FEASIBILITY ANALYSIS FOR A SOLAR POWER PLANT IN LIBYA

A MASTER'S THESIS

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Electrical and Electronics Engineering

Atilim University

by

BOBAKER .B. BOBAKER HAMAD

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Approval of the Graduate School of Natural and Applied Sciences, AtılımUniversity.

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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ABSTRACT

FEASIBILITY ANALYSIS FOR A SOLAR POWER PLANT IN LIBYA

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A feasibility study is presented in this research for the Solar Power Tower Plant (SPTP) in the southern region of Libya . The proposed location for this plant was evaluated and selected as a most suitable place for this plant . The present situation and the future perspective for electricity energy in Libya was analyzed. With the help of the software System Advisor Model (SAM) a modelling for two cases of central receiver system were executed . The first case which has been simulated was a SPTP with gross capacity of 100 MW with no storage system. The other case was for SPTP with gross capacity of 50 MW and 8 hours storage capacity. The main purpose of this work is to evaluate the potential of SPTP utilization to cover a part of the electricity demand in Libya. The results of two cases comparison have proven that the plant with a storage system is feasible economically and there is a high potential for the SPTP utilization as an alternative energy source to contribute in supply a part of the electricity energy needs in Libya with no fuel consumption and no carbon dioxide emission.

Keywords- Solar Power Tower ; Concentrated Solar Power;

ÖZET

LİBYA'DAKİ BİR GÜNEŞ ENERJİ SANTRALİ İÇİN FİZİBİLİTE ANALİZİ

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Yüksek Lisans

Elektrik ve Elektronik Mühendisliği Bölümü

Danışman: Yardımcı Doçent Dr. Mehmet Efe Özbek

Temmuz 2017, 46 sayfa

Bu araştırmada, Libya’nın güney bölgesindeki Güneş Enerjisi Kule Santrali (SPTP) için tekno-ekonomik yapılabilirlik çalışması sunulmaktadır. Bu santral için önerilen konum, değerlendirmeye tabi tutuldu ve bu santral için en uygun yer olarak seçildi. Libya’daki elektrik enerjisinin şimdiki durumu ve gelecekteki perspektifi analiz edildi. Sistem Danışman Modeli (SAM) yazılımının yardımıyla, sistem simülasyonu yapıldı. Bu çalışmanın ana amacı, Libya’da elektrik enerjisi talebininin bir bölümünü karşılamak üzere SPTP kullanımı potansiyeline değer biçmektir. Sonuçlar, sistemin ekonomik olarak yapılabilir olduğunu; ve yakıt kullanmaksızın ve karbondioksit salımı yapmaksızın Libya’daki elektrik enerjisi ihtiyacının bir bölümünün tedariğine katkı sağlanmasında alternatif bir enerji kaynağı olarak SPTP kullanımının yüksek bir potansiyele sahip olduğunu ispatlamıştır.

Anahtar kelimeler- Güneş enerjisi kulesi/santrali (Solar Power Tower); Konsantre Güneş Enerjisi (Concentrated Solar Power)

Dedication

To my Mother, Father and All my Brothers

ACKNOWLEDGMENTS

I express sincere appreciation to my supervisor Assist .Prof.Dr. Mehmet Efe Özbek for his guidance and insight throughout the research. Thanks also go to my wife, Hanan, I offer sincere thanks for her continuous support and patience during this period.special thanks so much for my sister Hania for her help.

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LIST OF ABBREVIATIONS

CSP - Concentrating Solar Power

DNI - Direct Normal Irradiation

HTF - Heat Transfer Fluid

IRR - Internal Rate of Return

LCOE - Levelized Cost of Energy

NPV - Net Present Value

PPA - Power Purchase Agreement

SPTP - Solar Power Tower Plant

CHAPTER ONE

INTRODUCTION

Libya is one of the oil producing countries which located in the Middle of North Africa with 6.25 million of population distributed over a total area of 1,750,000 Km^2.It relies on the oil as the only source of energy generation. In contrast, industrial and population growth are causing significant increase in the electric energy demand all over Libya leads to more fuel consumption ,which is subjected to exhaustion, and investment in extra installations to generate electricity including power stations, transmission lines and substations . looking for an alternative source to supply the energy needs in Libya becomes necessary. About 80 % of Libya's area located in the Sahara desert which has a large amount of solar radiation with the daily average of direct normal irradiation ranging between 8.1 kWh/m2/day in the southern region and 7.1 kWh/m2/day in the coastal region with a sunshine duration hours more than 3500 for each year[1].This information indicates that there is a high potential of solar energy in Libya which is considered as a one of the best alternative energies in Libya that can be utilized to supply a part of the energy needs in Libya . The solar energy is converted into electricity energy by means of photovoltaic technology, which convert direct the solar to electricity energy or by a solar thermal technology which is known as concentrating solar power technologies (CSP) this technology are classified into four main types, Solar Power Tower, linear Fresnel Systems, Parabolic Troughs, and Stirling Engine.CSP technologies convert the energy of direct sun light into thermal energy using concentrator device. Electricity can then be produced using various methods including thermal engines or in a thermodynamic process with steam turbine[2].

1.1 Aims and Objectives

This research aims to present a techno economic feasibility study for a Solar Power Tower Plant (SPTP) for electricity generation in Libya. This work has been carried out with the following specific objectives.

- Collect data related to the SPTP including the its components and cost based on literature studies.
- Selection the suitable location in the southern side of Libya and evaluate it according to the site selection criteria.
- Evaluating the present situation and the perspective for electricity energy in Libya.
- Evaluating the technical performance according to the modelling results.
- Analyse the financial results and compare it with the financial present situation in Libya.

1.2 Thesis Structure

This study consists of five chapters, chapter two is background information and literature survey, this chapter introduces an idea to the Libyan energy and power sector ,solar energy potential in Libya and a general concept on the concentrating solar power technologies with main focus on the SPTP type. The last section of this chapter is a review for previous studies related to the our study field.The third chapter includes the SPTP system loss evaluation, components cost and A simulation for power system's performance was done by SAM software which also calculated the financial metrics for the system. In chapter four the technical and financial results were discussed . Chapter five is the last one which includes the conclusion based on the obtained results.

CHAPTER 2

BACGROUND INFORMATION AND LITERATURE SURVEY

This chapter introduces an idea to the Libyan energy and power sector ,solar energy potential in Libya and a general concept on the concentrating solar power technologies including a brief overview on the main components and principle operation for each type of them .Solar central receiver system is the main focus of this thesis, therefore it is discussed in a separate section contains of a historical background ,working principle, its components that make it up . The last section of this chapter is a review for previous studies related to the our study field.

2.1 The Libyan Energy and Power Sector Situation

Libya relies on the natural gas and fuel as the only sources of the electricity energy generation.The annual report 2010 of General Electricity Company of Libya(GECOL) shows that the consumption amounts of fuel and natural gas in 2010 year were 1,812,930 m^3 heavy fuel, 4,205,111 m^3 light fuel and 3,793,184,511 m^3 natural gas which corresponded to 32,558,000 MWh of produced electricity energy for the same year. The contribution percentage in the electricity energy production for each is shown in Figure 2.1 .The CO_2 emission is estimated to be 0.93 kg/kWh.

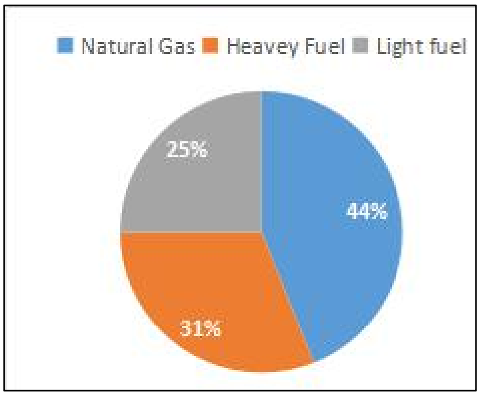

Figure 2.1 Percentage of gas and fuel used in electricity generation

GECOL is a company which totally owned by the Libyan state and it is responsible for the operation of the whole electric power sector. All the power generation plants in Libya have been installed by this company. Locations of the installed power generation plants in Libya are shown in Fig 2.2.

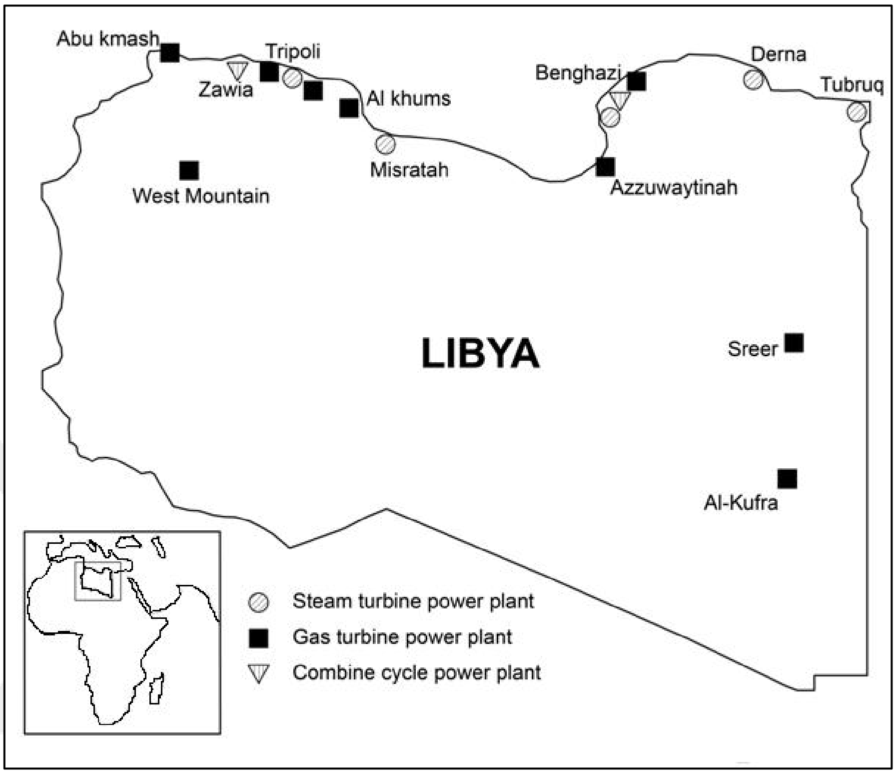

Fig 2.2 Power plants locations in Libya [25].

