors, the location of the installation, the climatic data, the storage system, the nature of the storage fluid, the pumps, the heat condenser, the heat exchanger and the turbine driving the generator. All these parameters and equipment are referred to as design conditions (Yasin and Draidi, 2016). The sizing of a parabolic trough concentrating solar thermal power plant supplying the MUTSAMA center then involves data collection, system configuration, simulation using SAM software, analysis of the results found, and the final sizing, which enables us to determine the specific system equipment suited to the power plant for producing electrical energy.

The selection of inlet and outlet temperatures is based on the heat transfer fluid (HTF), which is Therminol VP-1. Therminol VP-1 operates in two phases, the liquid phase between (12ºC -400ºC) and the vapor phase between (260ºC - 400ºC). Table 2 highlights the main characteristics of the fluid used in the solar thermal power plant. The fluid used in the storage system is Therminol VP-1.

Table 2. Fluid characteristics.

Thermal fluid	Therminol VP-1
Limit temperature of the fluid	400°C
Specific heat of the fluid at 343°C	2.436 kJ/kgºC
Maximum mass flow through the collector loop	12 kg/s
Minimum mass flow through sensor loop	1kg/s

The Solagenix (SGX-1) collectors were chosen for this project. The solar thermal power plant consists of two collectors, each made up of twelve modules. The technical characteristics of our collectors are shown in Table 3 (Perera, 2019).

Table 3. Collector characteristics.

Length of collector (m) L	100 m
Width of opening (m) Wa	5 m
Aperture area (m2) ApAp	498 m^2
Reflectivity of the mirror ρ	0.93

The choice of appropriate receivers for our energy production source supplying the MUTSAMA center is based on the UVAC3 brand receivers and Table 4 contains the technical characteristics of this receiver.

Table 4. Technical characteristics of the receiver.

Receiver outside diameter (m) D_0 (m)	0.07 m
Receiver inner diameter D_i (m)	O.066 m
Outside diameter of the absorber D_{C0} (m)	0.121 m
Inner diameter of absorberD_{Ci} (m)	0.115m
Optical efficiency	0.875
Overall heat loss coefficient for T=370°C	5.25
Dirt factor	0.964
Average value of transmission absorption product $(\tau\alpha)_b$	0.86
Interception factor, the fraction of radiation intercepted by the absorber tube γ	0.96

To store the energy, the fluid at the system's low temperature is pumped from the first tank, called the "cold tank", into the solar field or to an exchanger, heated to the high temperature, and then injected (or stored) in the second tank, called the "hot tank". To remove the energy initially charged, the hot fluid is pumped from the hot tank, sent to an exchanger (of the power unit or the process requiring heat), the stored energy is used, and then the fluid, which has returned to its low temperature, is re-injected into the cold tank (Zalba et al. 2003). Table 5 shows the technical characteristics of the storage system.

Table 5. Characteristics of the storage system.

Parameters	The value
Tank diameter	4.37 m
Tank height	12 m
Minimum height of liquid in the tank	1 m
Volume of storage tank	359.43 m^3
HTF storage fluid	Therminol VP-1
Available HTF volume	329.47m^3
Number of tanks	2
Min temperature of HTF	12°C
Maximum HTF temperature	400°C
HTF density	765.46 Kg /m^3
Hot tank heater temperature	365°C
Cold tank heater temperature	250°C
Storage time	12 Heures
Initial percentage of hot HTF	30%
Thermal efficiency of the tank	0.98

The steam turbine adapted to the parabolic trough solar thermal power plant is based on an ellipse law and isentropic efficiency (El Hefni, et al. 2014). The turbine driving the generator is brand N0.5-1.3. The technical specifications of this turbine are given in Table 6.

Table 6. Turbine parameters.

Rated power in KW	1250 KW
Rotation speed	3000 rpm
Inlet temperature	450°C

A heat exchanger is a device for transferring thermal energy from one fluid to another without mixing them. The heat flow passes through the exchange surface that separates the fluids. Based on the first principles of mass, momentum, and energy balance equations, the following phenomena are represented: transverse heat transfer, mass accumulation, thermal inertia, gravity, and pressure drop within the limits of the local flow rate (El Hefni, 2014). Table 7 shows the characteristics of the heat exchanger used for the solar thermal power plant.

Table 7. Heat exchanger characteristics.

