Absorbed Solar Energy in Parabolic trough Collector in Alexandria, Egypt

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***Abstract*— The huge amount of solar energy available on Earth's surface has heightened awareness in concentrating solar power. This paper focuses on thermal power generation using parabolic trough collector, which concentrates the power from the sun and converts it to thermal energy, which is used in thermal process. Steam turbine followed by generator is used to convert thermal energy to mechanical energy and then to electrical energy. To be able to achieve the desired power from thermal using parabolic trough the direct normal irradiance must be known. Absorbed solar energy for four seasons is calculated to compare the amount of heat in each season.**

***Keywords*— Renewable energy, Solar energy, Concentrating solar power; Parabolic trough collector**

I. INTRODUCTION

Historically, energy use has varied over time with the level of economic growth, weather conditions, and energy prices, among many other aspects. Starting in the late 1980s and continuing all the way through 2000s, energy consumption increased with a decrease in energy prices and strong economic growth but recently, energy prices escalated and the potential for more energy conservation received increased attention. As a result, Egypt is now struggling to meet its own energy needs. It can be concluded that with the high demand for oil, which won't be covered for a long period of time, along with the rapid growth rate in energy consumption and the depletion of fossil oil resources, its prices will keep escalating. One of the main solutions to this dilemma is to exploit the enormous potentials of renewable energies which are constantly available and will never run out, by using manifold opportunities for increasing the energy efficiency with new technological solutions.

Several renewable energy technologies made significant penetrations in the energy market. These technologies include solar (solar thermal and photovoltaic) which comes either directly or indirectly from the sun. The increased interest and rapid growth of these applications have been stimulated by a significant drop in cost over the previous decades, and a remarkable technical improvement which increased their efficiency, reliability, longevity as well. Other advantages of renewable energy applications are their modularity, large solar potential in developing countries, favorable land-use features and ease of decommissioning.

Energy from the sun travels to the earth in the form of electromagnetic radiation like radio waves, but in a different frequency range. The annual average total solar radiation over Egypt ranges from about 1950 $kWh/m^2/year$ on the Mediterranean coast to more than 2600 $kWh/m^2/year$ in Upper Egypt. About 90% of the Egyptian territory have an average total radiation greater than 2200 $kWh/m^2/year$ [1].

Concentrated solar power (CSP) is the most likely candidate for providing the majority of this renewable energy, because it is amongst the most cost-effective renewable electricity technologies and because its supply is not restricted if the energy generated is transported from the world's solar belt to the population centers [2]. Among CSP technologies parabolic troughs, by far the most mature technology, have been demonstrated in the field. Today, these systems achieve annual solar-to-electricity efficiencies of about 10–15%, with the aim that they should reach about 18% in the medium term.

The objective of this paper is to calculate the amount of solar irradiance in Alexandria, Egypt and to calculate the max amount of absorbed solar energy to be used in parabolic trough calculations.

II. SYSTEM DESCRIPTION

Solar thermal power plants are systems for power and electricity generation by employing solar radiation as a thermal source. A complete schematic diagram for the parabolic trough collector with heat exchanger (HE) will be found in figure 1[3].

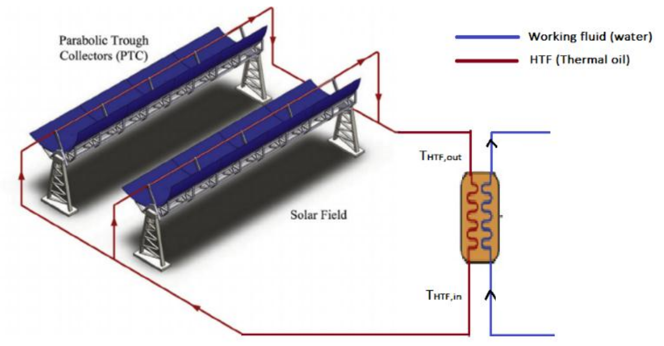

Fig.1. Schematic Diagram of PTC connected with HE

A case study was made for Egypt where sunshine direct solar radiation is varying, through the year, from 1950 kWh/m^2 to 2600 kWh/m^2. The collector is of LS-2 type and of 5m width and 50m long for a single collector, solar collector assembly is shown in figure 2. The HTF fluid used is Therminol Vp-1 where it has good thermal properties and it has a good temperature range [4]. This HTF is used in many different power plants driven by parabolic trough solar collector [5]. The solar heat is absorbed by the parabolic trough solar collector where the HTF is heated, and then the heated oil will be used in a heat exchanger to heat up the working fluid (usually water).