Libya has a total capacity of installed power generation plants of 6.357GW.The local electricity grid in Libya consists of an ultra high voltage lines capacity of 400kV With a total length of lines 2290 km, high voltage transmission level of 220kV with a total length of lines 13,706 km, sub transmission lines level 66kV with a total length of 14,312 km and The distribution network's voltage capacity is 33kV with a total length of 11,142 km .The production of the electric energy in Libya has been provided by gas-turbine, steam-turbine and combined cycle power plants, which use heavy fuel oil, light fuel oil and natural gas .The gas turbine and combined cycle power plants have a contribution of 43% and 37% respectively of the total installed power plant capacity. The steam power plants shares in 20% in total capacity. Recently the capital cost for the combined cycle power plant estimated by 1125$/kW.Table 2.1 shows the electric power plants in Libya [3,4,5].

Table 2.1 Electric power generation plants capacities in Libya

Name of power Plant	Fuel type	No of units	Unit capacity MW	Plant capacity MW	Available power MW	Data of commissioning
1.Steam generation power plants						
Alkhoms	HF & NG	4	120	480	300	1982
West of Tripoli	HF	4	65	260	70	1976
West of Tripoli	HF	2	120	240	100	1980
Derna	HF	2	65	130	40	1985
Tobruk	HF	2	65	130	80	1985
Total of steam power plants		**14**	**435**	**1240**	**590**	
2. Gas generation power plants						
Abokammash	LF	3	15	45	17	1982
Alkhoms	LF & NG	4	150	600	500	1995
South of Tripoli	LF	5	100	500	400	1994
Zwitina	LF & NG	4	50	200	120	1994
Alkufra	LF	2	25	50	25	1982
Western mountain	LF & NG	2	156	312	280	2005
Western mountain	LF & NG	2	156	312	280	2006
North of Benghazi	LF & NG	2	285	570	500	2009
Musrata	LF & NG	2	285	570	500	2010
Western mountain	LF & NG	1	156	156	140	2010
Zwitina	LF & NG	2	285	570	500	2010
Alsreer	LF & NG	1	285	285	250	2010
Total of gas power plants		**30**	**1948**	**4170**	**3487**	
3. Combined cycle generation plants						
Alzawia Gas & Steam	LF	4	165	660	600	2000
		2	165	330	300	2005
	NO FUEL	3	150	450	375	2007
North of Benghazi Gas & Steam	LF & NG	3	150	450	390	1995
		1	165	165	140	2002
	NO FUEL	2	150	300	250	2007
Total of combined cycle plants		**15**	**945**	**2355**	**2055**	
4. Other sector plants						
Musrata steel	HF & NG	6	84.5	507	180	1990
Alsreer river project	LF & NG	6	15	75	45	1990
Total of other sector plants		**12**	**99.5**	**582**	**225**	
Total of all plants		**71**	**3428**	**8347**	**6357**	

HF = Heavy fuel , LF = Light fuel and NG = Natural gas

2.2 Load Growth and Electricity Demand in Libya

The studying of load growth is one of the important subjects with respect to load demand prediction .According to the GECOL 2010 annual report, the demand on the electricity energy increases annually by 9% .Based on this ratio, the energy demand value will reach to 9.5 GW by 2020 as shown in Figure 2.3.This increasing will lead to more fuel consumption resulting in reduction in the national economic revenue and more emission of carbon dioxide. The price of the used oil for electricity generation can be estimated as each liter of oil can produce approximately11 KWh [3].

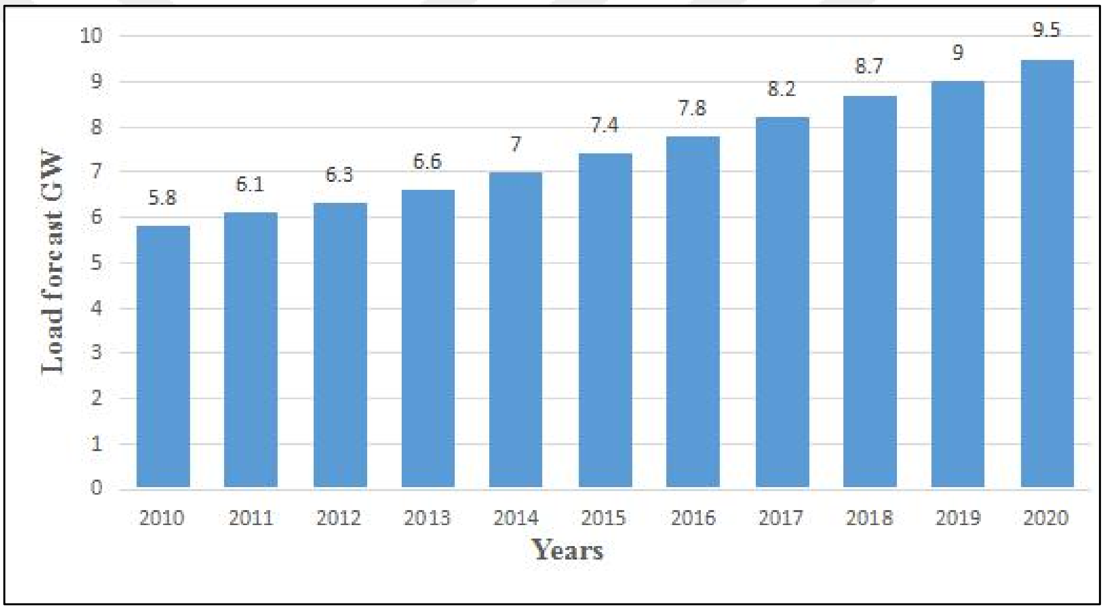

Figure 2.3 Libyan peak load growth 2010- 2020

2.3 Solar Energy Potential in Libya

Libya has a greater rate of solar radiation. In the southern regions, the daily average of the direct normal irradiation (DNI) on horizontal plane is around 8.1 kWh/m2/day while the DNI is 7.1 kWh/m2/day in the coastal regions. With an annually average of the sun shine of more than 3,500 hours per year. Figure 2.4 shows the annually average of direct normal irradiation [1].

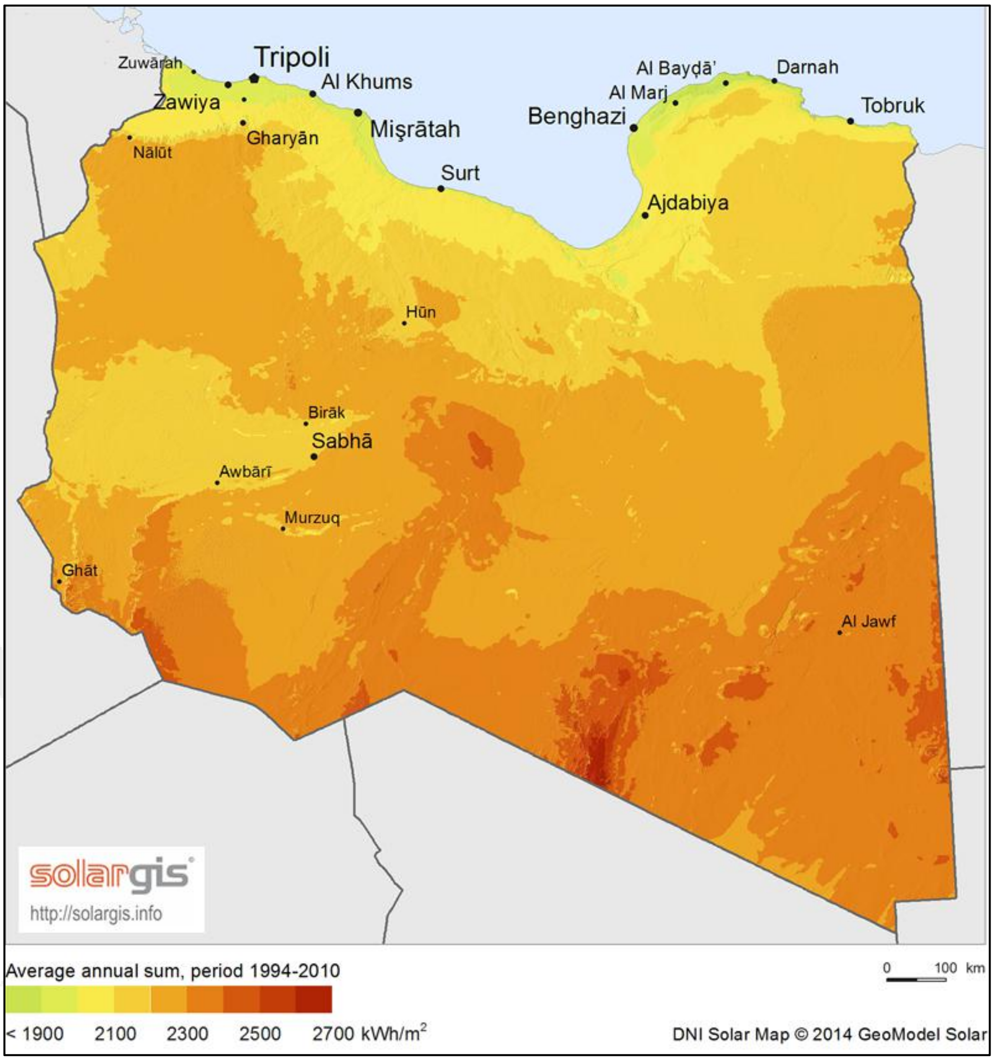

Figure 2.4 Annual average of direct normal irradiation in Libya [26]

As can be seen in the above figure the Libyan Desert covers around 88% of Libya's area with high solar irradiation which makes it suitable for building solar power plants. Unlike the photovoltaic, solar thermal power plants require > 5 kWh/m2/day DNI for operation. The excellent DNI radiation in the world falls in sun belt region where Libya occupy a large part of it. Figure 4 shows the Potential for CSP around the world [6],[7].

2.4 Concentrating Solar Power (CSP) Technologies

CSP technologies is based on the use of solar mirrors to focus a large amount of sunlight into a small area which generates very high temperatures for that area. The resultant heat is then conveyed by means of a heat-transfer fluid (which may be water/steam, air, molten salts or thermal oils) and is then used to power a turbine and generate electricity in a thermodynamic procedure. This heat can also be stored in a liquid or solid medium such as molten salts, concrete or ceramics and can later be used at night or in the absence of solar radiation. There are four kinds of CSP technologies that are being used as shown in Figure 2.5: Solar Power Tower, linear Fresnel systems, parabolic Troughs, and Stirling Engine [2], [8]. CSP plants are categorized into two groups , dependent on whether the solar collectors do focus the rays of the sun on a central point or along a line. Line concentration systems are the Parabolic Trough plants and Linear Fresnel have tracking systems that are single axis. Point concentration systems are the Solar Power Tower systems and Parabolic Dish systems which track the movements of the sun with a heliostat with dual axis tracking system and then reflect the rays of the sun into the receiver [9].

