A REVIEW OF SOLAR THERMAL ELECTRICITY PRODUCTION

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ABSTRACT
Problems related to the decrease of fossil energy, especially in its liquid form (oil) or gas (natural gas) and the stocks of uranium available for nuclear energy are now decrease. The burning of fossil resources causes the release of carbon dioxide (CO2) that accumulates in the atmosphere a greenhouse gas (GHG) which would change the balance of global climate. So that many research are interested for renewable energy in their different forms: wind, solar thermal, photovoltaic, hydro, biomass and geothermal, which now represent only 7.5% total world energy. The solar rays are an inexhaustible source of energy throughout the world. It is used in various applications as a source of clean and renewable energy. Indeed it is used in Desalination, air conditioning, cooking. Among this solar thermal applications include electricity generation. This paper reviews the electricity generation from solar thermal energy based specially on solar heated Rrankine cycle. Examples of solar thermal power plants will be discussed in this paper.

Keywords: *Electricity production, solar thermal energy, Rankine Cycle, solar thermal plant*

1. INTRODUCTION

Under Kyoto agreement, by 2012, industrialized countries committed themselves to reducing their emissions of greenhouse gases by 5.2% on average between 2008 and 2012 compared to 1990. According to most forecasters, the consumption of commercial primary energy will double by 2030 and triple the horizon of 2050 [1].

Renewable energy supplied by solar, wind, heat waterfalls, tides or plant growth do not generate waste or gases emissions. They participate in the fight against the greenhouse effect and releases CO2 into the atmosphere. They facilitate the sustainable management of local resources, generate jobs. Solar (solar photovoltaic, solar thermal), hydro, wind, biomass, geothermal energy are inexhaustible flow compared to stock exhaustible energy derived from fossil fuel resources being scarce petroleum, coal, lignite , natural gas).

With recent technological advances in Renewable energy (RE), solar energy may be gaining ground compared to fossil fuels for its Environmental benefits through reduced use of fossil fuels, reducing problems associated with pollution and global warming, resulting in cleaner air and cleaner water. In addition solar energy presents financial benefits by reducing electricity bills, we can also earn by selling more electricity to the local authority energy management. The other good thing about the use of solar energy is that its uses are so varied that most developed countries will have access to either technology thermal power generation according to their economic and industrial capacity.

Many developed countries have also taken this important and give a great interest in renewable energy in particular solar energy is a highly profitable and growing. Isolated communities can be supplied with electricity power by eliminating the steps for installing cables, long and costly implementation and maintenance. Desert may become strategic solar deposits. Countries rich in sunlight may choose at their leisure between the simple sale of solar electricity, or transfer technology.

Tunisia is a non-oil producing country. Its domestic recoverable energy resources are limited and don't satisfy the demands of increasing population and economic growth [2]. The electricity is produced from power plants that use fossil fuels (heavy fuel oil and diesel fuels). Tunisia set a policy framework to promote energy conservation, environmental security and encourages the use of renewable energy technologies. The Electromechanical Systems laboratory of the National Engineering School of Sfax – Tunisia develop an autonomous environmental friendly System of Electricity Production by a Mechanical Power Generation based on Solar-Heated HFC -134a Rankine Cycles. This installation will be tested in Gafsa-Tunisia located in south-Western Tunisia, 350 kilometres from the capital which have a very high natural potential of solar energy availability, with more than 3500 hours of sunshine per year.

2. ORGANIC RANKINE CYCLE

The organic Rankine cycle (ORC) is generally used in heat recovery applications at low temperature. Many researches have been performed for the study and the choice of the appropriate working fluids.
ORC Technology is similar to the steam cycles technology: a working fluid is heated to vaporization by solar thermal energy. The steam is then expanded in a turbine to produce mechanical energy and then electricity through a generator. This steam is then condensed to close the thermodynamic cycle. The difference between a conventional cycle and an organic cycle is that the working fluid in organic cycle is an organic fluid. The Rankine cycle is the most commonly used cycle in conventional power plants. It is the duty cycle used for all steam engines since the beginning of the industrial era. The working fluid is pumped to a storage tank where it is evaporated. Then it will be condensed while passing through electricity generator turbine.