Parameters	Values
Hot inlet temperature	400°C
Hot outlet temperature	391°C
Cold inlet temperature	42°C
Cold outlet temperature	291°C
Temperature between fluids	206.23446 °C
Power	22935.97 W

A condenser is a device whose main function is to liquefy (or condense) vapor, i.e. to change it from a gas to a liquid, through a cold surface or a heat exchanger, kept cold by the circulation of a refrigerant fluid. Table 8 shows a condenser based on the first principles of the mass and energy balance equations for the fluid and vapor, with the following phenomena represented: swelling and shrinkage phenomena, heat exchange between the vapor/fluid and the wall, and heat exchange between the external wall and the external environment (El Hefni et al. 2012).

Table 8. Characteristics of the condenser used.

Parameters	Values
Inlet temperature	20°C
Output temperature	42°C
Power	3706.7156 W
Evaporator temperature	146.98196°C

The technical characteristics of the first pump adapted to the solar thermal power plant supplying the MUTSAMA center are shown in Table 9.

Table 9. Characteristics of the pump 1.

Pump	Features
Power	0,75KW
Min flow rate	18 m^3/h
Maximum temperature	90 °C

Regarding the temperature and pressure at the inlet to the manifolds, a centrifugal pump has been chosen whose technical characteristics are compiled in Table 10.

Table 10. Characteristics of Pump 2.

Pump	Features
Power	0.55 KW
Country of origin	Turkey
Manufacturer	ERDURO
Max flow (l/min)	38 m^3/h
Min flow (l/min)	30 m^3/h
Inlet pipe diameter	DN50
Outlet pipe diameter	DN32
Rotational speed	300 rpm
Maximum temperature	350 °C
Maximum discharge height	48 m
Cost	2379.25 €

3.1 Designing a tracker to adapt the collectors to the sun

The Tinkercad tool was used to adapt the collectors of the solar thermal power plant to the path of the sun. Tinkercad is used for programming and system simulation.

Fig. 3 shows the design of a system for orienting the collectors, which must necessarily include an Arduino Uno board, two photoresistors, a servomotor, and two resistors. The operating principle of the system varies according to the value of the photoresistor. If the value of photoresistor 1 is higher than the value of photoresistor 2, the parabolic cylindrical collectors through the servomotor turn towards the photoresistor with the highest value, in other words towards the sunniest place. If the value of resistor 2 is higher than resistor 1, the collectors turn towards resistor 2 with the highest value, of course going from degree to degree.

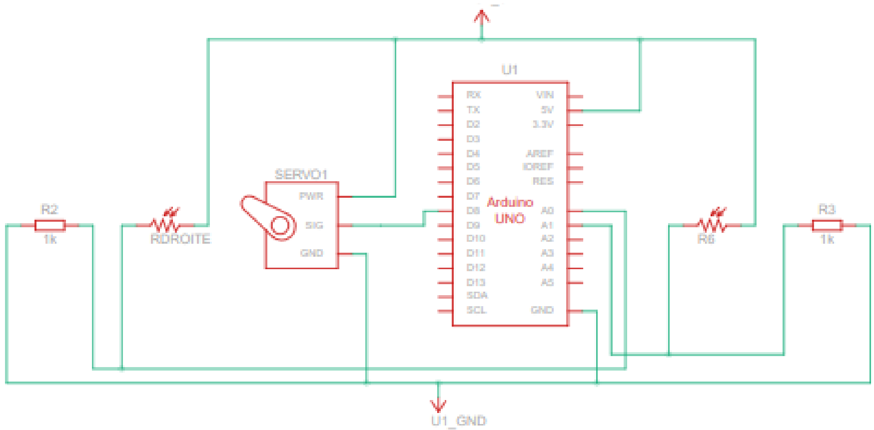

Fig. 3. Designing an orientation system

3.2 Financial study of the project

The SAM software offers several approaches for the financial analysis of renewable energy systems. The simplest is the LCOE calculator method. LCOE is a key economic factor, defined as the total life-cycle cost of a plant, expressed as a cost per unit of electricity produced over its lifetime (Asiri and Suliman, 2021).

LCOE is important for investors and researchers and can be used to compare different technologies. The LCOE calculator method in the SAM software uses four parameters to calculate the LCOE value, as expressed in the following Eq. (26):

$$\mathrm{LCOE} = \frac{\mathrm{FCR} \times \mathrm{FOC} \times \mathrm{VOC}}{\mathrm{AEP}} + \mathrm{VOC} \tag{26}$$

Where TCC: capital cost ($)

FOC: represents the annual fixed operating cost ($),

COV: represents the operating cost per unit of electricity produced ($/kWh),

AEP: represents the electricity produced annually (kWh) and

FCR: stands for fixed charge rate, which is the return per amount of investment required to cover the investment costs (ETSAP and IRENA, 2012).