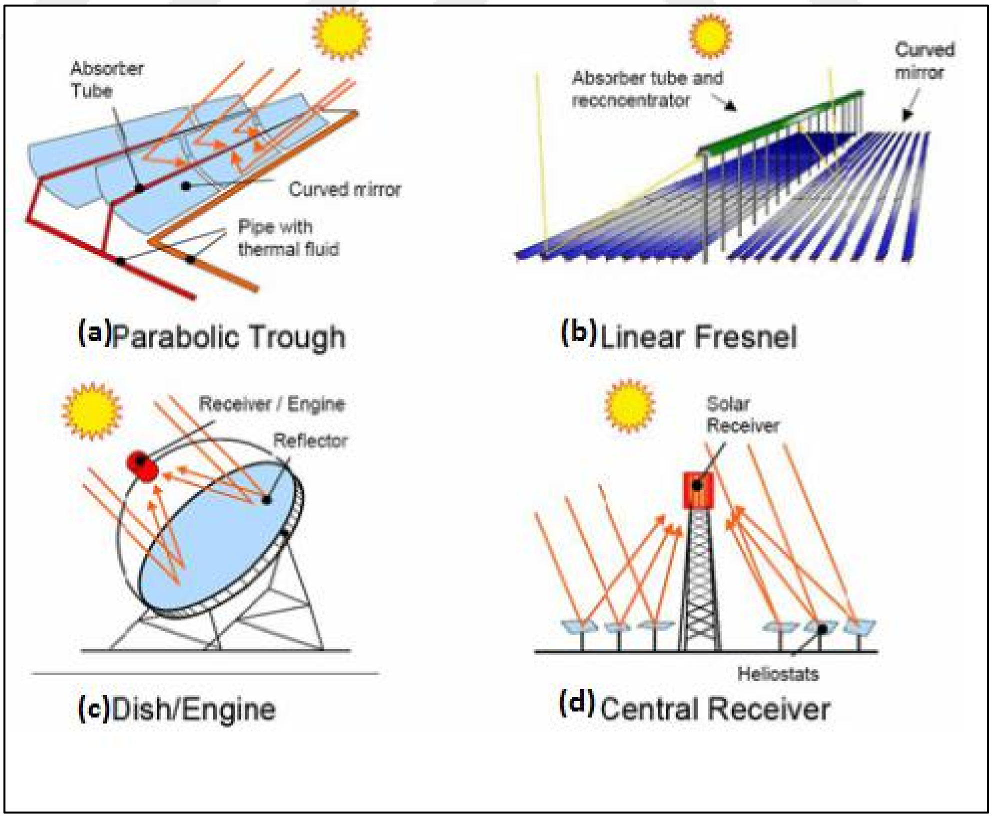

Figure 2.5 four main types of CSP technologies[10]

2.4.1 Parabolic Trough

The parabolic trough mirrors as shown in Figure 2.5(a), produces a linear focus of the sun’s radiation on the receiver when it is positioned on the central line of parabola. The solar radiation that is concentrated on the absorber tube heats up the (HTF) heat-transfer fluid which is then used to power a turbine thus generating electricity. It has a single axis tracking system that follows the movement of the sun. Thermal oil widely used as a heat transfer fluid (HTF) for this technology. Generally speaking, the parabolic trough power generating plant comprises of three sub-systems; the solar collector field with the oil circuit ,the steam generator and the power generating system [2],[11].

2.4.2 Linear Fresnel

It is similar in structure with the parabolic trough systems due to the fact that they are both line focusing technologies and possess single-axis tracking system. With the use of flat mirror reflectors, the solar radiation is then focused on a linear absorber. This concentrated heat energy on the linear absorber is then transferred onto the thermal fluid after which the fluid goes through the heat exchanger in order to power the steam generator which is used to generate the electricity. The major difference from parabolic trough is in the placement of the absorber tube which is fixed above the field of mirrors as displayed in Figure 2.5(b) [2].

2.4.3 Parabolic Dish

The Solar Dish system consists of reflecting mirrors that reflect direct solar irradiation onto a receiver which situated at the focal point of the dish .This receiver is a generator may be a Stirling engine or small gas turbine, Fig 2.5(c).The heat on the receiver transfers into the fluid (HTF) or the gas to be used in generating electricity.The dish has two-axis tracking system to track the sun position [11].

2.4.4 Solar Power Tower Plant (SPTP)

The Solar Power Tower , which is also known as the 'central receiver' plant makes use of “heliostats” which is a large quantity of mirrors and has a dual-axis control system (situated on the horizontal and vertical axis). These heliostats reflect the solar radiation incident on their surface to a fixed receiver that is situated on the tower top. Fig2.5(d). The reflected solar radiation then heats up the receiver which transfers the heat by means of the HTF that passes through the receiver. The HTF powers a thermodynamic cycle, which is usually a water-steam cycle that drives a turbine which then generates the electricity [12]. The development of SPTP technology began in 1976 with the establishment of the National Solar Thermal test facility at Sandia National Laboratories in Albuquerque, New Mexico. This gave rise to the building of several experimental facilities throughout the world, the largest of which was the central receiver named Solar One with a solar tower that was 90m in length and a capacity 10 MWe, located near Barstow in California [13]. The key components that make up the SPTP are heliostats field,receiver,power block and thermal storage system figure 2.6 shows that.

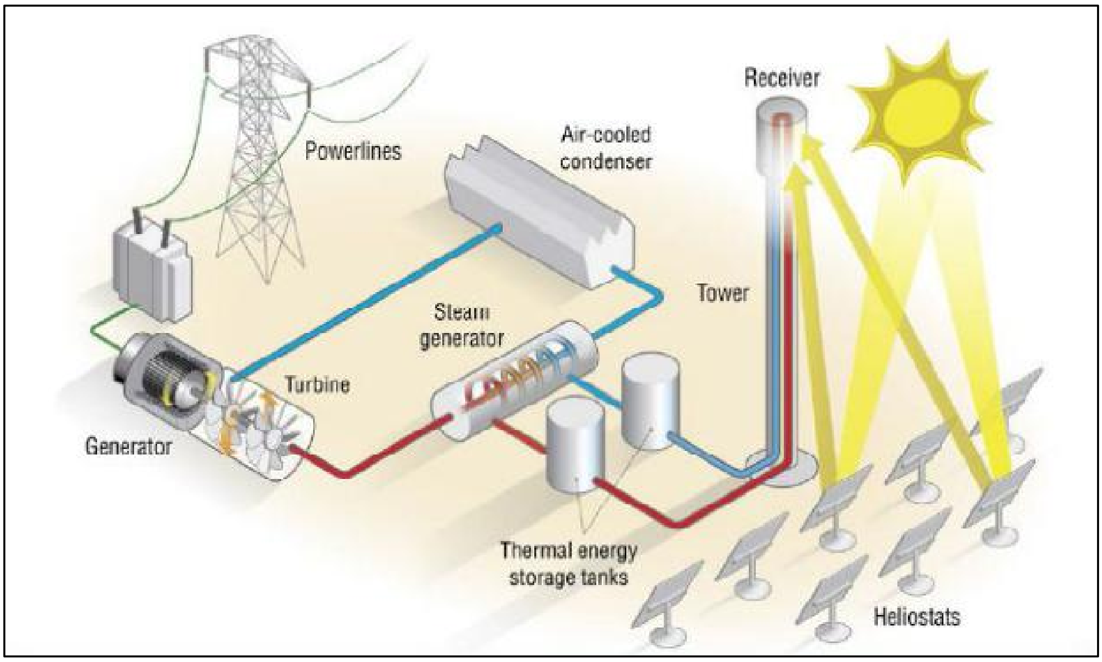

figure 2.6 Solar Power Tower plant [14]

2.4.4.1 Heliostats

A large mirror or a set of mirrors joint to a tracking control system that moves two axes all over the day in order to follow the sun and maintain the sun's radiation reflecting to the center of the receiver . Heliostats main components are mechanical structure, mirrors, facets, foundation, tracking system, control system, and necessary fixings as in next Figure 2.7. They are mirrors controlled by computers which enables the sun rays to reflect on a target as the sun goes across the sky [15].

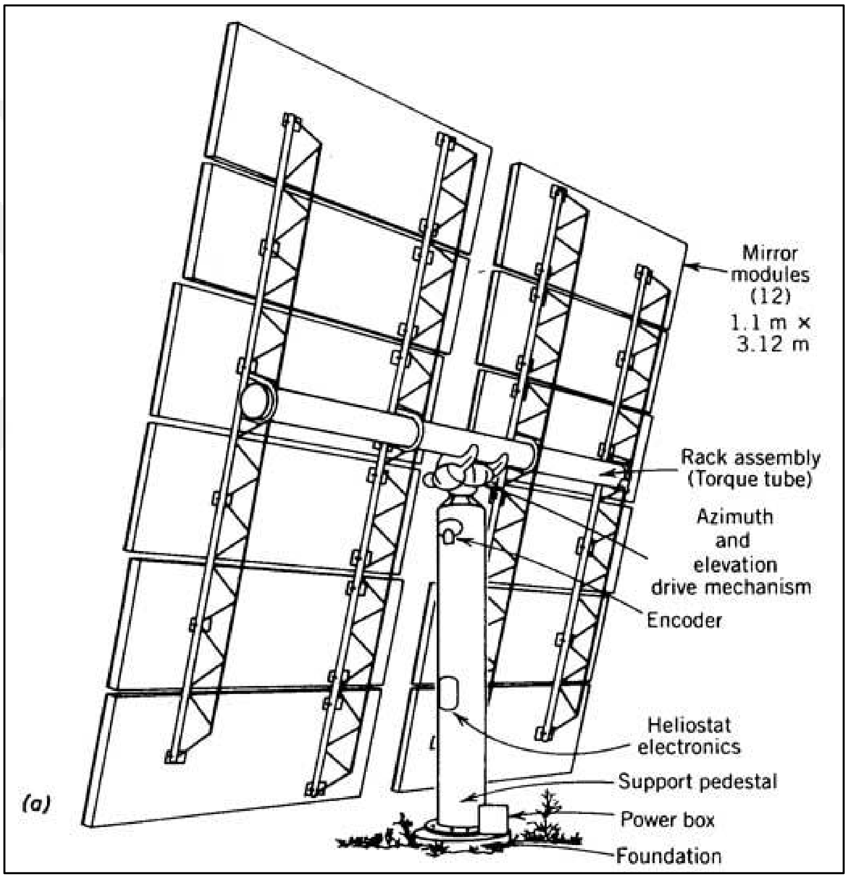

Figure 2-7: A heliostat components [15].

2.2.4.2 Receivers

One of the most essential parts of tower plants is the receiver. We have two types of tubular receivers used for liquid HTF: The external cylindrical receiver and cavity receivers .