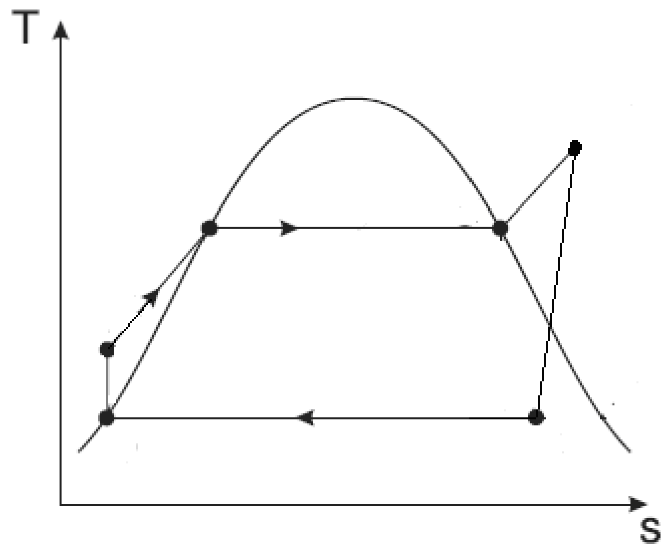

Figure 1: *ideal Rankine cycle*

3. WORKING FLUID

Many researches have been performed for the study and the choice of the appropriate working fluids [3-7]. The appropriate fluid is one that offers the most system efficiency. It is selected depending on the critical pressure and the boiling temperature and mechanical work provided [6-8]. However, the thermodynamic parameters of the fluid are not the only criteria for selection. In fact the Montreal Protocol, an international treaty to protect the ozone layer and the Regulatory CE 2037/2000 prohibit the use of substances that can threaten the ozone layer [6].
G. Kosmadakis et al. [9] have conducted a comparative study of 33 working fluids. In this study, they showed that fluid R245fa appears satisfactory for operation at high temperature. This fluid is consistent with all environmental regulations. They showed that the choice of fluid R245fa is the best compromise between the different criteria, the most important are the thermal efficiency, power output and environmental performance. This study also showed that the refrigerant R134a is best used for the Rankine cycle operating at low temperature. Other studies have shown that this fluid is most suitable for such application since it fulfills all the criteria of choice. R134a in fact appears as the most appropriate fluid for solar applications from many experimental studies have demonstrated the effectiveness of this fluid for application based on ORC [9-14]. Among 20 studied refrigerant Tchanche Fankam Bertrand et al. [10] have concluded that R134a is the most appropriate for small scale solar applications. R152a, R600a, R600 and R290 offer attractive performance, but their use requires safety precautions because of their flammability.

4. SOLAR THERMAL POWER TECHNOLOGY

Concentrating solar power plants are a relatively new technology, with significant development potential. They offer an opportunity to sunny countries. The most promising areas for the implementation of these technologies include South western U.S., South America, north Africa, the Mediterranean and Middle East, the desert of India and Pakistan, Australia, etc..
Concentrating solar thermal power plant (STP) technologies is based on four basic elements: concentrator, receiver, transport-storage, and a generator. The collector captures and concentrates solar radiation, which is then delivered to

the receiver. The receiver absorbs the concentrated sunlight, transferring its heat energy to a working fluid which would be synthetic oil. The transport-storage system passes the fluid from the receiver to the generator. As solar thermal power conversion systems, Rankine, Brayton, Combined or Stirling cycles have been successfully demonstrated [15]. There are four types of power plants in operation or under development: (i) parabolic trough solar power plants (ii) solar tower plants (iii) dish-stirling systems (iv) Fresnel central reflector. In this paper we are interested in solar thermal power plants.

