

Review on Solar Thermal Electricity in Libya

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Abstract: Libya is facing an increasing deficit in electrical energy supply which needs great efforts to find new and renewable alternative sources of power. Solar thermal electricity is one of the most promising and emerging renewable energy technologies to substitute the conventional fossil fuel systems. A review of the research literature of solar thermal electricity in Libya is presented in this article. The state of the art of these technologies including design, operation principles and global market is demonstrated. Detailed reviews of research activities that have been conducted by Libyan researchers or institutions are presented. It has been found that Libya as a country needs a strategic plan and more research efforts in order to adopt these new technologies and put them in production mode.

ورقة مراجعة عن الطاقة الشمسية الحرارية لتوليد الكهرباء في ليبيا

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ملخص: تواجه الدولة الليبية عجزاً متنامياً في إمدادات الطاقة الكهربائية مما يتطلب مضاعفة الجهود من صنع القرار و الباحثين لإيجاد مصادر جديدة و مستدامة لتغطية هذا العجز ، تعد أنظمة توليد الطاقة الكهربائية باستخدام الطاقة الشمسية الحرارية أحد أهم البدائل الحديثة و المتجددة للمصادر التقليدية المعتمدة على الوقود الأحفوري ، هذه الورقة تقدم دراسة استعراضية للأبحاث المنشورة في هذا المجال في ليبيا ، تستعرض الورقة شرحاً لأحدث الأنواع من هذه المنظومات متضمناً تصاميمها و آليات عملها و مدى مساهمتها في إنتاج الطاقة الكهربائية عالمياً ، ثم تستعرض الورقة الأبحاث التي تم نشرها في هذا المجال من قبل بحاث ليبيين أو مؤسسات ليبية أو قيام الدراسة على البيئة الليبية ، خلصت هذه الدراسة إلى أن الدولة الليبية تحتاج إلى وضع خطة استراتيجية و دعم البحث العلمي في هذا المجال للوصول إلى مرحلة الإنتاج الحقيقي لمثل هذه المنظومات.

Keywords: Solar thermal electricity, Parabolic troughs, Dish concentrators

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1. INTRODUCTION

The continuing increase in population growth, global industrialization and the change in life style of modern societies put an increasing pressure on energy demand worldwide. Currently, fossil fuel resources are used intensively to satisfy this demand. However, it has generated many critical issues including global warming, climate change and harmful environmental pollutions. In addition, the over exploiting of these resources increases the risk of fast depleting. Therefore, sustainable and safe alternative energy resources such as solar and wind are exploited and their technologies are developed by many countries [1].

Solar energy is one of most amateur and commercially developed renewable source of energy which has been widely used to generate useful power. Solar thermal electricity, also known as concentrating solar power, generates thermal energy by concentrating solar direct normal irradiance using special types of reflectors. The thermal energy produced is used to drive heat engines, mainly steam turbines, to generate electricity. Solar thermal electricity (STE) has different types of concentrators, configurations and sun-tracking systems but all of them work according to the same principle. This technology is not only clean and sustainable but also has the possibility to integrate with thermal energy storage or in hybrid operation with conventional technologies which gives it the advantage to be dispatchable power and intermittent free [2].

Libya has enormous potential of solar energy with its area of about 1,759,540 km² area at the centre of North Africa. It has a long coast of 1900 km on the Mediterranean Sea and the great part of its land is desert with high potential of solar radiation. The direct normal irradiance reaches up to 2500 kW/m²/year in the south region of the country. Libya is facing an increasing demand on energy due to the population growth and the economic development. This continuing demand requires significant investments in power generation in terms of amount of production and alternative resources. Based on the German Aerospace Centre, each square kilometer of this region receives solar energy equivalent to 1.5 million barrels of crude oil. Moreover, low population density and high availability of arid areas makes solar thermal electricity a promising technology

for electricity generation to satisfy the continuing growth in energy demand in Libya [3].