External Cylindrical Receivers:- In the external cylindrical receiver type, the vertical tubes are placed side by side, in some kind of cylindrical pattern while the radiant flux from the heliostats surrounds from all directions. The tops and bottoms of the vertical tubes are joint to headers that provide heat transfer fluid to the down of each tube and takes from the top of the tubes heated fluid .Figure 2.8 shows the external cylindrical receivers that was used in Solar One plant . The receiver exposed to higher convection losses because it is subjected to the atmosphere [12].

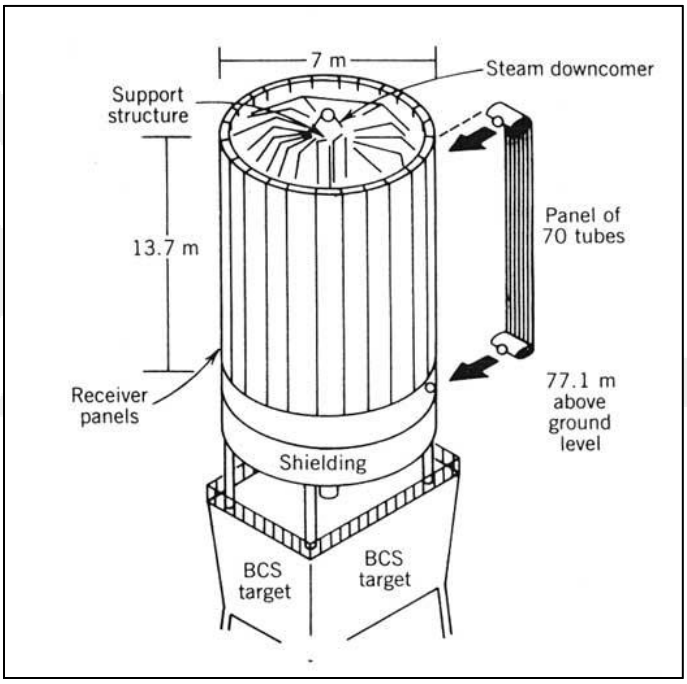

Figure 2.8 External cylindrical receiver [15]

Cavity Receivers:- The solar cavity receiver contains tubes that are arranged inside a cavity in order to minimize the convection losses. The heliostats are arranged within the range of possible incident angles onto the receiver. The cavity receiver can be either be a single or dual cavity type. The single cavity receiver will have solar field on one side of the receiver while the dual cavity receivers will have solar field on either sides of the receiver. Figure 2.9 shows the dual cavity receiver [12]

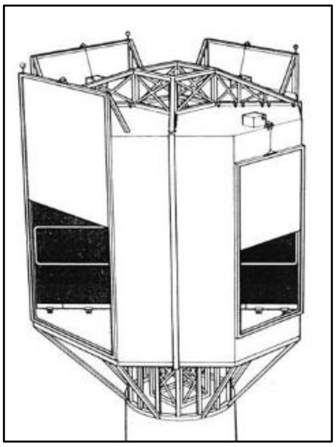

Figure 2.9 Dual cavity receiver [15]

2.4.4.3 Power Cycle

One essential component of the plant is the power block. The solar energy which is gotten by the receiver is changed to a more useful form which is electricity. Steam generator, electric generator, turbine, and condenser makes up the power cycle as in figure 2.10 .Rankine cycle is the main power cycle that is used in SPT plants. Water is the working fluid in this cycle. Here the water is boiled by HTF and changed to steam. The dry saturated vapour spreads through the turbine generating power. When it leaves the turbine at a low pressure, a low quality steam goes through a condenser where it is changed to a water. This is pumped from a low pressure to a higher pressure [12].

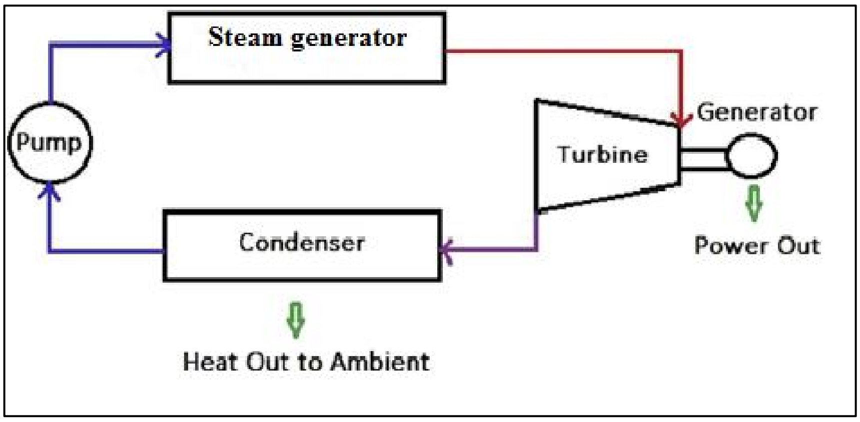

Figure 2.10 Rankine cycle [16]

2.4.4.4 Molten Salt

Molten salt is a salt that melts as a result of applied heat. Its mixture consists of 60 % sodium nitrate (NaNO3) and 40 % potassium nitrate (KNO3). This salt was selected for use with a central receiver system plant as a result of its upper stability temperature limit (600 ℃) allowing a high-efficiency rankine cycle turbine to be used. In a case of molten salt being HTF, a heat exchanger is used as a means of transferring thermal energy from HTF to water so that it can produce steam. The use of molten salt as HTF enables easy thermal storage. [12],[17].

2.4.4.5 Thermal Storage System

The thermal storage comprises of storage tanks, circulation pumps and heat exchanger as in figure 2.6 above .The direct storage system has been successfully used in the SPTP technology. The HTF, which is heated in the receiver, is used directly as a medium for storage. The HTF is stored in a double tank (hot and cold tank) which is used as a source of energy at night with 86 % efficiency[18],[46].

2.5 Literature Survey

Al-Chaaban, F [19], conducted a comparative study on photovoltaic and thermal energy concentrators in 2013. The most popular PV concentrators were given. There were illustrations and comparison of various thermal concentrators. The cycles, heat transfer fluid and storage techniques were also treated. The results has revealed that the use of troughs and central receiver systems is the most suitable for big grid-connected power projects in the 30-200 MW size. CSP tower offers a high capacity factor with a low cost and an efficient thermal storage.

In 2014, Shah .R [20], investigated the performance of various CSP systems in a climactic condition. This analysis has been carried out for different design assumptions in the selected sites at Queensland with various comparisons. The analysis results reveals that the energy production throughout the year from central receiver system technologies overcomes parabolic trough technology and linear Fresnel.

A feasibility study on the establishment of a central receiver plant of 10 MWe on various Algerian sites is presented by Aichouba, A in 2013 [21]. A performance simulation for central receiver system was done by SAM software,System Advisor Model.Technical and meteorological data for each site were entered to the SAM. Based on these data the energy production and discounted costs were estimated by SAM for the three sites and the Daggett as a reference site. The results showed that southern Algeria is very interesting with production levels and costs comparable to those of the reference site.

In Lebanon, 2012. Hajjar, A [22], brought out a feasibility study based on the central receiver technology. The study considered the insolation conditions and weather in that specific area, and also the financial circumstances as regards Lebanon, including rules pertaining to tax and costs of the various components of the plant. The study included a simulation for two cases storage and no-storage central receiver system, the results were compared so as to select the optimal case for a solar power plant .The final findings revealed that the project proved feasible, with a high profit margin which makes it suitable for any project involve in such project.

In 2014, Srilakim [23], presented an analysis of the opportunities, challenges and possibilities of central receiver technology for Indian situations. This work was carried out by assessing existing plants based on different parameters like solar to electric conversion adequacy, land area being used, field layout, height of the tower and size of receiver. Also the study included the challenges and opportunities for in India based on technical, financial and policy perspectives for critical parameters. The assessment study concluded that this is an achievable target. Given the challenges with conventional methods of power generation, the use of tower technology in harnessing solar power will play a pivotal role in meeting India's future energy demands.

The literature studies which have been reviewed indicated that the central receiver system technology represents one of the most promising technologies that can be used as an alternative to the conventional energy sources .In general CSP technologies require sufficiently large (> 5.2 kWh/m2 /day) direct normal irradiation (DNI) [7] .Libya has an average daily direct solar radiation reach to 7.17 kWh/m^2/day which is considered as a one of the highest CSP potential around the world [24] .Based on this survey a feasibility study has chosen as a thesis topic research to evaluate a central receiver power plant in Libya.

CHAPTER THREE

DESIGN & MODELING FOR CRS

3.1 Project Site Selection Criteria

Choosing the location of the project is one of the most important factors which must be studied before embarking on any point of the project,therefore many aspects were studied in order to locate a suitable area to implement the proposal project.One location has been selected to conduct this study which is located in the southern desert of Libya at 27.654 latitude and 21.657 longitude.Climate state,land and water availability and infrastructure suitability are the factors which were considered.

3.1.1 Climate Condition

DNI (Direct normal irradiation) is the first parameter that is considered in the assessment of site in terms of energy resource and is defined as the quantity of solar radiation that is received for every unit area on a surface that is always placed perpendicularly in alignment with the position of the sun such that the rays always fall on it in a straight line. The typical daily amount of DNI received in this position is 7.17 kWh/m^2/day, 850 w/m^2 for an average 8.43 sunshine hours which is said to rank among the maximum CSP potential worldwide. The total average temperature is approximately 26.4 Celsius and total average speed of the wind is 3.7 m/s [24],[27].

3.1.2 Land Availability

CSP facilities require a relatively high expanse of land when compared to other conventional power generating plants . The precise surface area needed for a central receiver power plant is approximately 0.041 km^2 per MWe [28]. Land availability is a key site criterion in the building of large collector fields for SPTP. A land with an area of 4 km^2 was identified in the designated region

.

3.1.3 Water Availability

The SPTP plants require some amount of water to carry out its operations. It takes into account water needed for construction, the steam cycle, and cooling process in addition to the periodic cleaning of the solar mirrors or collectors. The quantity of water needed for each operational process for SPTP is outlined below.

- Cleaning water for the solar mirrors: - 75 to 150 litres per MWh.
- Water for the steam cycle: - 120 to 220 litres per MWh.
- Steam cycle cooling system: - 2800 to 3400 litres per MWh [8].

What recognize this region is the presence of an abundant source of groundwater where there is a large project, an artificial river, which is a system of underground pipelines brings fresh water from the aquifers deep to the coast of Libya for industry, agriculture and domestic use. As such, this region is rich in water .

3.1.4 Infrastructure Suitability

Certain infrastructures are needed for the successful operation of SPTP. An essential site criterion is the presence of existing infrastructure because any infrastructure that is not present will necessitate higher financial investment. A SPTP would require access to a network of good roads as well as access to other forms of transportation ways. It also needs a medium - high voltage power grid and access to a large body of water if wet-cooling is intended. All the above requirements are present in the locality of this particular site and they include a good road network, high voltage power grid and substations, in addition to an abundant supply of water Figure 3.1 (google earth picture) shows this.