4. PRESENTATION AND DISCUSSION OF THE RESULTS

In this part, we show the results obtained after the simulation with the SAM software and those obtained during the dimensioning of the solar thermal power plant supplying the MUTSAMA center. The analysis of these two results obtained is made on the second point of discussion of the results.

4.1 Presentation of the results

The solar thermal plant supplying the MUTSAMA center consists of two collectors, each formed by 12 modules. The heat exchanger adapted to the plant has a nominal power of 22935.97 kW, the air condenser has a power of 3706.7156 kW and a turbine with a power equal to 1250 kW operating at a temperature of 450°C. The results obtained by simulation using the SAM tool are shown in Table 11 and summarize the results for the solar thermal power plant supplying the MUTSAMA center.

Table 11. Summary of results for the solar thermal power plant.

Parameters	Values
Annual AC Energy in Year 1	325939kWh-e
Gross-to-net conversion	40%
Annual Freeze Protection	370383kWh-e
Annual Field Freeze Protection	1198kWh-e
Power cycle gross electrical output	814878kWh-e
Annual Water Usage	322 m^3
Capacity factor	8.3 %.
Net capital cost	$ 4 247848
LCOE Levelized cost of energy real	42.01 $/kWh
LCOE Levelized cost of energy nominal	55.93$/kWh

Fig. 4 shows the power generated by the solar thermal power plant over a year as a function of operating hours.

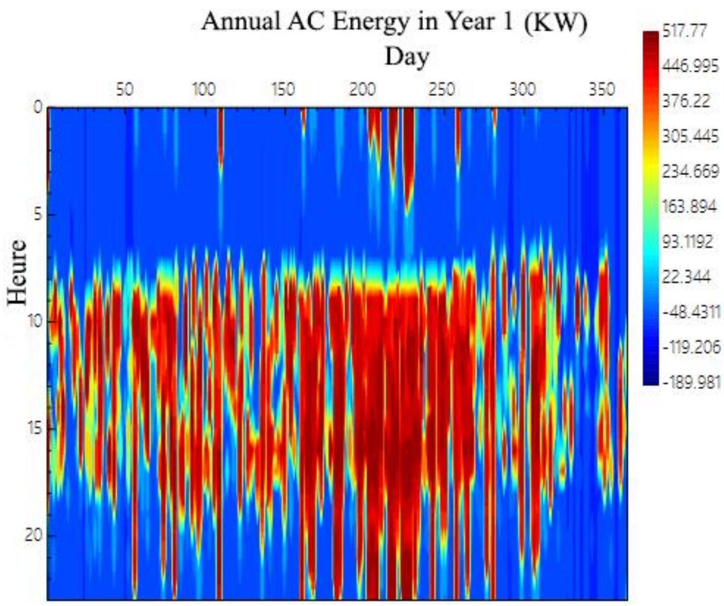

Fig.4. The power of the plant.

The energy produced by the solar thermal power station supplying the MUTSAMA center changes according to the month of the year, and Fig. 5 shows the electricity generated monthly.

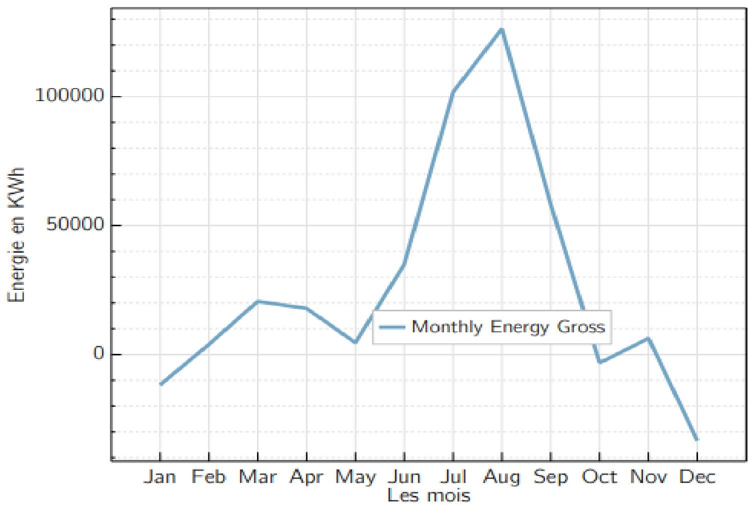

Fig.5. Energy produced by the solar thermal power plant.