This paper presents review of research activities and applications of solar thermal electricity in Libya. Firstly, a detailed exploration of the up to date solar thermal electricity technologies and their applications is provided in different sectors. Then, a literature review of the published studies in Libya is presented. The aim is to highlight the research hot points in the field to encourage and guide future research in order to deploy this technology in the country.

2. SOLAR THERMAL ELECTRICITY TECHNOLOGIES

The principle of solar thermal electricity is based on converting sun light into heat energy using assembled solar collectors called solar field. Then, the generated heat is used to produce electricity by conventional power cycles including Rankine and Bryhton cycles. These systems have the possibility to integrate with backup boiler or thermal energy storage in which the heat can also be produced during the night to keep the power block running. These systems can be classified into two groups: high and medium temperature STE also called concentrating solar power (CSP) and low temperature STE.

2.1- Concentrating solar power plants (CSP)

CSP technology, also known as high and medium STE, depends on concentrating solar direct normal irradiance (DNI) on a focal line or point receivers to generate heat energy. There are four types of CSP collectors represented in order of the most amateur and commercial as parabolic trough, central receiver, linear Fresnel reflector and parabolic dish.

2.1.1- Parabolic trough solar power plants

The parabolic trough solar collectors consist of central pipe receiver located at focal line of parabolic curved mirrors. The parabolic trough solar collectors are arranged in series lines called loops and the number of loops generate solar field, as illustrated in Fig. 1. The solar collectors are oriented in North-South direction in which tracking system is required to follow the sun from East to West. The receiver pipes are filled with heat transfer fluid (HTF) such as molten salt, Therminol-VP or pure water in case of direct steam generation. The parabolic mirrors concentrate DNI on the receiver and HTF convert it into heat energy. The concentrating ratio of sunlight is between 70-100 times and operating temperature of the HTF can reach up to 550°C. The thermal energy generated is transferred to operate the power block using heat exchangers. The power block normally used with parabolic troughs is regenerative Rankine cycle. The system is integrated with thermal energy storage (TES) to ensure continuity in electricity production. Normally the capacity of thermal energy storage is in the range of several hours in which it is filled with HTF during the day and emptied after sunset to maintain the electricity production even after sunset. It can be said parabolic trough solar power plant represents the most mature and commercial CSP technology for electricity generation [3, 4].

2.1.2- Central receiver solar power plants

This technology is also called “solar tower systems”. In this system, the solar field is assembled of circular two axis tracking arrays. The arrays consist of a number of slightly bended or flat heliostats. Each heliostat is configured of a number of individually sun-tracking mirrors, see Figure 2. The solar field concentrates the DNI onto a solar receiver located at the top of tower at the centre of the arrays. The central receivers are classified into volumetric receivers, cavity receivers, particle receivers and external receivers. The working temperature in these systems reaches up to 800°C in which sunlight can be concentrated 600-1000 times. The solar receivers produce heat energy transformed by HTF to the power block to generate electricity. The high temperature achieved by this technology gives it the flexibility to drive different power cycles including

steam cycle, gas turbine and combined cycle. The annual solar electric efficiency can reach 25% average and 35% peak. These systems can also integrate with TES systems to continue generate energy after sunset [4, 7, 8].

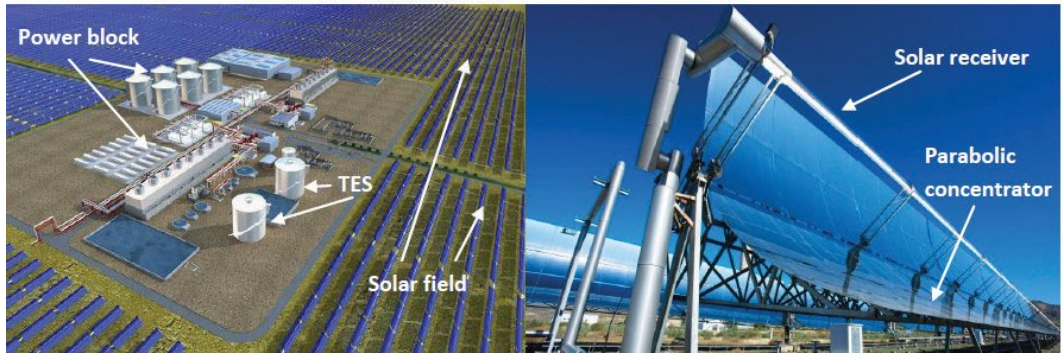


Figure (1). Parabolic trough solar power plant [5, 6]