Fig 3.1 The location by google earth picture

3.2 Evaluation of The Heliostat Field Optical Efficiency

Different types of losses affect the heliostat field optical efficiency, that is to say reflectivity loss, cosine loss, atmospheric attenuation loss, intercept factor or spillage losses,i.e.,the energy directed toward the receiver which does not fall on the absorbing area and losses due to the shadowing,blocking.Estimating the performance of the heliostats gives the field efficiency which describes how much energy is expected to reach to the receiver based on the total heliostat area. Figure 3.2 shows the losses involved with heliostats[29].In general, the optical efficiency of the field can be given by:

$$\eta_o = \rho \cos\omega \, f_{at} \, f_{int} \, f_{sb} \quad (1)$$

where ρ is the actual mirror reflectivity,cosω the cosine of the incidence angle between the sun rays and the heliostat normal,f_{at} the atmospheric attenuation factor, f_{int} the intercept factor,i.e., the fraction of the energy spot reflected by the heliostat hitting onto the receiver surface,and finally f_{sb} is the shadowing and blocking efficiency [30].

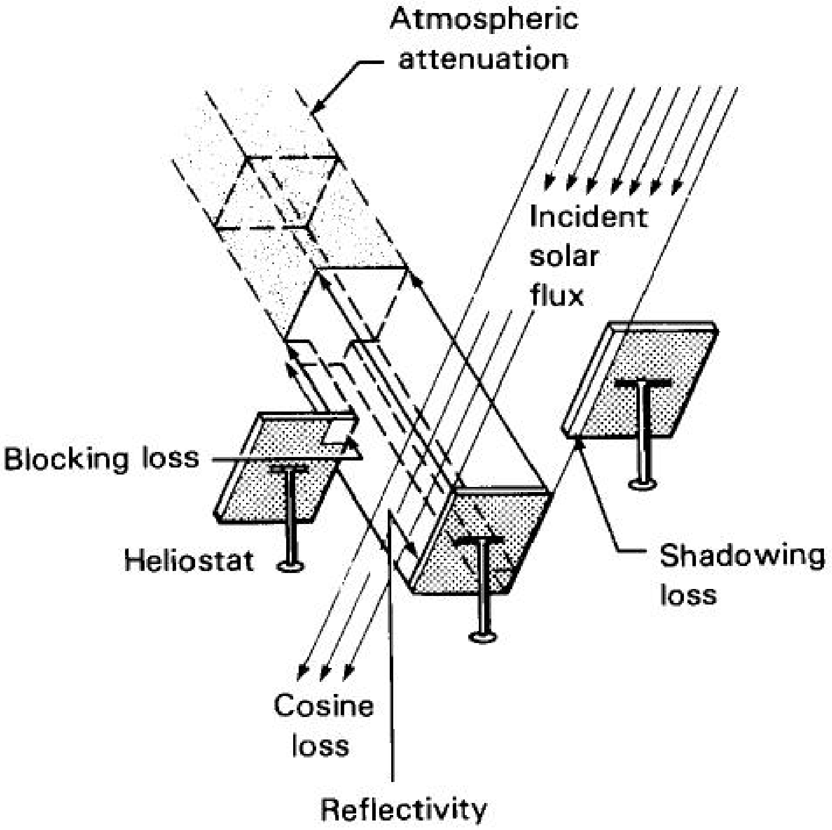

Figure 3.2: Heliostat losses [30]

3.2.1 Reflectivity Loss

Reflectivity is an optical property of material, which describes how much radiation is reflected from the material in relation to an amount of radiation incident on the material. ASUP 140 heliostat model with total reflection area 140 m2 was chosen in this study as shown below in the figure 3.3. Its reflectivity levels of over 95 %. The reflectivity decreases when Imperfections such as dust and dirt form a layer over the mirror surface[31].

Figure 3.3 ASUP 140 heliostat model[31]

3.2.2 Cosine Loss

This loss depends on both the sun’s location and the position of the individual heliostat relative to the receiver.A heliostat’s reflected radiation is most effective when the heliostat is normal to the incident beam of sunlight.If vector H is not fall in line vector S , an incident angle, θi, is introduced, as shown in Figure 3.4. In order to find the value of cosine efficiency for the heliostat field ,the number and direction of heliostats must be known.However, the average value of cosine efficiency of 81% is used according to the optical performance results for the future 100 MWe power tower under South African conditions[32].

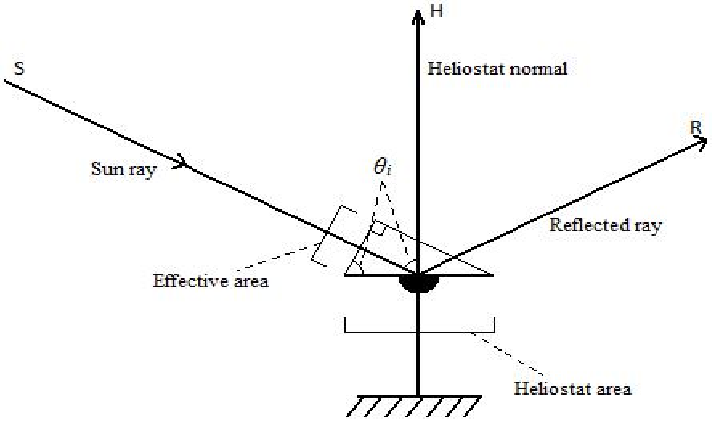

Figure 3-4 Heliostat effective area reduction through the cosine effect [29].

3.2.3 Atmospheric Attenuation Loss

During their paths from reflector to the receiver, reflected rays are subjected to the atmospheric attenuation.The losses due to the atmospheric attenuation are function of the distance between heliostat and the receiver located on the top of the tower. The Atmospheric attenuation efficiency of 92.6% is used as a rough value to calculate the heliostat field optical efficiency[32].

3.2.4 Intercept Factor or Spillage Losses

When the receiver's aperture is not large enough to intercept the entire image of the mirrors, fraction of the energy will disperses on the receiver surface and spillage losses occur. Spillage losses can be reduced by increasing the size of the receiver.According to reference [30], spillage losses of 4% are taken in order to design for worst case in this study.

3.2.5 Shadowing and Blocking Losses

Blocking occurs when a heliostat in front of another heliostat blocks the reflected rays to the receiver. Shading is similar to the blocking, but it affects incident rays, heliostat placed in front of its neighbour shades the heliostat behind. Shadowing and blocking losses for 3% are taken for each[32].

3.3 Receiver Sizing

The power block design and gross output of the turbine affects the size of the receiver. The efficiency of the power block set is 42% [33]. Then from this, the thermal power input to the receiver is estimated as follows.

$$P_{in,PB} = \frac{P_{out,PB}}{\eta_{PB}} \tag{2}$$

When the power input to the power block is determined, the efficiency of the receiver is assumed to be 85%, and then the power input to the receiver is achieved.

$$P_{in,r} = P_{in,PB}/\eta_r \tag{3}$$

The receiver material and HTF physical properties determine the allowable average flux .1000kW$_{th}$/ ㎡ is the allowable estimated value for maximum flux density of molten salt [34] .

$$\text{Receiver area} = P_{in,r}/\text{flux}_{,max} \tag{4}$$

3.4 Tower Height

According to the system adviser model the optimum tower height is generally about 0.1 of the farthest heliostat length from the tower, as shown in Figure 3-5

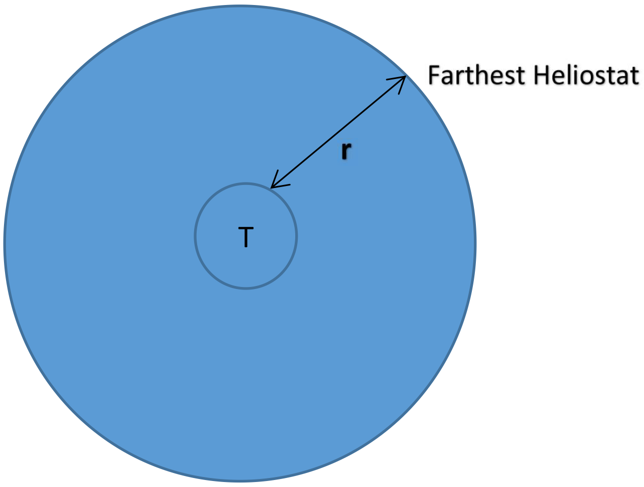

Figure 3-5 Tower and heliostat geometry

Approximate the area of the field including the equipment area is 4 km^2, from this area the r value is calculated as following.

$$r = \sqrt{A/\pi} \tag{5}$$

Where r is the farthest heliostat from the tower,A is the field area ,the tower height is equal to the next[35] .

$$T_h = r*0.1 \tag{6}$$

3.5 Thermal Conversion and Power Block Efficiency

The power cycle set convert the thermal energy into electric energy, the high temperature molten salt flows into the steam generator resulting in a steam which drives steam turbine to produce electricity.The efficiency of a thermodynamic system can be calculated by the Carnot Cycle as shown in Figure 3.6

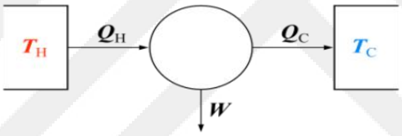

Fig 3.6 Carnot cycle sketch

$$\eta_{carnot} = \frac{W}{Q_H}, \quad W = Q_H - Q_C \tag{7}$$

$$\eta_{carnot} = \frac{Q_H}{Q_H} - \frac{Q_C}{Q_H} = 1 - \frac{Q_C}{Q_H} = 1 - \frac{T_C}{T_H} \tag{8}$$

Where W is the work done by the system ,Q_H is the heat input into the system , Q_C the remeaning heat , T_c is the absolute temperature of the cold reservoir, and T_H is the absolute temperature of the hot reservoir[36].

The gross efficiency of thermal to electric conversion can be formulated as following.

$$\eta_g = \eta_o \eta_r \eta_{pb} \tag{9}$$

Wher η_o is the optical efficiency, η_r the receiver efficiency and η_{pb} is the power block set efficiency.The thermal power incident on the field can be calculated from the following equation.

$$P_{in-th}=P_{out,PB}/\eta_g \quad (10)$$

The total area of the heliostats can be calculated from the following equation,wherethe DNI is the direct normal irradiation w/㎡.

$$A_T=P_{in-th}/\,DNI \quad (11)$$

Then, the number of heliostats, N, is given by:

$N=A_T/A_h$,where A_h is the area of each heliostat (m2) [37]. (12)

3.6 SPTP Components Cost

It is important to find out the cost of each component to get the total cost of The project. The project total cost can be broken down into various categories. The international studies of expenses and manufacturing prices determine the cost of each component.