The storage system of the solar thermal power plant supplying the MUTSAMA center consists of two tanks, each 4.37 m in diameter and 12 m high. Fig. 6 shows the variation in temperature of the cold tank and the hot tank of a storage system supplying the MUTSAMA center.

4.2 Discussion of results

The solar thermal power plant supplying the MUTSAMA center produces an output of 0.5 MW. Fig. 7 shows a comparison of the results obtained using the SAM tool. The solar thermal plant can then produce a power equal to 0.517 MW as shown in Fig. 4. Note that this power is at the margin since the nominal power of the turbine used is 1.250 MW.

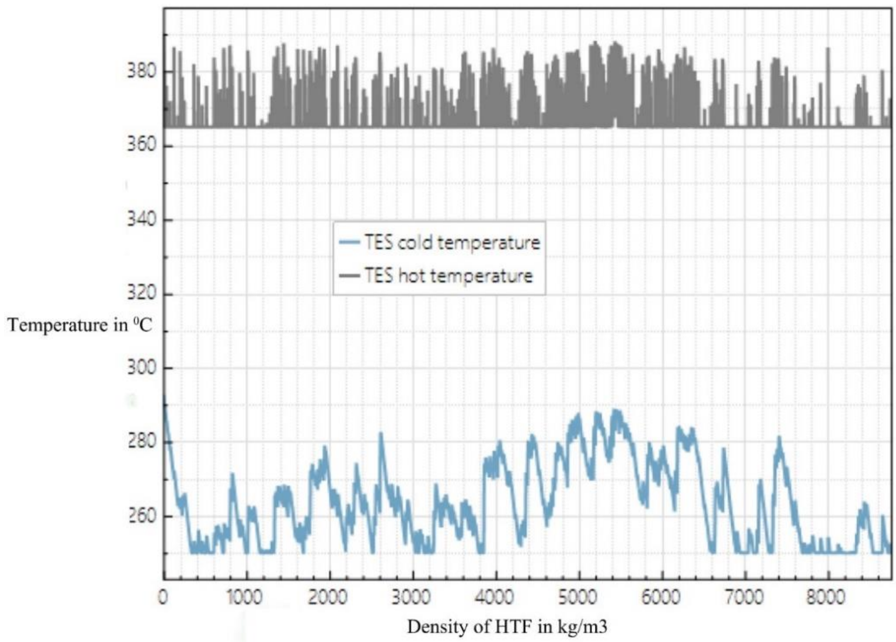

Fig.6. Temperature variation in the storage system.

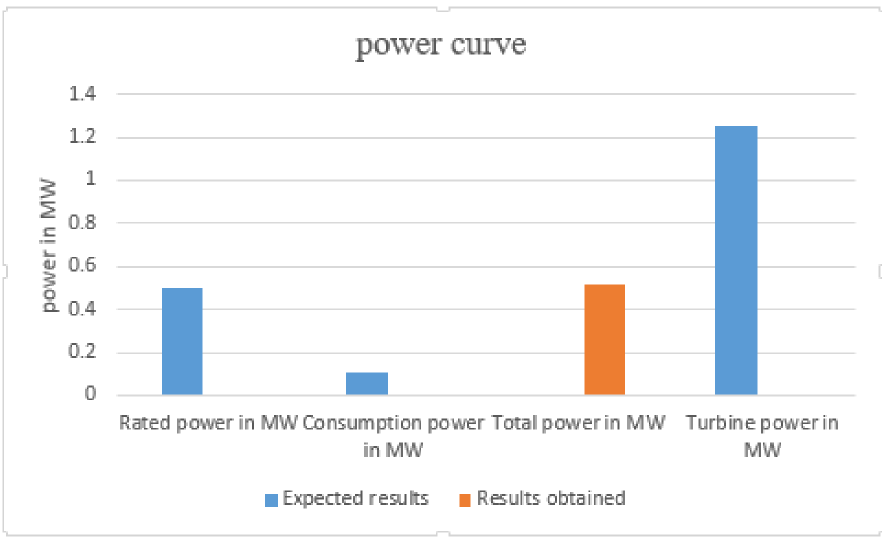

Fig.7. Comparison of power consumption.