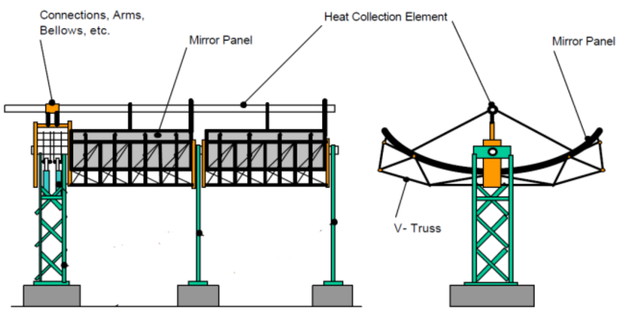

Fig.2. Solar Collector Assembly

A. *Solar Field*

Differential equation for the HTF collector outlet temperature is obtained after energy balance on solar field. The energy equation analysis for the system in this section is based on the equations presented in [4].

$$\rho_{HTF} C_{HTF} V_{col} \frac{dT_{HTF,out}(t)}{dt} = Q_{gain}(t) + L_{col}\left[q_{abs}(t) - q_{amb}(t)\right] \quad (1)$$

The energy gained by the HTF is given by:

$$Q_{gain}(t) = \rho_{HTF} C_{HTF} \dot{V}_{HTF} T_{HTF,in}(t) - \rho_{HTF} C_{HTF} \dot{V}_{HTF} T_{HTF,out}(t) \quad (2)$$

the volume contained in the solar field

$$V_{col} = \frac{\pi}{4} D^2_{abs} L_{loop} . n_{loop} \quad (3)$$

The overall heat transfer loss to the environment per unit length, $q_{amb}(t)$ is given by:

$$q_{amb}(t) = h_{amb} A'_{abs,surf}\left[T_{HTF,out}(t) - T_{amb}(t)\right] \quad (4)$$

III ABSORBED SOLAR ENERGY

When solar radiation enters the earth's atmosphere, a part of the incident energy is removed by scattering in the atmosphere which is called diffuse radiation, another part of the incident energy is removed in the earth's atmosphere by absorption of radiation in the solar energy. The remaining part of the solar radiation that enters the earth's atmosphere without having been scattered by the atmosphere or having been absorbed, is called beam radiation. Beam radiation incident on a plane normal to the radiation is called the direct normal radiation.

The component of the solar beam radiation vector may be found by multiplying the amount of solar beam radiation with the cosine of the angle of incidence. Therefore, a relationship for the angle of incidence is needed [4].

$$\cos\theta = (\cos^2\theta_z + \cos^2\delta \sin^2\omega)^{\frac{1}{2}} \quad (5)$$

The zenith angle, θ_z, is the angle between the vertical (the local zenith) and the line to the sun in figure 3 [6]. The zenith angle is within a range of $0° \le \theta_z \le 90°$. The zenith angle is given by [4]:

$$\cos\theta_z = \cos\emptyset \cos\delta \cos\omega + \sin\emptyset \sin\delta \quad (6)$$

ϕ is the latitude which gives the position of the collector north or south from the earth's equator. Latitude of Alexandria is $\phi = 31.2^{\circ}$ N.