3.6.1 Heliostat Field Cost

The size of the heliostat ranges between 2 m2 up to 140 m2. When the area of the heliostat is increased it can result in better features. In this study, the ASUP 140 heliostat model was chosen. It has a total reflection area of 140 m2. 20 $ and 165 $ per square meter are the estimated cost of heliostat field and the improvement of the site. [38].

3.6.2 Tower & Receiver Cost

Concrete and metallic structures are the two different types of tower structure. The concrete structure has a slightly lower costs, especially for high tower heights, but the difference in price of the two types is not considered to be significant in the feasibility of the system. The tubular receiver has two different types called cavity receivers and cylindrical receiver. The cavity receiver can be chosen for its lower convection losses, with an insignificant change in the total cost. In this study we use the generic cost figure (180 \$/kWth.) provided in [38] to calculate the total cost of the tower and receiver.

3.6.3 Thermal Energy Storage Cost

In recent times, in CSP applications, the most practical form of energy storage is the two-tank storage. The more common use method is a direct storage method, in the direct storage system method the HTF is directly used as a storage medium. The price estimated is of 30\$/ kWh_{th}.. [38].

3.6.4 Power Block Set Cost

Components of the conventional power block such as a condenser and turbine are used by the CSP power plants. In this study, the ranking cycle that has a dry cooling has been selected because it makes use of less water. Steam generation and Power block cost is estimated at 1140\$/kWe. [38]

3.6.5 Balance of Plant Cost

The balance of plant is a term which refers to the auxiliary systems and supporting component of a power plant which is required for energy delivery instead of the generating unit itself. The distance between the substation and the solar plant location was measured to be 3 km in length. A 220 KV power transmission line with a capacity of 150 MVA has been planned between the substation and the solar plant. The cost of the line has been estimated to be 271,000 $ per km . The balance of plant also includes a 11kV to 220 kV step-up power transformer with the same capacity, 150 MVA. The estimated cost of the step-up power transformer is 21,800 $ per MVA [39],[40].

3.6.6 Indirect Costs

Any cost that cannot be determined with a particular piece of equipments is known as an indirect cost. Contingency is one of the parameters which is taken into account for expected uncertainties in direct cost estimates. This value was taken as 7% of the direct cost, in accordance with the value used in SAM. Another indirect cost component is the land cost. The price of land in the region under consideration is determined by the Libya government as 1.5 $\$/m^2$. Managing, consulting, geotechnical and environmental survey, legal fees, project development and inventories of spare parts are 13% of the overall direct cost [41].

3.6.7 Operation & Maintenance Costs

Operating and maintenance costs mean the annual expenses and the services that take place after the installation of the system. The cost of O & M are a fixed and variable costs estimated by 65 $ KW per year and 3.5 $/MWh [38].

3.6.8 Financing the Project

80% of the project cost is considered to cover by a 3.5% interest loan with an 18 years loan term, this aid in the financing of project. Some other financial matters included in this study are 2.5% rate of inflation per year, increase in PPA price of 1% per year, a discount rate of 5.5% per year, an income tax of 20% and an annual insurance rate of 5%[42,43].

3.7 Modelling Tool (System Advisor Model)

3.7.1 Introduction

National Renewable Energy Laboratory (NREL) in the University of Wisconsin provided the software known as System Advisor Modelis (SAM). This software is a financial model created to help people who are in the renewable energy industry make decisions. It enables performance predictions and energy cost estimates for projects that are grid-connected which are based on operating costs, installation and parameters of system design that are specified as the model's input. In the following section, you would see the model structure described in detail.

3.7.2 Model Structure

As shown below in Figure 3.7 The SAM software diagram which consists of three main parts, a user interface, calculation engine, and programming interface.

The User Interface:- It is a part of SAM performs three basic functions.The first one is that it provides access to input variables which are organized into input pages.

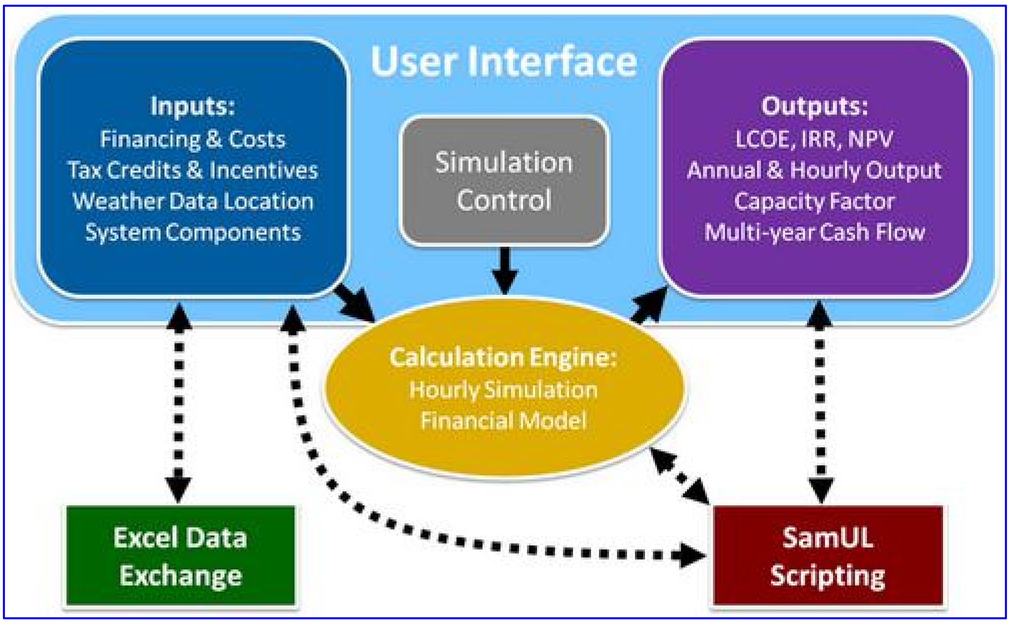

Figure 3.7 The SAM software diagram [44]

These variables describe the physical characteristics , cost and financial assumptions for the project.The second function of the user interface is the simulation control which makes the user capable to run a basic simulation, or more advanced simulations .Third function is that the user interface provides access to output variables in tables and graphs on the results page .

Calculation Engine :- performs a simulation of a power system's performance and a set of annual financial calculations to generate a project cash flow and financial metrics.

Programming:-The programming interface allows external programs to interact with SAM [44].

During the simulation process the SAM applies the mathematics equations that were mentioned earlier in the sections 3.3,3.4 and 3.5 to estimate the receiver size,tower height and the number of heliostats respectively.

SAM uses cash flow models to calculate the levelized cost of energy (LCOE), net present value (NPV), internal rate of return(IRR) ,power purchase agreement (PPA) and other financial metrics. The equations which are used by SAM to calculate the financial metric are described below.

The Levelized Cost of Energy is the overall cost of installing and operating a project which is an energy generated by the system in dollars per kilowatt-hour. This formula is used by SAM to calculate the real Levelised Cost of Energy.

$$\text{real LCOE} = \frac{\sum_{n=1}^{N} \frac{R_n}{(1+d_{\text{nominal}})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d_{\text{real}})^n}} \qquad (13)$$

Where, $d_{\text{nominal}} = [\ (1 + d_{\text{Real}} \div 100) \times (1 + \text{Inflation Rate} \div 100) - 1\ ] \times 100$

Q_n (kWh) is the electricity generated by the project in year n, N is the analysis period in years, Rn project revenue from electricity sales in year n,d_{real} and d_{nominal} are the real and nominal discount rates.

The NPV is a measure of the economic feasibility of this project, a project that is economically visible is indicated by a positive net value while a negative net value is indicated by a project that is economically infeasible. The next equation explains NPV.

$$\mathrm{NPV} = \sum_{n=0}^{N} \frac{C_{AfterTax,n}}{(1 + d_{nominal})^n} \tag{14}$$

Where C is the after-tax cash flow in year n.

IRR Internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. IRR calculations rely on the same formula as NPV does.

$$NPV = \sum_{n=0}^{N} \frac{C_{AfterTax,n}}{(1 + IRR)^n} = 0 \tag{15}$$

PPA is the contract which define the electricity price between the electricity seller and the electricity buyer[44].

$$\text{Levelized PPA price (real)} = \frac{\dfrac{\sum_{n=1}^{N} R_n}{(1 + d_{nominal})^n}}{\dfrac{\sum_{n=1}^{N} Q_n}{(1 + d_{real})^n}} \tag{16}$$

3.7.3 Modelling Approach

In this study a modelling for two cases of central receiver system were executed with the help of SAM software .The first case which has been simulated was a central receiver system with gross capacity of 100 MW with no storage system and the solar multiple, which is defined as the ratio of the receiver thermal power to the cycle thermal power, for a system with no storage should be close to or equal to one .The other case was for central receiver with gross capacity of 50 MW and 8 hours storage capacity with solar multiple 2. Both plants were applied for the same field size of heliostats and the same size of receiver and tower. The power block capacity and the balance of plants are different as in the table 4.1/2. The IRR was specified on a target value of 11% to be achieved in the year number 12, for two cases and the SAM applies a research algorithm to find the PPA price required to meet this target. The results were classified into two categories, Technical and Financial results. Comparison between the two cases was carried out and the optimal plant was chosen based on the highest profitability which corresponds to the maximum Internal Rate of Return (IRR), Power Purchase Agreement (PPA) price less than 34 ₵/kWh which is the current electricity production cost in Libya [45].

3.7.4 Simulation Data

A simulation has been carried out using SAM advisor which enables the prediction of performances and estimated cost of energy for power projects that are grid-connected based on operating cost and installation parameters for system design and financial parameters that are specified in the next tables 3.1,3.2 as inputs to the model.