Fig. 8 shows the variation in the consumption of electrical appliances at the MUTSAMA center. Finally, it can be seen that the power of all the appliances consuming electrical current does not exceed 103.755 kW out of 500 kW produced by the power station, and daily energy is evaluated at 835,290 kWh. Note that the appliance that consumes the most power does not exceed 44 kW for an operating period of 6 hours a day.

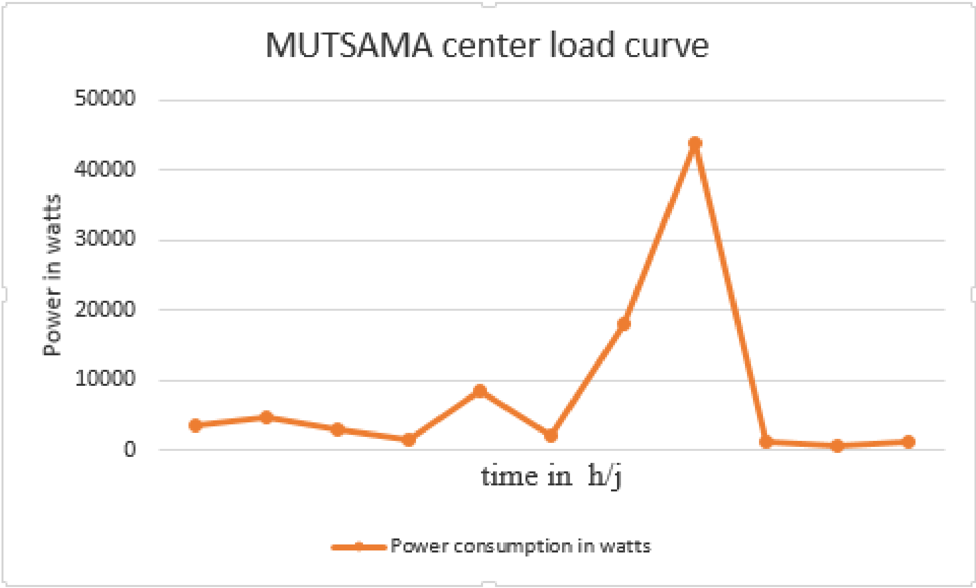

Fig.8. MUTSAMA center load curve.

The annual energy requirements of the MUTSAMA center are estimated at 300704.4 KWh. Fig. 9 shows an energy comparison of the results obtained after the simulation. It can be seen that the energy required at the MUTSAMA center is lower than that obtained, at around 325935 KWh.

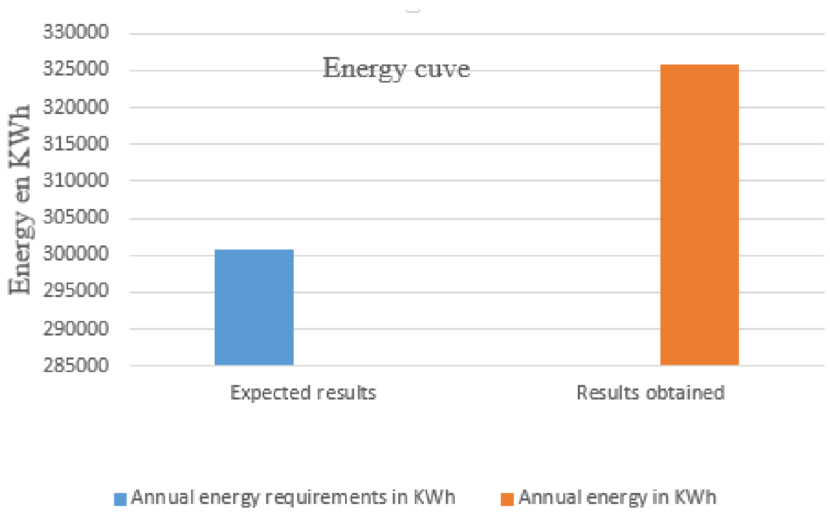

Fig. 9. Energy comparison.

Fig. 10 shows the temperature variation of the fluid in the storage system and it can be seen that the results obtained in Fig. 6 are higher than those presented in the storage system design for the cold tank. The minimum temperature is 250°C and the maximum temperature is 290°C, compared with 12°C and 250°C, as shown in Table 5. For the hot tank, the results obtained in Fig. 6 are similar to those presented in Table 5.