The declination, δ, is the angular position of the sun at solar noon with respect to the plane of the equator.

$$\delta = 23.45 \sin\left[\frac{360}{365}(d_n + 284)\right] \quad (7)$$

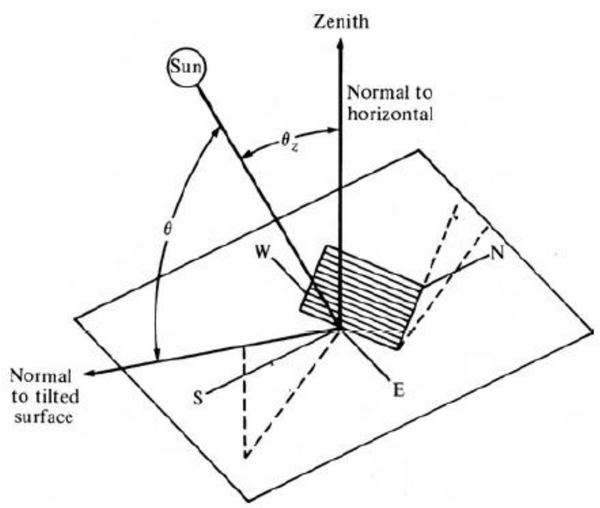

Fig.3. Zenith angle θ_z, angle of incidence θ

The hour angle, ω, is the angle through which the Earth has rotated since solar noon. Since the Earth rotates at $360^{\circ}/24$ h = $15^{\circ}\ h^{-1}$ the hour angle is given by [4]:

$$\omega = (15^{\circ}\ h^{-1})(t_{solar} - 12h) \qquad (8)$$

an expression for the absorbed solar energy is obtained [4]:

$$q_{abs}(t) = G_{bn} \cos\theta \qquad (9)$$

IV RESULTS

Figure 4 shows the comparison of the direct normal radiation vs. time through the year in Alexandria in the beginning of each season. The first line shows the measurement for an almost clear spring day, the second line shows the measurements for a completely clear (no clouds) summer day, the third one shows the beam radiation during a fall day and finally the fourth one for a spring day. Notice the direct normal radiation is not constant between sunrise and sunset because the effects of the atmosphere in scattering and absorbing radiation are variable with time as atmospheric conditions.

the declination angle is within a range of $-23.45° \le \delta \le 23.45°$. A plot of the declination ,δ, vs. month is shown in figure 5.

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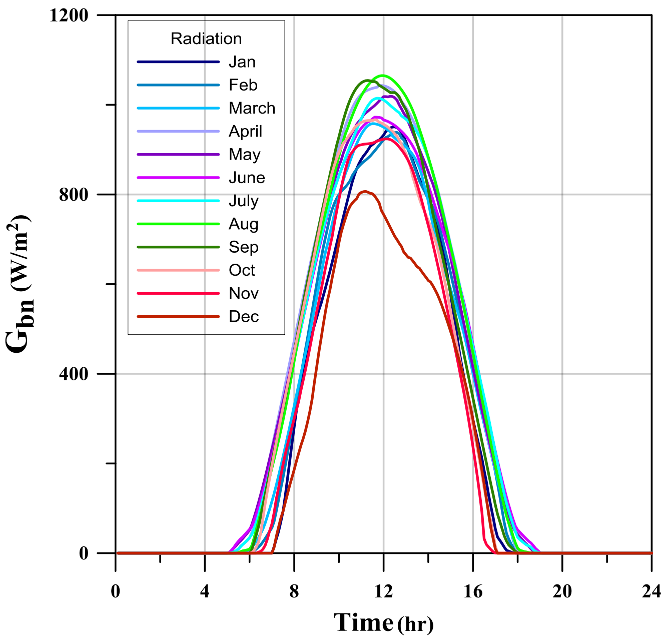

Fig.4. Direct Normal Radiation Vs. Time (hr.)