2.1.3- Linear Fresnel solar power plants

Linear Fresnel system is a line focal solar collector similar to parabolic trough collectors. The solar field consists of a number of arrays assembled in linear or curved mirror strips which works as Fresnel lenses, as demonstrated in Figure 3. The mirrors concentrate solar radiation onto fixed tube receiver mounted in parallel on the top of the collector. Secondary concentrator can be used with this system to increase concentrating ratio in which it varies between 25 to 100 times. By the same principle, heat energy is generated using HTF and used to operate conventional power cycles with working temperature reaching to 500°C. One of the most advantages of this technology is simplicity and low cost of its components [4, 9].

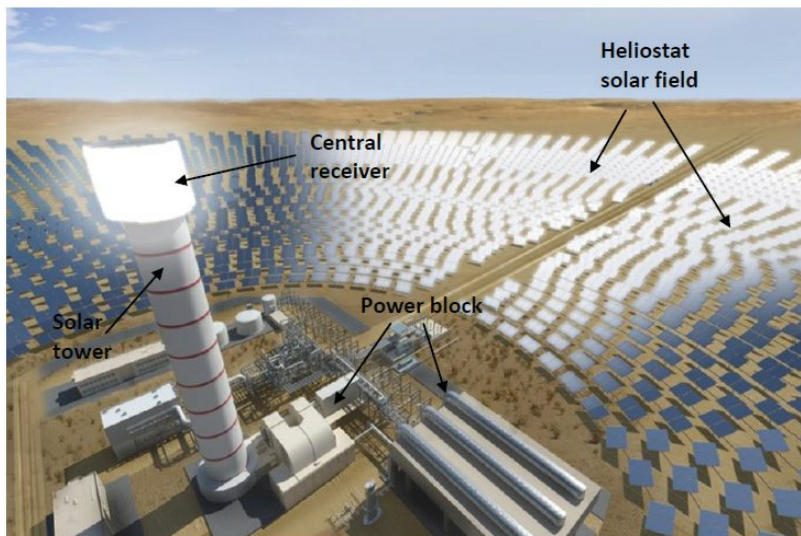


Figure (2). Central tower solar power plant

2.1.4- Parabolic dish solar power plants

The parabolic dish reflector is a two axis point-focus system which concentrates solar energy onto a receiver attached to the focal point of the dish, Figure 4. The focal receiver is filled with HTF, in this system fluid or gas, is heated to high temperature, up to 1000°C. The dish reflector is attached to Stirling engine or gas turbine to convert the absorbed heat energy to electricity. This technology is available only in demonstration prototypes because the energy generated from this technology is still expensive [9, 10].