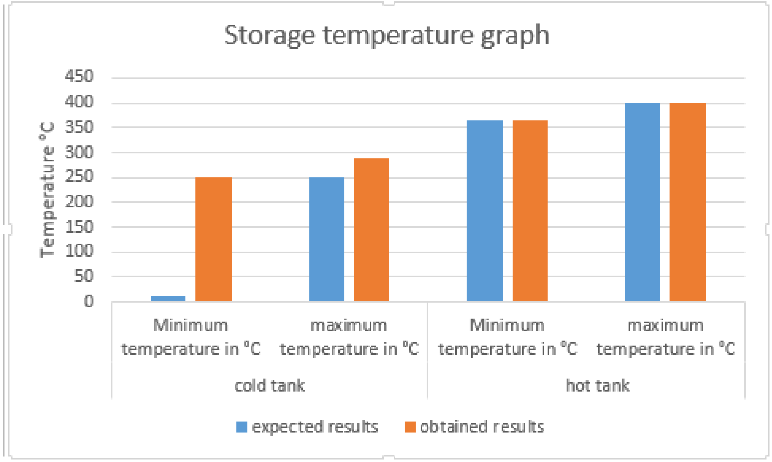

Fig. 11: The storage temperature curve.

CONCLUSION

During this research, answers were found to the major problem of resolving the shortage of electricity and increasing the performance of the Mutsama center by helping to satisfy its customers, by meeting the need for electrical energy, which is the driving force behind development. The general objective of this work is to design and propose the construction of a solar thermal power plant to ensure the smooth running of the MUTSAMA center. To answer the research question, an analysis of the meteorological conditions, the sizing, and the thermal and economic performance of the solar thermal power plant was carried out using SAM software. The solar thermal power plant supplying the MUTSAMA center has a capacity of 0.5 MW and operates for 12 hours in the absence of sunshine. The solar thermal plant consists of two parabolic trough collectors, each formed by twelve modules, with a heat exchanger rated at 22935.97 W, an air heat condenser rated at 3706.7156 W, and a turbine rated at 1250 kW operating at a temperature of 450°C. The fluid used in the energy storage system is Therminol VP-1. To maximize the power and thermal energy of the solar thermal power plant, the parabolic trough collectors were aligned with the path of the sun. The collector orientation system was created and simulated using Tinkercad, and the various main characteristics of the plant were updated using Matlab software. The solar thermal power plant supplying the MUTSAMA center is showing good results, spending even more than expected at the end of the year, and can produce a power of 517.17 kW with an interval of 10 to 16 hours producing maximum power. The plant can also give an annual energy of 325939 kWh with a capacity factor of 8.3 %. A simple analysis was carried out to estimate the plant's real discounted energy cost (LCOE), which is in the order of $42.01 / kWh.

REFERENCES

Amin TE, Roghayeh G, Fatemeh R, Fatollah P. Evaluation of Nanoparticle Shape Effect on a Nanofluid Based Flat-Plate Solar Collector Efficiency. Energy Exploration & Exploitation. 2015;33(5):659-676. doi:10.1260/0144-5987.33.5.659

Asiri, I. M., AL-Yahya, S. (2021). Design and Analysis of Parabolic Trough Collector Power Plant in Saudi Arabia. International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 12(2), 12A2F, 1-13. http://TUENGR.COM/V12/12A2F.pdf DOI: 10.14456/ITJEMAST.2021.27

Bakha, W., Harnane, Y., & Bouzid, S. (2021). Calcul Du Refroidisseur Des Fumées D'un Incinérateur Industriel BIOWAS.

Bashir, A.A.A. and Özbey, M. (2022). *Modelling and analysis of an 80-MW parabolic trough concentrated solar power plant in Sudan*. Clean Energy, vol. 6(3), pp. 512-527. doi: 10.1093/ce/zkac032.

Bourret, B. *Les échangeurs de chaleur*, INSA Toulouse Civil Engineering Department.

El Hefni, B. and Bouskela, D. (2014). Dynamic modeling of concentrated solar power plants with the ThermoSysPro library, Proceedings of the 10th International Modelica Conference; March 10-12; 2014; Lund; Sweden. DOI:10.3384/ecp140961113

El Hefni, B., Bouskela, D. and Gentilini, D. (2012). Dynamic modelling of a Condenser/Water Heater with the Thermo-SysPro Library. Proceedings of the 9th International MODELICA Conference; September 3-5; 2012; Munich; Germany DOI: 10.3384/ecp12076745.