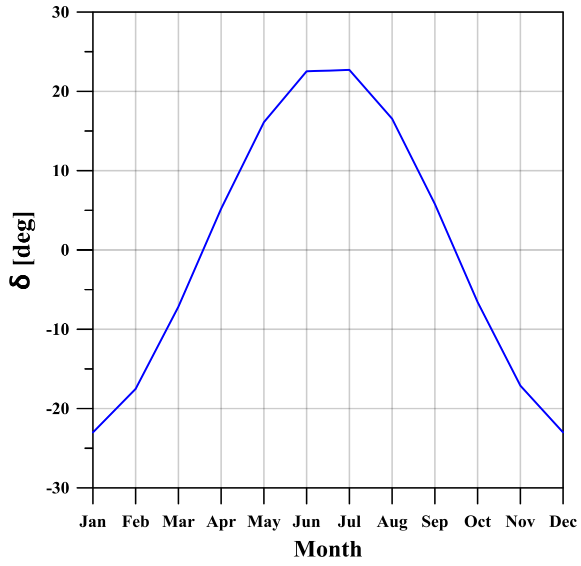

Fig.5. Declination vs. Month

As long as the intensity of direct normal radiation changes with time along the day, the absorbed solar energy is also varying along the day related to direct normal radiation. The comparison of absorbed solar energy along the day vs time in four seasons in figure 6, one day in each season was selected

Results shows that the Alexandria's weather is very clean in most days of the year, the sunny days in the year is in range of 325 day, and it is suitable enough for stablishing solar projects especially parabolic trough collector due to its reliability and it's considered as a mature technology and cost efficient in compare to other technologies.

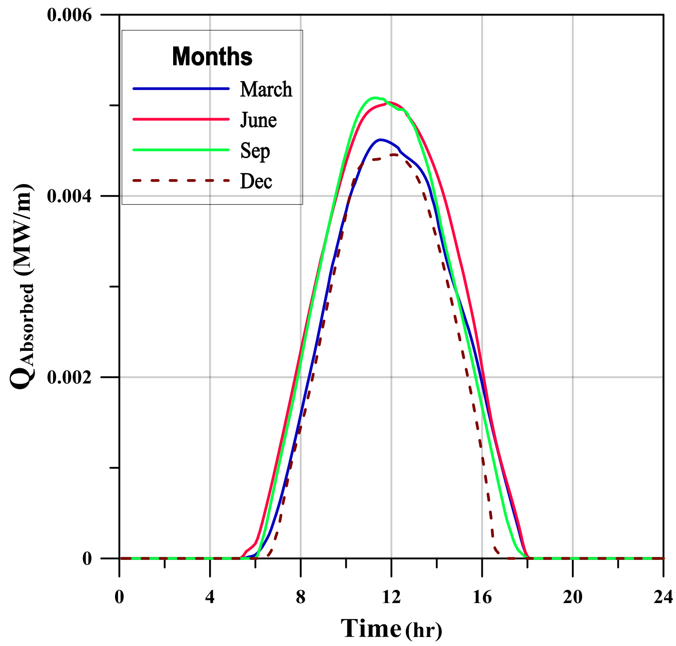

Fig.6. Absorbed solar energy vs. time through the four seasons

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III. CONCLUSION

In this paper, the study of using parabolic trough collectors in Alexandria's weather was clearly illustrated. The absorbed solar energy for the four seasons was calculated to show that the number of sunny hours in the day ranges from 8 to 10 hours and the absorbed energy ranges from .0042 MW/m in winter to .005 MW/m in summer.

IV. NOMENCLATURE

Symbol	Subject	Unit
$A'_{abs,surf}$	Surface area of absorber per unit length	m
D_{abs}	Inner diameter of the absorber pipe	m
d_n	Number of the day in the year	--
G_{bn}	Direct normal irradiance	W/m^2
h_{amb}	Overall heat transfer coefficient	W/m^2 K
L_{col}	Length of the collector	m
L_{Loop}	Total length in one loop	m
n_{loop}	Number of loops in the solar field	--
Q_{gain}	Energy gained by the Heat transfer fluid per unit length	W/m
q_{amb}	Overall heat transfer loss to the environment per unit length	W/m
q_{abs}	Absorbed solar energy per unit length	W/m
$T_{HTF,Out}$	Heat transfer fluid outlet temperature.	˚C
V_{col}	Volume of the collector	m^3
$\dot{V}_{HTF}$	Volume flow rate of heat transfer fluid	m^3/s

V. ABBREVIATIONS

HTF	Heat transfer fluid
CSP	Concentrating solar power
HE	Heat exchanger

VI. REFERENCES

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