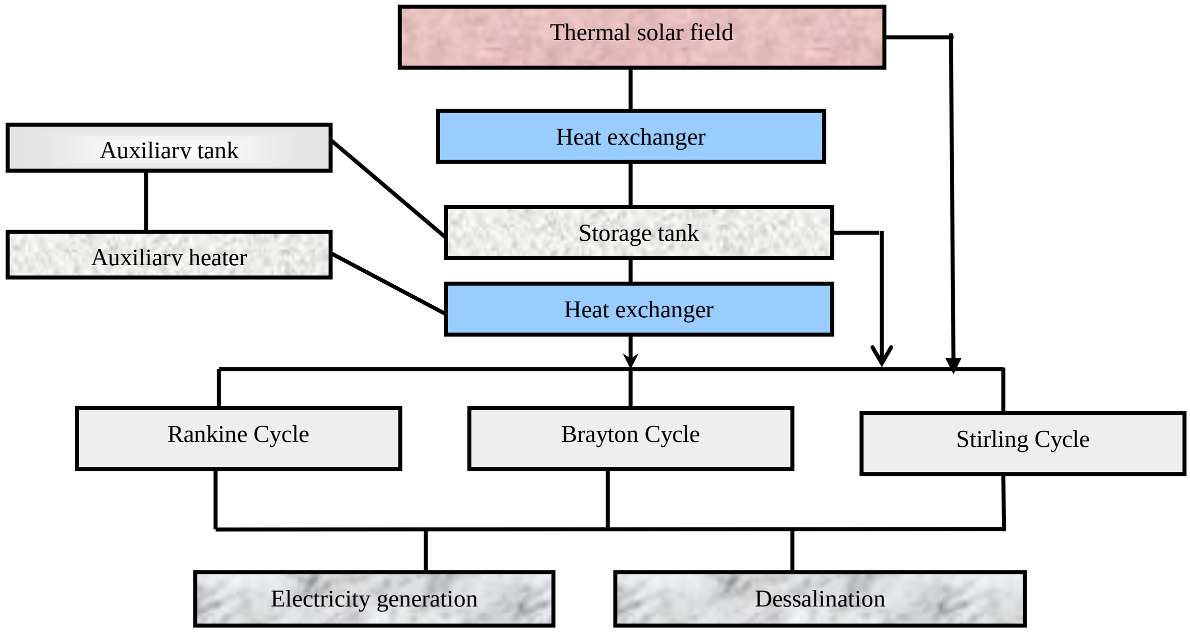

Figure 2: *solar thermal technology*

Many projects of electricity generation by solar thermal energy are realized. Among these projects are mentioned according to their production capacity:

4.1 solar energy generating systems in California

The total capacity of these power plants is 354 MW. Solar Energy Generating Systems (SEGS) is the largest installation of solar energy in the world. It consists of nine solar plants in the Mojave Desert in California, where sunshine is one of the best available in the United States. SEGS I-II (44 MW) are located in Daggett SEGS III-VII (150 MW) are located at Kramer Junction, and SEGS VIII-IX (160 MW) are at Harper Lake. Next Energy Resources operates and partially owns the plants located at Kramer Junction and Harper Lake. The plants have an installed capacity of 354 MW, which in fact in 2005 the largest solar installation, all types, in the world. The average gross average power for all nine SEGS plants is about 75 MW, a load factor of 21%. In addition, the turbines can be used at night by burning natural gas [15].