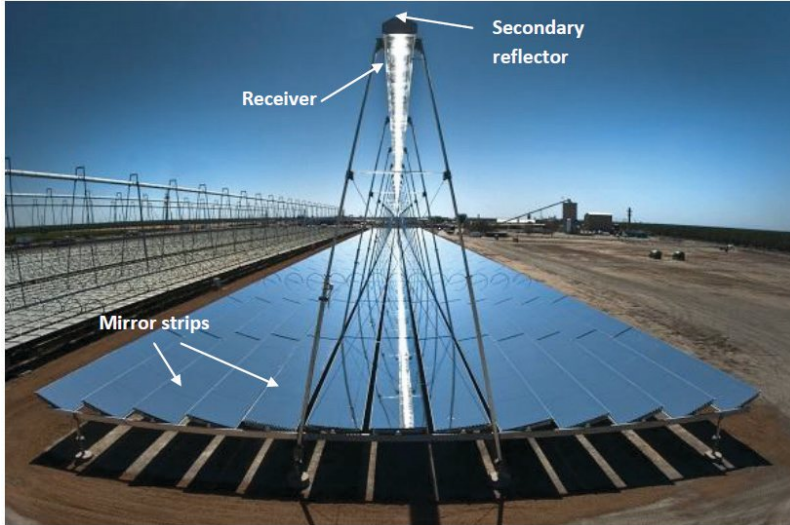


Figure (3). Linear Fresnel solar power plant [11]

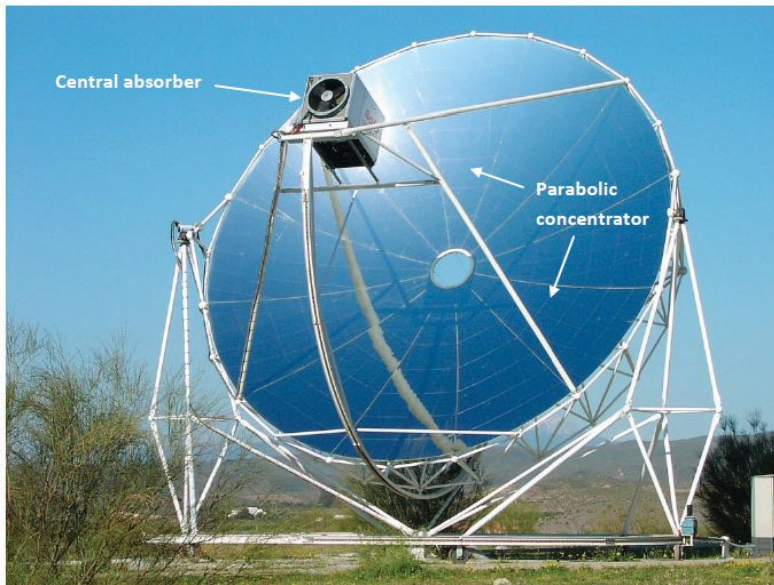


Figure (4). Parabolic dish solar power system [12]

2.2- Solar Organic Rankine Cycles

The organic Rankine cycle (ORC) technology uses low temperature solar collectors such as flat plate or evacuated tube to generate heat energy which is required to operate the cycle. The operating principle of these systems is similar to the conventional Rankine cycle. Figure. 5 shows schematic diagram of solar ORC system. The ORC use low boiling point working fluids including organic fluids such as methyl chloride, toluene and refrigerants (R-11, R-114...etc). In this case, the working temperature of the cycle is relatively low and that reduces cost of the energy generated. Solar thermal electricity of this type has small scale generation capacity of up to 50 KW with average cycle efficiency of 20% [13].

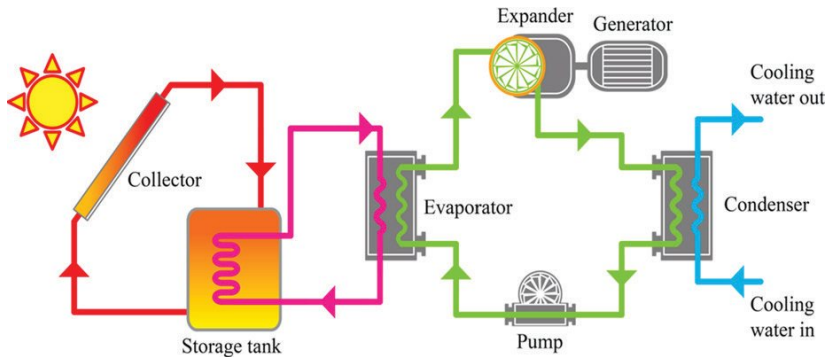


Figure (5). Schematic diagram of solar Organic Rankine Cycle [14].