Table 3.1 .summary of the components costs as an input data to the SAM

Direct costs of plant component	
Site Improvements $\$/m^2$	20
Heliostat field $\$/m^2$	165
Tower & receive $\$/kw_{th}$	180
Thermal storage system $\$/kw_{th}$	30
Power block system $\$/kw_e$	1140
Balance of plant $\$/kw_e$	41
Indirect costs	
Contingency cost (%) of direct cost	7
Land area $\$/m^2$	1.5
EPC & owner cost (%) of direct cost	13
Fixed O/M costs $/kw-yr Variable O/M costs $/MWh	65 3.5

Table 3.2 The design and financial parameters as an input data to the SAM

Parameters definition	Input data	
	No storage	with storage
Direct normal irradiation (DNI)	850 w/m2	850 w/m2
Analysis periodic	25 years	25 years
Lifetime degradation rate /year	0.5%	0.5%
Solar multiple	1	2
System storage hours	0	8
Heat transfer fluid	Molten salt	Molten salt
Heliostat area	140 m2	140 m2
Cycle thermal efficiency	0.42	0.42
Turbine gross output	100 MW	50 MW
Debt fraction	80%	80%
Annual interest rate	3.5 %	3.5%
Loan repayment period	18 years	18 years
PPA escalation rate / year	1%	1%
Inflation rate / year	2.5%	2.5%
Discount rate / year	5.5	5.5
Insurance rate of installed cost/ year	0.5 %	0.5 %
Tax income rate	20 %	20 %

CHAPTER FOUR

RESULTS DISCUSSION AND ANALYSIS

4.1 Selection of The Most Appropriate Plant

Two cases, storage and non-storage were both optimized and studied, a comparison between them were carried out in order to choose the appropriate plant . It is noted that in the next tables 4.1a and 4.1b , the system with storage has a lower total cost , higher energy outputs and higher capacity factor. The case with storage also achieves a less PPA price,that makes it more interesting for the producers of electricity energy, therefore the plant with capacity of 50 MW_e and 8 hours of storage capacity is the more suitable .

Table 4.1a. Summary of results of both cases storage and no Storage

Parameters definition	Central receiver plants output values	
	100 MW with no storage	50 MW & 8 hours of storage
Annual generated energy (year 1) KWh	136,120,848	148,404,064
Capacity factor (year 1)	17.3 %	37.6 %
Levelized PPA price	26.74 ¢/kWh	20.47 ¢/kWh
Levelized COE	23.33 ¢/kWh	17.59 ¢/kWh
Net present value	$ 59,374,888	$ 54,854,152
IRR at the end of project	16.12 %	16.22 %
Net capital cost	$ 317,634,682	$ 283,118,654
Equity	$ 63,526,936	$ 56,623,730
Size of debt	$ 254,107,745	$ 226,494,923
Total installed cost per net capacity	3,529.27 $/$kW_e$	6,291.71 $/$kW_e$
Number of heliostat	3614	3614
Total land area m^2	2747815	2772096

Table 4.1b Two systems components costs comparison

1. Direct costs					
Item		100 MW without storage		50 MW With 8h storage	
		Quantity	Total $	Quantity	Total $
Site Improvements $/m2	20	490781	9,815,620	490781	9,815,620
Heliostat field $/m2	165		80,978,865		80,978,865
Tower & receive $\$/\text{kw}_{th}$	180	280000	50,400,000	280000	50,400,000
Thermal storage system $\$/\text{kwh}_{th}$	30	0	0	952000	28,560,000
Power block system $\$/\text{kw}_{e}$	1140	100000	114,000,000	50000	57,000,000
Balance of plant $\$/\text{kw}_{e}$	41 & 79.26	100000	4,100,000	50000	3,963,000
Subtotal		Without storage 259,294,485		With storage 230,717,485	
Contingency cost (%) of subtotal	7	18,150,613		16,150,223	
Total direct cost for each system $		Without storage 277,445,098		With storage 246,867,708	
2.Indirect costs					
Item		Quantity	Total $	Quantity	Total $
Land area $/m2	1.5	2747815	4,121,722	2772096	4,158,144
EPC & owner cost (%) of direct cost	13	277,445,098	36,067,862	246,867,708	32,092,802
Total installed cost		Without storage **317,634,682**		With storage **283,118,654**	

4.2 Technical Results

4.2.1 System Efficiency

Figure 4.1 has revealed a comparison between the net electric output power generated by the chosen power plant and the incident solar thermal power. The total solar to electric efficiency of the plant has a range between 13% and 25% with an average of 21.7% annually.

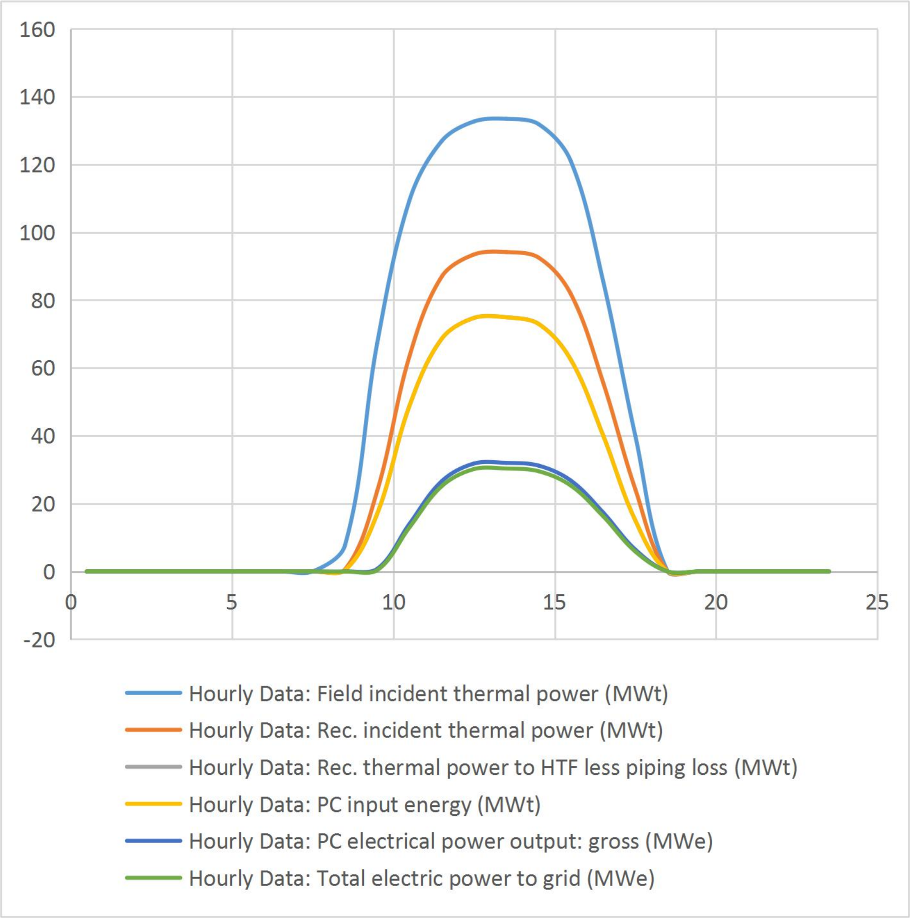

Figure 4.1 Annual net electrical output power to incident thermal power

The obtained results show that the plant has a capacity factor of 37.6 % which represent the ratio of the actual generated electric energy KWh to the nominal generated electric energy KWh in a specific periodic. The results also shows that the plant covers a total area of 2772096 m^2 and the heliostat field is composed of 3614 heliostats.

4.2.2 Annual Energy Production

In Figure 4.2 the annual electricity output for the 25 years under analysis is shown. The figure is taken from SAM. The main reason for the system electricity decrease during time is the annual system degradation factor of 0.5 % / year, which is applied to the total electricity output. The values for each year are presented in the table 4.1 .

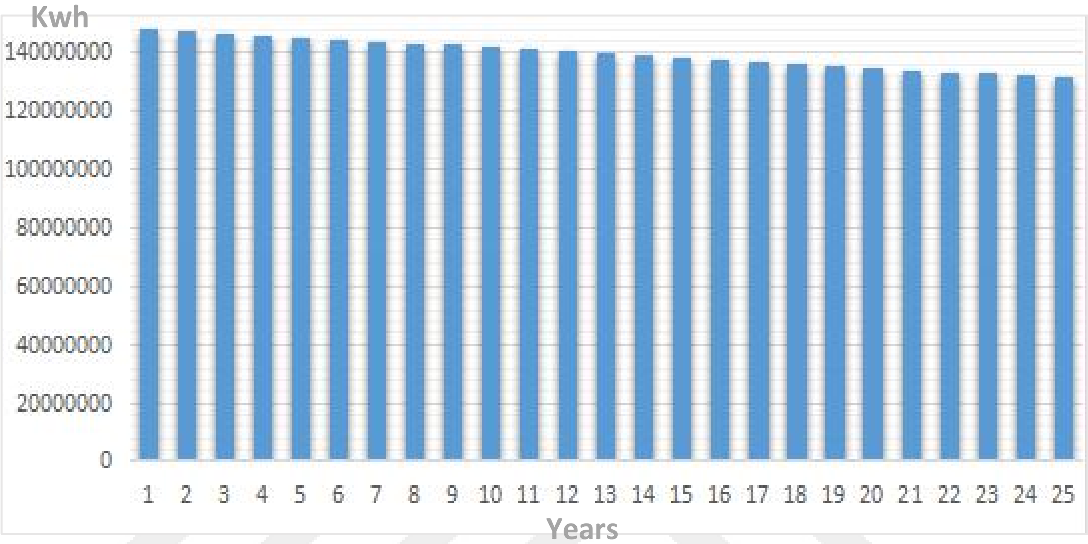

Figure 4.2 Annual energy production kWh

Table 4.2 Annually produced energy

Years	1	2	3	4	5
Energy kwh	148404000	147662000	146924000	146189000	145458000
Years	6	7	8	9	10
Energy kwh	144731000	144007000	143287000	142571000	141858000
Years	11	12	13	14	15
Energy kwh	141149000	140443000	139741000	139042000	138347000
Years	16	17	18	19	20
Energy kwh	137655000	136967000	136282000	135600000	134922000
Years	21	22	23	24	25
Energy kwh	134248000	133577000	132909000	132244000	131583000

The results also show that within each year there are changes in the produced energy value for each month . This behaviour due to the fact that the changes in the climate result in different values for the monthly received solar irradiation which is the essential source of produced energy . Next figure 4.3 shows the electric generated energy for the first year month by month , the highest and lowest values for energy are in the July and December respectively .The monthly energy values are shown in table 4.3 below.

