Modeling and Simulation of Medium Temperature Solar Thermal Rankine Cycle for Arid regions of Pakistan for Energy and Clean Water Production

By

UMER SALEEM

00000203447

Session 2017-19

Supervised by

Dr. ADEEL WAQAS

A Thesis Submitted to U.S. Pakistan Center for Advance Studies in Energy in partial fulfillment of the requirements for the degree of MASTER of SCIENCE in ENERGY SYSTEM ENGINEERING

U.S. Pakistan Center for Advance Studies in Energy (USPCAS-E)

National University of Sciences and Technology (NUST)

H-12, Islamabad 44000, Pakistan

June 2021

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by Mr. UMER SALEEM, (Registration No. 00000203447), of U.S.-Pak Centers for Advance Studies in Energy has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is within similarities indices limit and accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Approved by:

Signature: ______________________

Supervisor Dr. ADEEL WAQAS

Date: ______________________

Signature: ______________________

HoD-ESE Dr. NASEEM IQBAL

Date: ______________________

Signature: ______________________

Principal: Dr. ADEEL WAQAS

Date: ______________________

CERTIFICATE

This is to certify that work in this thesis has been carried out by **Mr. UMER SALEEM** and completed under my supervision in, U.S.-Pak Centers for Advance Studies in Energy, National University of Sciences and Technology, H-12, Islamabad, Pakistan.

Supervisor:

Dr. ADEEL WAQAS
USPCASE
NUST, Islamabad

GEC member 1:

Dr. MAJID ALI
USPCASE
NUST, Islamabad

GEC member 2:

Dr. NADIA SHAHZAD
USPCASE
NUST, Islamabad

GEC member 3:

Engr. RASHID WAZIR
SEECS
NUST, Islamabad

HoD-ESE:

Dr. NASEEM IQBAL
USPCASE
NUST, Islamabad

Principal:

Dr. ADEEL WAQAS
USPCASE
NUST, Islamabad

ACKNOWLEDGEMENTS

I am exceptionally thankful to Almighty Allah without his majesty help I could not have been able to complete this work. All the help and support from my parents and teachers were only because of Allah's Will.

I am grateful to my supervisor, Dr. ADEEL WAQAS, for the tremendous supervision, motivation and guidance he has conveyed all through my time as his understudy. I have been exceptionally honored to have a supervisor who thought such a great amount about my work, and who responded to my inquiries and questions so immediately.

I am thankful to Dr. MAJID ALI, Dr. NADIA SHAHZAD, lab engineers, lab technicians, and USPCAS-E for their provision all over the program.

I am particularly appreciative to my parents who supported me throughout my life. I am also grateful to My Loving Wife for spiritual support during the research work.

DEDICATION

I bestow this thesis to my inspirations in life, my FATHER MUHAMMAD SALEEM, who taught me how to fight against the struggles of life, my MOTHER who supported me through every thick and thin of life, my FRIENDS who taught me to be patient and work hard until you achieve your goals, my TEACHERS whom guidance helped me to achieve this status in my life and my WIFE who were always there for me.

ABSTRACT

The use of renewable energy sources to produce electrical energy and fresh water seems to be a cost-effective way to reduce the dependency on fossil fuels. To reach the objective of achieving 30% renewable energy by 2030 it would be beneficial to tap enormous solar potential of Pakistan, especially in the arid regions.

With the recent developments in solar energy conversion technologies, concentrating solar power (CSP) system attached with desalination technology for power and clean water production has become an attractive solution.

Currently, CSP systems using Parabolic Trough Collectors (PTCs) are dominating the global CSP market since these are the most mature technology and the most installed CSP systems in the world. The much lower primary energy consumption of reverse Osmosis (RO) compared to other desalination techniques suggests that RO is the preferred desalination technology. In this paper, only the electricity output of the CSP plant would be exploited in order to meet both power and clean water demands because RO is the only desalination technique which requires electricity to operate. Therefore, Simulation of a proposed solar power plant is executed using the TRNSYS software under climatic conditions of Quetta valley in Pakistan which results in power output of 15 MW. Quetta is selected due to high direct normal radiation and scarcity of the clean water.

Key Words:

Concentrating Solar Power (CSP), TRNSYS, Reverse Osmosis (RO), Renewable Energy, Parabolic Trough, and Heat Transfer Fluid (HTF).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Current Energy Scenario of Pakistan

Electricity and water are two supplies which are the necessities required by the people. For economic development energy is the basic requirement while Pakistan is suffering from energy crises and its demand for energy is increasing bit by bit due to increasing population and development in industrial and agriculture sector [1]. Energy intake per person is the index of measuring social prosperity of a nation. Energy intake per person in Pakistan is 3894 kWh against the world normal of 17620 kWh and thus Pakistan stands at 100th position in the ranking among the other states of the world [2]. Pakistan has limited conventional energy resources and it is meeting 20 % of its total energy demand indigenously while remaining 80% is met through imports [3]. The limited local energy resources have created a great concern for its future availability and energy security while in case of imports; Pakistan is spending billions of dollars which constitutes about 25% of the total imports [4, 5]. The high price of the imported fuel affects the country's economic conditions. Apart from the scarcity of the fossil fuel recourses clean water is also one of the biggest challenges for Pakistan About 20% of the whole population of Pakistan has access to safe drinking water. The remaining 80% of population is forced to use unsafe drinking water due to the scarcity of safe and healthy drinking water sources. As stated by International Monetary Fund (IMF), Pakistan is rated as third amid countries which are dealing with severe water and energy deficiency [6]. Pakistan needs to overcome the energy and clean water crises for the economic development and prosperity. It is, therefore, need of the time to explore such sources of energy which are everlasting, cheap and can also be used for production of clean water through desalination.