2.3- Solar Chimney Power Plant

The working principle of solar chimney technology is slightly different from the previously described. Solar chimney is a combination of solar thermal and aerodynamic systems to convert solar heat into electricity. This technology consists of open solar air collectors to convert sunlight to heat up air as working fluid in wide open area. The density variation, which is occurring due to the rise in the temperature, drives the air to leave the system through a long chimney by buoyancy force, as illustrated in Figure 6. A wind turbine coupled with electric generator is staged at the base of the chimney. The heated air flow through the chimney operates the turbine in which kinetic energy is converted to electric energy [15].

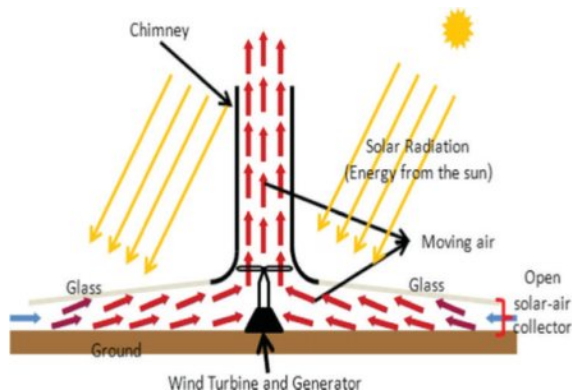


Figure (6). Schematic diagram of solar chimney power plant [16]

3. SOLAR THERMAL ELECTRICITY MARKET

STE technologies have increasing attention due to the durability and dispatchability of these systems. Currently, the total installed capacity is around the world about 5 GW with large-scale solar thermal power plants connected to the grid. Spain and USA are the leading countries in this technology in which they have 61% and 18% respectively of the total generated capacity. New markets are emerging in countries like South Africa, Morocco and Chile due to their solar resources and political dedication of their governments. Figure 7. shows the current distribution of the technology across the world [17].

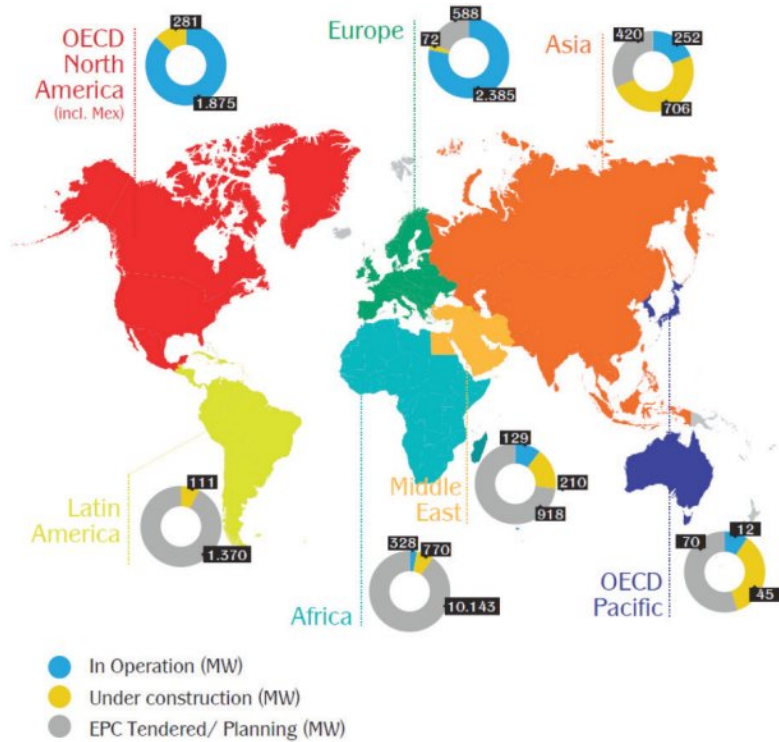


Figure (7). Solar thermal electricity global market [17].