ETSAP and IRENA. (2012). Water desalination using renewable energy, IEA-ETSAP and IRENA Technology Brief I12 – March 2012.

Ghodbane, M., Boumeddane, B., Largot, S. and et Heniat, N.E. (2015). Simulation numérique d'un concentrateur cylindro-parabolique en El Oued, Algérie, *International Journal of Scientific Research & Engineering Technology (IJSET*), ISSN: 2356-5608. Vol. 3(2), p. 68-74.

Hamilton, W.T., Newman, A.M., Wagner, M.J. and Braun, R.J. (2020). Off-design performance of molten salt-driven Rankine cycles and its impact on the optimal dispatch of concentrating solar power systems. *Energy Conversion and Management*, vol. 220, 113025, DOI: 10.1016/j.enconman.2020.113025.

Irshad, M., Yadav, A., Singh, R. and Kumar, A. (2018). Mathematical modelling and performance analysis of single pass flat plate solar collector, *IOP Conf. Ser.: Mater. Sci. Eng.*, 404, 012051, DOI: 10.1088/1757-899X/404/1/012051.

Mills, S. (2018). Combining solar power with coal-fired power plants, or cofiring natural gas. *Clean Energy*, vol. 2, n° 1, p. 1-9.

Moya, E. Z. (2012). Parabolic-trough concentrating solar power (CSP) systems, *in Concentrating solar power technology*, p. 197‑239. DOI:10.1533/9780857096173.2.197

Perera, G. A. S. (2019). Feasibility of concentrated solar thermal power plant for grid connected system in Sri Lanka (Doctoral dissertation).

Rawani, A., Sharma, S.P. and Singh, K.D.P. (2017). *Enhancement in Performance of Parabolic Trough Collector with Serrated Twisted-tape Inserts*. International Journal of Thermodynamics. Vol. 20 (2), pp. 111-119, 2017. doi: 10.5541/ijot.5000210005.

Remili, A. and Saadi, H. (2022). *Intégration de système photovoltaïque aux pivots d'irrigation de Type ANABIB*, PhD Thesis, faculté des sciences et de la technologie univ BBA (Algeria).

Yasin, A.M. and Draidi, O.I. (2016). *Design and sizing characteristics of a solar thermal power plant with parabolic trough collectors for a typical site in Palestine*. Energy and Environmental Protection in Sustainable Development, Hebron – Palestine, April 2016, ICEEP IV, vol. 1.

Zalba, B., Marín, J. M., Cabeza, L. F. and Mehling, H. (2003). Review on thermal energy storage with phase change: materials, heat transfer analysis, and applications, *Applied thermal engineering*, vol. 23(3), p. 251-283. DOI:10.1016/S1359-4311(02)00192-8

Zibouche, S. and Mekaoui, H. (2021). *Etude, conception et réalisation d'un récepteur trapézoïdal pour un système solaire à concentration linéaire de Fresnel*. PhD Thesis, Université Mouloud Mammeri Tizi Ouzou (Ageria).

Websites

"BTKF-K 40-160 (1500) high temperature centrifugal pump without motor - Sealing.com.ua", https://sealing.com.ua/fr/pumps/console-pumps/nasos-dlya-garyachogo-masla-btkf-k-40-160-1500-/, Accessed: 20 June 2023.

"Surface centrifugal pump 380V - 0.75kW - 1"1/2 – Pompe & Moteur ", https://www.pompe-moteur.fr/3217-pompe-de-surface-centrifuge-tri-230-400v-075kw-11-2-pompe-centrifuge-3701000141874.html, Accessed: 16 July 2023.

Small steam turbine Power Plant 100 Kw 500 Kw 1250 KW 1500 KW 1600 KW 1800 KW 3000 kW », Made-in-China.com, https://fr.made-in-china.com/co_grindingballsupplier/product_Small-Power-Plant-Steam-Turbine-100-Kw-500-Kw-1250-Kw-1500-Kw-1600-Kw-1800-Kw-3000-Kw_rgoyoyhsg.html, Accessed: 20 June 2023.

THERMINOL®* VP-1 - FRAGOL, https://www.fragol.de/en/heat-transfer-fluids/heat-transfer-fluids/products/therminolr-vp-1.html, Accessed: 7 November 2023.