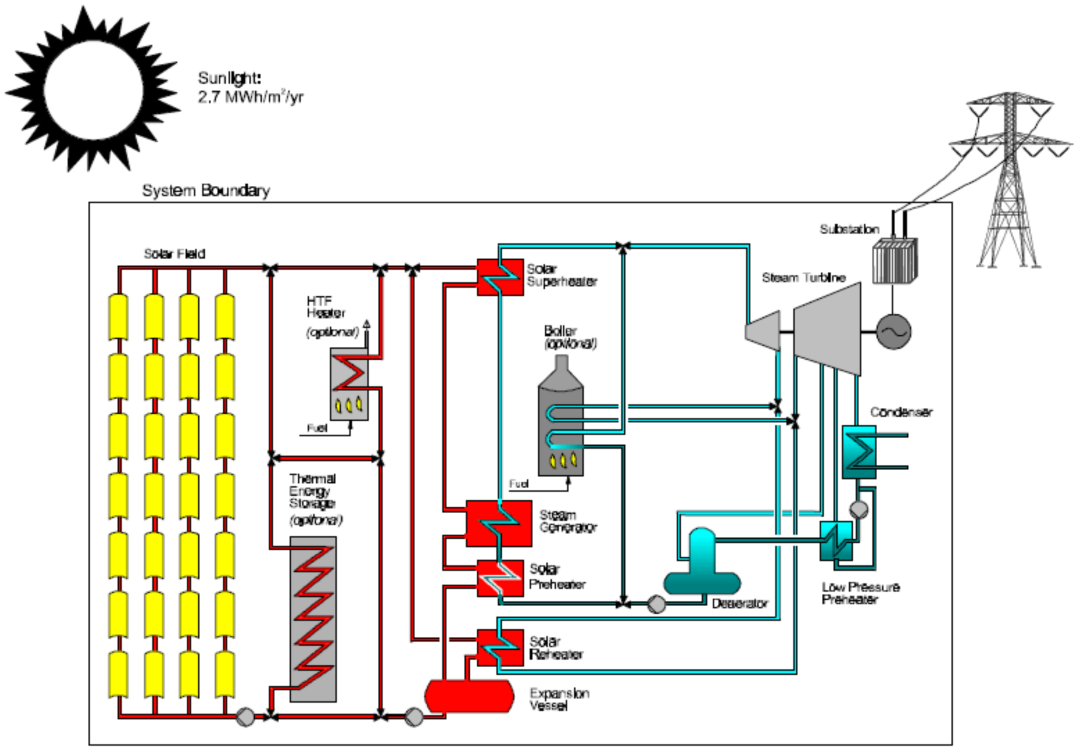

Figure 3: *Scheme of Solar energy generating system in California* [16].

The plants are constituted a total of 936,384 mirrors and cover more than 6.5 km^2. Aligned, the parabolic mirrors extend over 370 km. The plant uses solar thermal technology via parabolic trough, complemented by natural gas to produce electricity. 90% of electricity is produced by sunlight. Natural gas is used only when sunlight is insufficient to meet the demand of Southern California Edison, the electricity distributor in Southern California [17].

4.2 Solnova solar troughs plants in Spain

Solnova is an electrical power station composed of 5 different units with 50 MW each one. It's located on Solar Platform, inside Sanlúcar la Mayor. With such capacity Solnova is considered as le biggest plant in the world. The solar trough field heats synthetic heat transfer oil. Energy in the oil is used to generate superheated, high pressure steam that is delivered to a steam turbine. This turbine powers an electrical generator, creating electricity [18].

4.3 AndaSol solar power station

The project concerns two new concentrating solar thermal power generation plants based on the parabolic trough technology (linear concentration system with parabolic mirrors CSP) with a capacity of 50 MWe each. It's developed in a valley north of the Sierra Nevada, some 60 km southeast of Granada. The project consists of a field that covers 510,120 square meters of parabolic troughs along which a vacuum tube circulates a fluid which heats up to over 400°C.The heat is then used in a heat exchanger to produce power in a vapor turbine. The parabolic troughs are set up in 312 collector rows which are connected by pipes [19].
In Arab countries, they are functional solar power plants and others that are being construction or study. Among these units are:

4.4 Beni Mathar Plant

The Concentrated Solar Power plant of Ain Beni Mathar in morocco is now supplying electricity to the Moroccan grid. It's an operational Solar Thermal Power Stations. It's Located in the East of Morocco near the Algerian border. That plant capacity is 20 MW. It's composed of a large array of 224 parabolic mirror collectors concentrating solar energy. It's based on Integrated **Solar** Combined Cycle (ISCC) technology. The solar thermal plant of Ain Beni Mathar supplies of clean electric energy. This power plant will enrich the experience of this country for such development what types of units. This technology will enable the development of the national economy [20,21].
In addition to these stations which are in operation, there are others that are under construction:

4.5 Hassi R'mel integrated solar combined cycle power station

This solar plant presents a total capacity of 25 MW. It's based on Integrated **Solar** Combined Cycle (ISCC) technology. It will be functional this year (2011). It's located at Hassi R'mel Algeria [22]. This plant is based on fossil Combined Cycle (CC). Steam Turbine is additionally fed with solar generated steam during daytime. At night it operated like conventional Combined Cycle power plant [23].