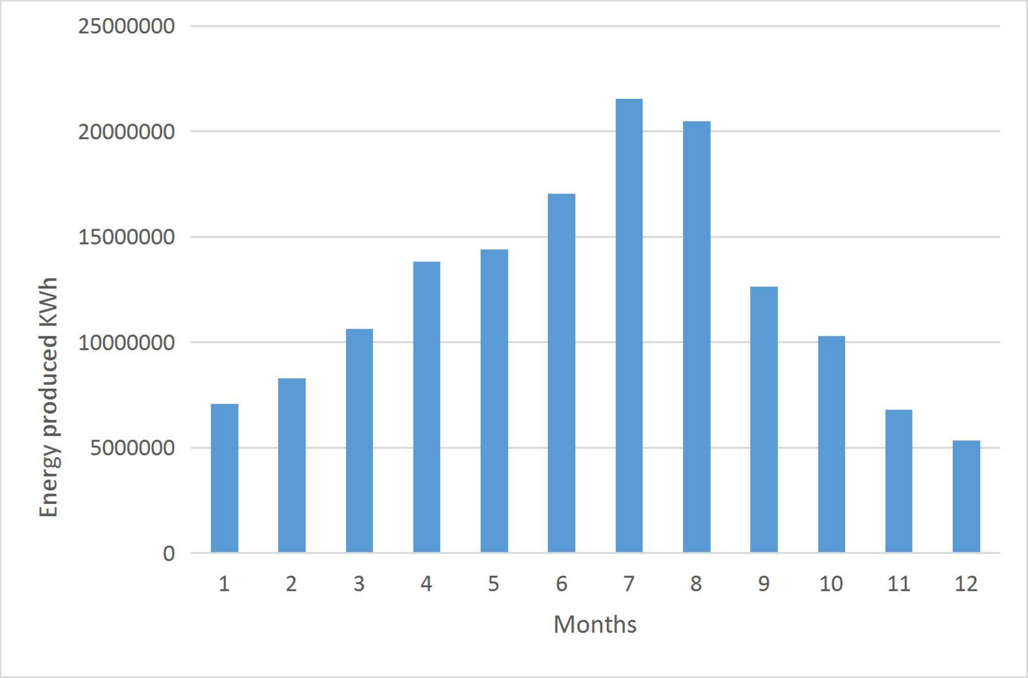

Figure 4.3 First year month by month produced energy kWh

Table 4.3 Monthly produced energy during the first year

Months	1	2	3	4	5	6
Energy kWh	7084780	8293580	10623900	13818400	14403800	17053200
Months	7	8	9	10	11	12
Energy kWh	21543700	20478600	12642800	10300700	6808820	5351700

4.3 Financial Results

In figure 4.4, the annual cash flow is represented. It comprises of over twenty-five years of the plant's lifetime. The negative cash flow of the first year means the initial 20% that required to pay by the investor. During the following years, there is a positive cash flow which decreases as a result of ageing parts and inflation rate, after a loan term of eighteen years, the reduction in payments which is specified for interest payment and loan repayment leads to an increase in cash flow .Next table 4.4 shows the parameters which calculate the net cash flow after tax which equal to the revenue from the selling of the electricity minus the manually expenses.

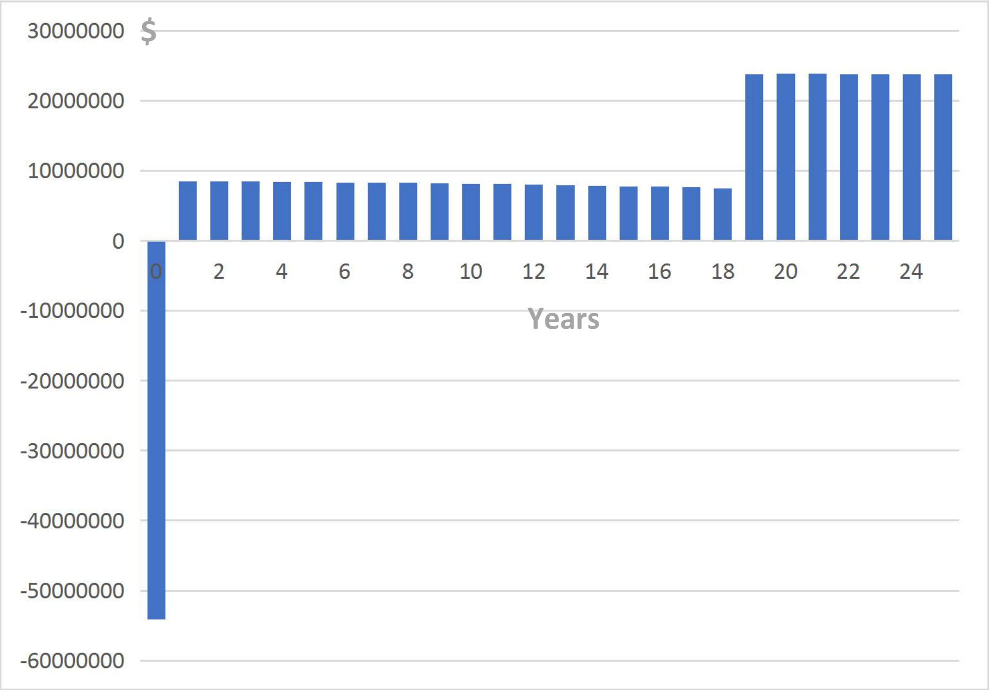

Figure 4.4 After tax cash flow

Table 4.4 cash flow calculation values

year	Energy (kWh)	PPA price cents/ kWh)	Total revenue ($)	Total operating expenses ($)	Debt total payment ($)	Benefit tax ($)	After-tax cash flow ($)
0	0	0	0	0	0	0	-54167900
1	148404000	23	34042500	4798610	16427400	-4332080	8484470
2	147662000	23	34211100	4915920	16427400	-4404230	8463530
3	146924000	23	34380400	5036100	16427400	-4478140	8438790
4	146189000	24	34550600	5159230	16427400	-4553860	8410110
5	145458000	24	34721600	5285390	16427400	-4631470	8377370
6	144731000	24	34893500	5414640	16427400	-4711040	8340420
7	144007000	24	35066200	5547070	16427400	-4792620	8299130
8	143287000	25	35239800	5682750	16427400	-4876300	8253350
9	142571000	25	35414200	5821770	16427400	-4962150	8202920
10	141858000	25	35589500	5964200	16427400	-5050240	8147700
11	141149000	25	35765700	6110120	16427400	-5140660	8087520
12	140443000	26	35942700	6259640	16427400	-5233500	8022220
13	139741000	26	36120600	6412820	16427400	-5328820	7951620
14	139042000	26	36299400	6569770	16427400	-5426740	7875550
15	138347000	26	36479100	6730580	16427400	-5527340	7793830
16	137655000	27	36659700	6895340	16427400	-5630710	7706280
17	136967000	27	36841200	7064140	16427400	-5736950	7612690
18	136282000	27	37023500	7237100	16427400	-5846180	7512870
29	135600000	27	37206800	7414310	0	-5958500	23834000
20	134922000	28	37391000	7595870	0	-5959020	23836100
21	134248000	28	37576000	7781900	0	-5958830	23835300
22	133577000	28	37762000	7972500	0	-5957910	23831600
23	132909000	29	37949000	8167790	0	-5956240	23824900
24	132244000	29	38136800	8367880	0	-5953790	23815100
25	131583000	29	38325600	8572890	0	-5950540	23802200

CHAPTER FIVE

CONCLUSION

Even with plant components that have high price rates; the project achieves a profit margin relatively high that makes the project investors give more interest for investment in such this project. On the other hand, the low price of PPA which is considered feasible economically compared to the cost of electricity production in Libya which is 34 ₵/kWh. This prices make it interesting for the Libyan Renewable Energy Authority in the utilization of solar energy projects. Furthermore, the investment of this project does not need to invest a large amount of initial cost, where a large fraction of this project is covered by loan with long periodic and low interest rate. The maintenance and operation of the plant can be an opportunity to create jobs for people locally. In the first year, a 148.4 GWh net energy is produced by this plant which equivalent to a conventional oil plant with capacity 16.94 MWe non stop running over the year to generate roughly the same amount of energy output .Comparing the 50 MWe, 8 hours storage capacity SPT plant with a conventional plant, 283 million dollars considered to be high cost to be paid compared to only 21.175 million dollars, considering a customary 1.125 million dollar for each MWe installed power for conventional plants. A total of 148.4 GWh in one year equals to 3.49 TWh all throughout its lifetime for 25 years with degradation 0.5% / year, thereby avoiding 138012 tons of CO2 production per year. On the other hand with respect to the total cost along the lifetime ,The cost of the conventional power plant with 16.94 MWe throughout its lifetime is about 1261 million according to the rate of 34 c/kWh (current of electricity production in Libya).The results has proven that the utilization of the Solar Power Tower Plant with storage system in Libya could be best source of the alternative energy to contribute in the electricity generation with no fuel consumption and no carbon dioxide emission.

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APPENDECES

Table No 1. Annual produced energy for two systems

Years	Produced energy for 100 MW no storage system (kWh)	Produced energy foe 50 MW+ 8 hours storage capacity (kWh)
1	136121000	148404000
2	135440000	147662000
3	134763000	146924000
4	134089000	146189000
5	133419000	145458000
6	132752000	144731000
7	132088000	144007000
8	131427000	143287000
9	130770000	142571000
10	130117000	141858000
11	129466000	141149000
12	128819000	140443000
13	128174000	139741000
14	127534000	139042000
15	126896000	138347000
16	126261000	137655000
17	125630000	136967000
18	125002000	136282000
19	124377000	135600000
20	123755000	134922000
21	123136000	134248000
22	122521000	133577000
23	121908000	132909000
24	121299000	132244000
25	120692000	131583000

Table no 2. Storage system output electric power to the incident thermal power

Time of day (Annual average)	Hourly Data: Field incident thermal power (MWt)	Hourly Data: Rec. incident thermal power (MWt)	Hourly Data: Rec. thermal power to HTF less piping loss (MWt)	Hourly Data: PC input energy (MWt)	Hourly Data: Total electric power to grid (MWe)	Hourly Data: PC electrical power output: gross (MWe)
0.5	0	0	0	0	0	0
1.5	0	0	0	0	0	0
2.5	0	0	0	0	0	0
3.5	0	0	0	0	0	0
4.5	0	0	0	0	0	0
5.5	0	0	0	0	0	0
6.5	0	0	0	0	0	0
7.5	0	0	0	0	0	0
8.5	7.64759	0.573652	0.342588	0.342582	-0.0436316	0
9.5	67.2905	23.7266	17.0035	17.0042	0.375297	0.752406
10.5	109.426	63.4517	48.8207	48.8178	12.9767	14.013
11.5	126.925	86.937	68.6187	68.6134	25.1433	26.6054
12.5	132.689	93.4656	74.7758	74.7531	30.1861	31.8156
13.5	133.466	94.1854	74.9696	74.9364	30.3476	32.0162
14.5	131.904	92.5565	73.0083	72.9916	29.5551	31.2072
15.5	120.989	81.8129	62.4343	62.4323	25.3197	26.7948
16.5	85.6734	55.7509	40.1439	40.1583	16.2888	17.3956
17.5	39.9354	24.1963	15.0237	15.0306	5.85594	6.42672
18.5	Average = 95.594589	0	0	0		Average = 20.78076956
19.5	0	The annual efficiency= 21.7 %				0
20.5	0					0
21.5	0	0	0	0	0	0
22.5	0	0	0	0	0	0
23.5	0	0	0	0	0	0