The neighboring countries of Libya located in the Middle East and North Africa region (MENA) have taken advanced steps toward deploying this emerging technology. Morocco has a plan to operate 20 GW of solar power technology by 2020. The legal framework was approved in 2010 represented in Renewable Law. The legislation allows private and public companies to compete in creating and operating renewable energy facilities to generate electricity. Currently, the country has a 160 MW parabolic trough solar power plant (Noor I) in operation and connected to the electrical grid. Another 20 MW parabolic trough plant (Ain Beni Mathar) is in operation commercially. Noor II and Noor III with 200 MW parabolic trough and 150 MW central tower plants respectively are under construction and expected to start production at the end of 2017 [17, 18].

In 2015 Algerian government announced plans to generate 22 GW of electricity from renewable energy in which 2 GW of them will be produced by STE systems. The country has one commercially operating solar thermal plant. It is 20 MW parabolic trough-integrated solar combined cycle in the area of Hassi R'mel. In Egypt there is a target to produce 20% of its electricity demand from renewable resources by 2020 in which

2.2% is generated from STE and PV. In operation mode, there is one 20 MW parabolic trough-integrated solar combined cycle plant called Kuraymat plant. The country is currently constructing 100 MW parabolic trough plant (Kom Ombo) and the project is cooperated with National Renewable Energy Laboratories (NREL). A 250 MW central tower solar plant (Taqa) has also been approved and construction will start in near future [17, 19].

It is clear that Libya is not only behind the leading countries of this technology but also behind the countries in the same region with similar solar resources and economic situation. Libya has planned to develop renewable energy for electricity generation. The main target is to produce 10% of total electricity demand from renewable energy by 2025 which is equivalent to 2.219 GW. 375 MW is supposed to be generated from STE. However, this plan was interrupted in 2011 by the political uprising [18].

4. RESEARCH ACTIVITIES IN LIBYA

Internationally, there is a continuing increase in research efforts to make STE systems more reliable and cost competitive. Mainly, the research focus on reducing levelized cost of electricity, enhancing the efficiencies and developing the thermal energy storage systems integrated with these systems. However, there is clear lack of publications about this emerging technology conducted by Libyan researchers or institutions. Moreover, most of these are published in conference proceedings and local workshops which makes it difficult to find them in online scientific database. To the best of the authors' knowledge, this section presents a review of research efforts conducted by Libyan scientists, institutions or under Libyan climate conditions.

4.1- Research activities of concentrating systems

An investigation of the potential of implementation of CSP plants in Libya was discussed by Belgasim et al [20]. The socio-economic context, current energy situation of the country and different types of CSP plants were presented. Moreover, an assessment of site parameters required for CSP plants including solar resources, land use and topography, water resources and grid connections were analyzed in detail. Thermo-economic simulation of CSP plant was also performed. The simulation was conducted based on meteorological data measured by the weather station installed at the Centre for Solar Energy Research and Studies (CSERS) in Tajoura city. The outcome of the study proved that Libya is not only suitable but it can be economically competitive in the implementation of CSP technology.

Aldali et al presented the arguments for the use of direct steam generation (DSG) in preference to other forms of generation in particular locations according to the prevailing environmental and economic conditions [21]. This article reports on the development of a software model of the thermodynamic and thermophysical properties of water and steam in a hypothetical 50 MWe CSP plant located at Kufra in the south-eastern part of Libya, which takes into account the environmental conditions in the chosen geographical location. In addition, the model includes land requirement calculations for the plant, and the specification of a secondary natural gas-fuelled boiler required to maintain the design output of the overall facility. The hypothetical design discussed in this article is shown to yield a 76% reduction in greenhouse gas emissions compared to an equivalent gas-only plant over the 10-h daily period of operation and the solar fraction is 76%.