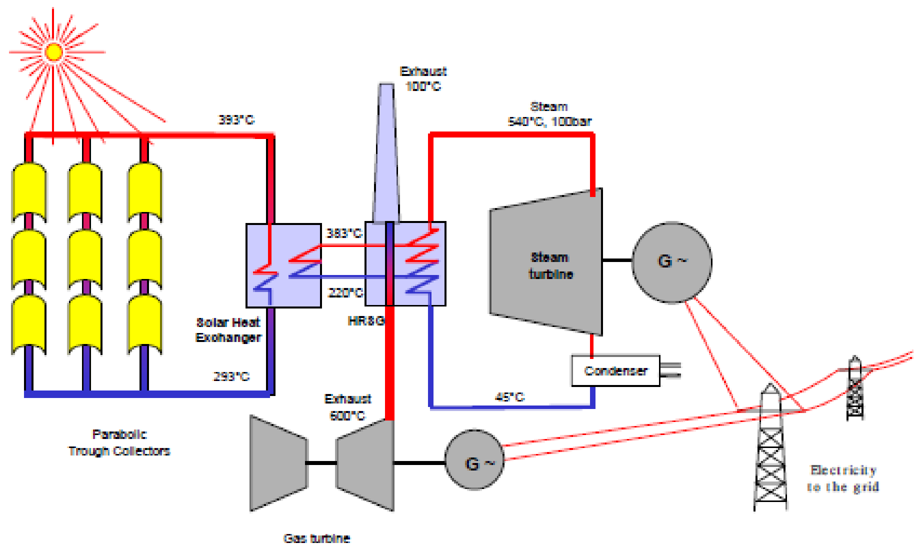

Figure 4: *Scheme Parabolic Trough Solar Power Plant at Hassi R'mal* [23]

4.6 Solar thermal electricity production systems in Tunisia

Tunisia has an average sunshine duration relatively large. Thus, two thirds of Southern Tunisian's regions benefit from sunshine duration of more than 3000 hours per year, with peaks of 3200-3400 on the southern coast (Gabes Gulf), while the minimum duration of sunshine in the northern third is between 2500 and 3000 hours per year. These data confirm that Tunisia has interesting solar field. Regarding the global solar radiation, the daily average is between 4.2 kWh/m^2/day in north-west and 5.4 kWh/m2/day in the far south. However, most of the territory (over 80%) is in the upper fringe of 4.75 kWh/m^2/day [24]. In Tunisia, attempts to produce electricity from solar energy are numerous. Among these projects, we find the projects, we find PROSOL ELECTRIQUE. This project consists in the creation of concentrated solar power plant (**CSP)** for electricity generation with a capacity of 25 MW integrated into combined cycle (ISCC) of 150MW. The main objective of this project is to experiment the technology of solar concentrators for power generation especially that Tunisia has a large solar field. This project will be implemented during the period between 2010– 2014. Besides this project we found ASEP-MPG-SHRC which is an Autonomous environmental friendly System of Electricity Production by a Mechanical Power Generation based on Solar-Heated HFC -134a Rankine Cycles is in progress [25]. This study is developed at the Laboratory of Electromechanical Systems of the National Engineering School of Sfax – Tunisia in order to produce autonomous electricity generation satisfying the priority needs of small villages in Gafsa city-Tunisia non accessible to the electricity grid.

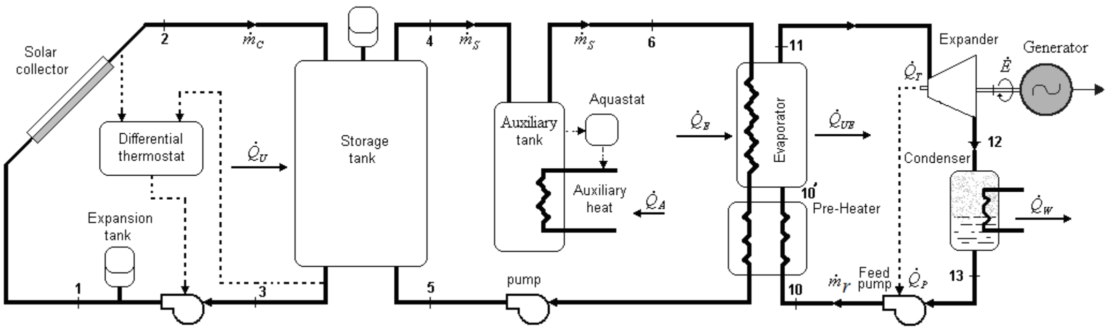

Figure 5: *Scheme* of *electricity production system Gafsa-Tunisia* [25]

A prototype of ASEP-MPG-SHRC installation is under test in Gafsa-Tunisia located in south-Western Tunisia, 350 kilometers from the capital, geographical coordinates are 34°25′ North and 8°47′ East, have a very high natural potential of solar energy availability, with more than 3500 hours of sunshine per year. The proposed unit of the thermal solar energy for (shaft) mechanical power generation used directly for electricity generation using an expander for electricity generation based on a solar-heated thermodynamic organic Rankine cycle at low temperature range [25].
The Solar irradiations over Gafsa city in south Tunisia where the system will be installed are in the figures below:

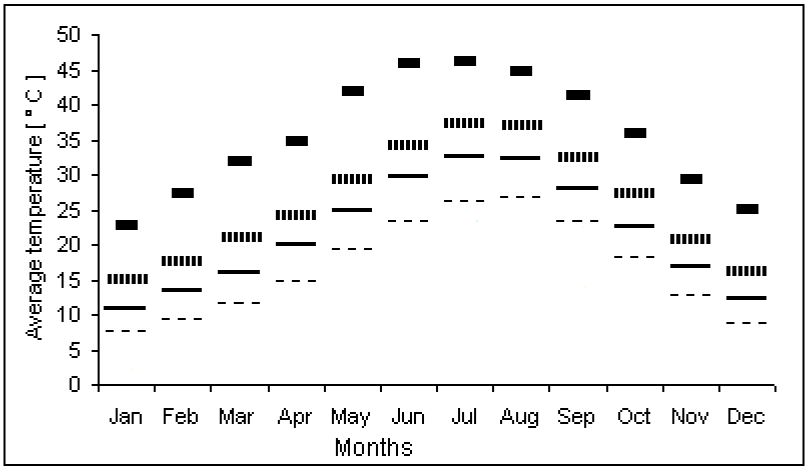

Figure 2*: Monthly average ambient temperature for Gafsa city from 1983 to 1997.*

▬ Maximum absolute temperature, ❙❙❙❙❙❙ Average monthly maximum temperature,
—— Average monthly temperature of the day, ▪▪▪▪ Average monthly temperature of the night.

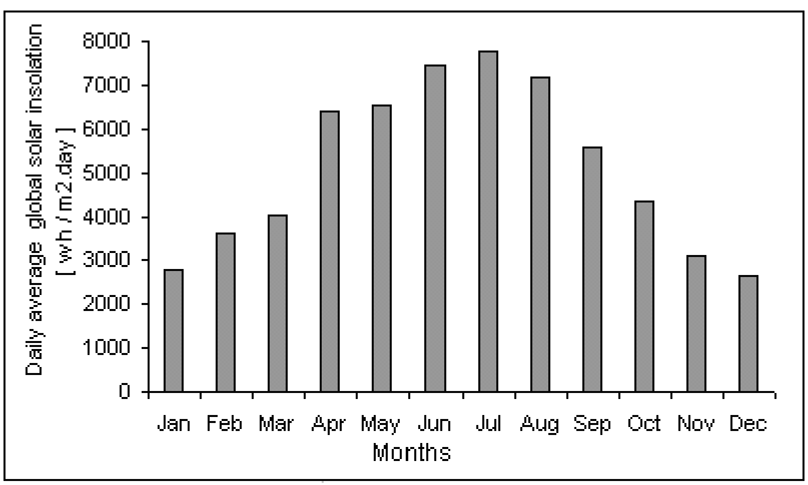

Figure 3: *Monthly average of the daily solar insulation of Gafsa city from 1983 to 1997 on horizontal surface.*

5. CONCLUSION

The use of solar thermal electricity production has enormous interests in the environment protection by reducing greenhouse gas emissions. Although the efficiency of this technology is very low compared to nuclear energy; it attracts the attention of all countries. Studies are outstanding for the improvement of these solar power plants. Among the drawbacks of these plants is that they are not immune to weather hazards such as storms that can destroy the solar collectors. Tunisian opportunities in the use of solar energy are enormous for the remarkable ability of sunshine especially in southern and central regions. Outstanding projects are testing locally with auto financing because the cost of making solar power plants with foreign partners are very high compared to country revenues.

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