Belgasim and Elmnefi [3] presented an evaluation and assessment of 100 MW parabolic trough solar power plant located at Tripoli. Techno-economic simulation in addition to solar field optimization was discussed. The study used System Advisor Model software developed by National Renewable Energy Laboratories for technical and economical simulation. They found this plant can generate about 313 GWh/year of net electric energy with average efficiency of 16.2%. The monthly energy generated was also predicted in this study. Economically, the levelized cost of electricity (LCOE) obtained was 0.23 \$/kWh and about 55% of this cost contributed by solar field and thermal energy storage.

An energetic and economic analysis of 50 MW parabolic trough solar power plant was carried out by Ehtiweh et al [22]. The power cycle was modeled using the Engineering Equation Solver (EES) while the solar field was simulated by MATLAB software. The two models were integrated in which thermal and energetic performance can be achieved. Greenius software developed by DLR, was utilized in the economic analysis of the study. The net electric energy generated was about 163.8 GWh/year with average efficiency of 14%. This plant was compared with reference Andasol system located in Spain and showed better performance in terms of energy generated and efficiency. Economically, the LCOE of this study was found to be about 0.17 €/kWh.

In addition, Ehtiweh et al [23] presented an exergetic analysis and life cycle assessment of parabolic trough solar plant. The main purpose of the study was to examine the cost and environmental impact of these plants during the whole life time of the system. The study used Eco-indicator 99 and the Cumulative Exergy Demand Methods. The SimaPro 8 commercial software was also performed to support the study. It was found that the solar field has the most important impact on the environment followed by molten salt and synthetic oil.

An economic feasibility study of CSP power plant based on parabolic trough collectors was conducted by Mashena and Akishriwi [24]. Three sites located in Tripoli, Sabha and Alkufra were included in the analysis. The study utilized System Advisory Model (SAM) program. The authors showed that Alkufra site has the best economic performance due to the high potential of direct normal solar irradiance (DNI). In addition, they concluded that Levelized cost of electricity (LCOE) declines by 4% for every 100 kWh/m²/year increase over 1800 kWh/m²/year.

Regarding central tower technologies, Elayeb et al [25, 26] developed a method for estimating shading losses in a heliostat field. The method is general in calculating the blocking factor generating from neighboring heliostats. It depends on subdivision of heliostat into a grid and the heliostat plan was defined in a coordinate system. In addition, an analytical expression and numerical iterative technique was developed and solved using MATLAB software. The method was applied on typical rectangular heliostats of N-S cornfield and radial staggers solar fields.

A computer program used for design and optimization of central tower power plant was developed and described by Siala et al [27]. The program called ARRASUD was developed at Centre for Solar Energy Research and Studies (CSERS). It presented unified package to study and analyze the central solar plant technically and economically in which it can calculate the instantaneous and annual power generated in addition to the levelized cost of energy (LCOE) of the whole system.

Aldali and Morad analyzed the thermodynamic and economic performance of a proposed integrated solar/North Benghazi combined power plant under Libyan climatic conditions [28]. The parabolic trough collector field with direct steam generation was considered as the solar system. A numerical model of two modes of operation with the same solar field were considered: fuel saving mode in which the generated solar steam was used to preheat the combustion air in the gas turbine unit and power boosting mode in which the generated solar steam was added into the steam turbine for boosting the electrical power generated from that steam turbine unit. They found that the fuel saving mode is more economical than power boosting mode for the same solar field and the greenhouse CO₂ emission was significantly reduced.

4.2- Research activities for non-concentrating systems

A dynamic simulation of small scale organic Rankine cycle powered by low temperature solar thermal collector was presented by Hossin et al [29, 30]. A mathematical model of the whole system was developed and implanted in MATLAB using Thermolib toolbox. The study presented simulation of the thermodynamic performance for whole day in different seasons of the year under environmental conditions of the UK.

Moreover, Hossin et al presented an evaluation study of 10 kW organic Rankine cycle operated by evacuated tube solar collectors [31, 32]. The required dimensions of the system components including solar collectors, evaporator and condenser were calculated. Furthermore, an investigation of different types of working fluids with their relevant flow rates was conducted in order to find the optimum working fluid.

Multi Criteria Analysis (MCA) was applied in the case of Libya to assess the electricity generation options available to satisfy the increasing electricity demand [33]. Four options were included in the study namely: conventional power plants, wind turbines, PV systems and CSP technology. These systems were evaluated against five objectives including environment, economic, technology requirements, political and technical aspects. The study concluded that power supply systems based on solar technologies, especially CSP, will play a greater role in generating peak and base load electricity in Libya

4.3- Research activities for thermal energy storage

A numerical and experimental analysis of a latent TES system with heat pipes used for solar thermal power generation was carried out by Khalifa et al [34]. The main objective was to enhance the heat transfer rate by utilizing axially finned heat pipes. The numerical model was developed using the thermal resistance method and the effective heat capacity formulation. The governing equations were implemented and solved in MATLAB package. An experimental test rig was installed using commercial paraffin and bar heat pipe with four axial fins. The experimental measurements were used to validate the numerical results. The heat pipe effectiveness increased by 24%.

In addition, Khalifa et al [35] presented performance investigation of high temperature latent heat TES with suspended finned heat pipes. The target was to develop the thermal performance of these systems. The mathematical formulation was developed and solved by MATLAB software using the same technique developed by the same authors described in the previous publication. An experimental prototype of the system was designed and installed in order to validate the theoretical results. The design applied on a twelve heat pipe configuration and the effectiveness obtained reached 2.4.

A new method to enhance thermal performance of latent heat TES was investigated by Khalifa et al [36]. The new approach used cooper-water miniature heat pipes integrated with paraffin wax as phase change material. A three dimensional numerical model was developed and theoretical results validated against experimental data collected from installed test rig of the new system. The study proved that the new method enhanced the effective thermal conductivity of TES system.

5. RESEARCH OUTLOOK

The electricity generated from STE technologies have a relatively high cost and required significant amount of land area with special specifications. These reasons have led to limited adoption of these systems by many countries. Many states are continuously funding significant research projects to make STE more economically competitive. The expectation is to reduce the production cost by 50-60% in the following 5 to 10 years during technical enhancements, scaling up and increasing volume production [37]. The following are examples of these research efforts:

- The SunShot project founded by the Department of Energy in the United States in 2011. The target is to reduce the Levelized cost of electricity generated from CSP technology to less than 0.06 \$/kWh and the cost of thermal storage to less than 15 \$/kWh and increase the exergetic efficiency to more than 90% [38].
- The Australian Solar Thermal Research Initiative (ASTRI) funded by the Australian Government. The target is to decrease the cost of STE to 0.12 AUD\$/kWh by 2020 [37].
- The DISTOR project funded by the European Commission. The target is to integrate high temperature

latent heat thermal energy storage with direct steam generation CSP system [39].

Based on the reviewed studies, more investments and research efforts are still required from the Libyan government, research institutions and industrial corporations in order to deploy the STE systems in the country. One of the key research areas is the modeling, simulation and optimization of different STE systems in Libyan environment and investigating the design parameters affecting the performance of these technologies. The studies should include exploring different locations and hybridization with thermal energy storage or backup boilers. Another identified research area is to develop economic competitive design of small scale with few kW for residential consumers. Discussing the connection of STE with the electric grid of the country is also important and interesting including analysis of the infrastructure and its development to adopt the new technology. In addition, integration study of these systems with other application units such as desalination, steam generation, heating and cooling should be conducted and investigated

6. CONCLUSIONS

This article presents a comprehensive review on solar thermal electricity technologies studies and research activities in Libya. A description of different systems of these technologies is reported including concentrating and non-concentrating types. The regional market of these systems is reviewed focusing on neighboring countries of Libya. Detailed literature review of research activities conducted by Libyan institutions or Libyan scientists is presented. It is recommended that more efforts from Libyan academics and government are required in order to deploy such emerging technology and to enhance its economic competitiveness in the country.

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