1.2 Problem Identification

Pakistan can meet the electricity demand by improving the exploration and mining techniques of conventional fossils fuels like oil, gas, coal, and uranium (for nuclear power plants). The fossil fuel resources have one or the other associated issues like oil and gas has limited availability which will cause resource depletion and environmental damage, coal has mining issue and not of a good quality and nuclear power plants has security problems. Dams are expensive to build for hydro power plant while transmission to furthest places is another problem. Wind energy is not available everywhere while geothermal and wave energy is limited to small scale. Thus, we left with one option; solar energy, it is extensively spread and richly presented everywhere in the country.

1.3 Solar energy potential in Pakistan

Pakistan is on sunny belt and is the sixth most blessed state in the world that is receiving maximum solar insolation and sunshine hours [7]. The solar energy is extensively spread and richly presented in the country with an annual average insolation of 4.45 to 5.83 kWh/m^2 and 2000 to 3000 annual sunshine hours [8]. The world normal solar insolation is 3.61 kWh/m^2 which is lower than the lowest value of insolation in Pakistan [9]. By capturing the solar radiations, Pakistan can generate around 2.9 million MW of electricity [10]. Figure 1.1 shows the solar radiation atlas of Pakistan which shows that Baluchistan and surrounding areas receive highest solar insolation. According to an estimate, if radiations on a 0.25% area of Baluchistan are captured by an average solar to electrical efficiency of 20%, it can meet the energy requirement of the whole country [11]. Solar energy is a renewable energy source, freely available, everlasting and environment friendly. Implementing solar energy technology can decrease the Green House Gas (GHG) emissions to 350 ppm against the current of 390 ppm [12]. Pakistan can capture these solar radiations and can generate electricity by two technologies.

- Photovoltaic technology
- Solar thermal technology

Photovoltaic technique involves solar panel which is made up of semiconductor material. When solar radiations in the form of photons falls upon solar panel, it excites the electrons in semiconductor martial into higher energy state which then acts as charge carriers for electric current whereas solar thermal technology involves the absorption of solar radiations by working fluid which then run the power cycle [13,14].

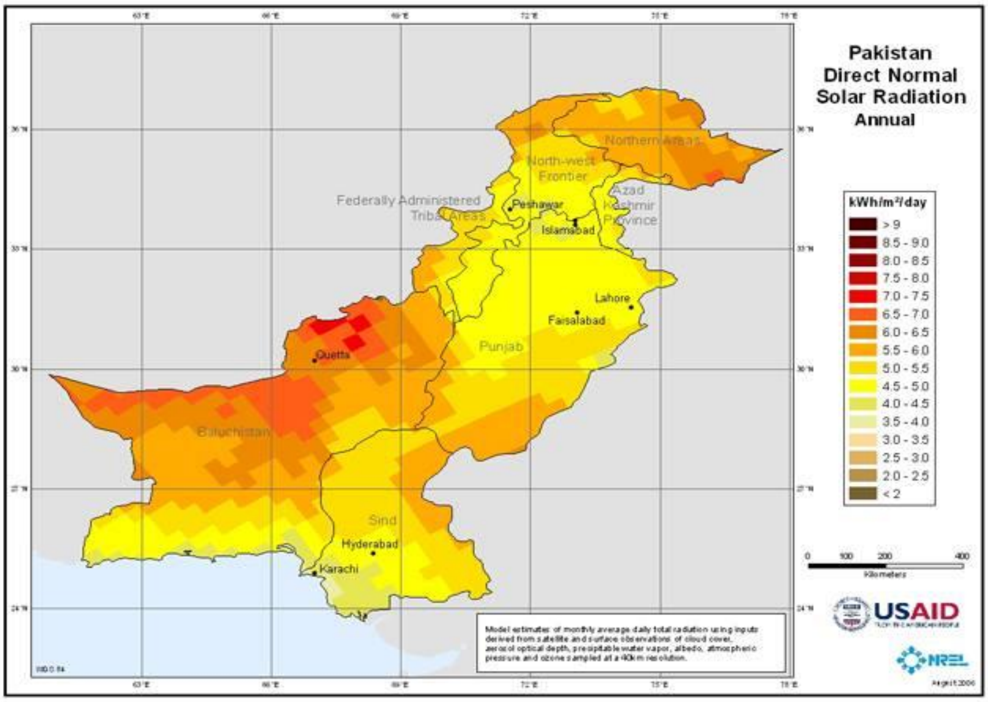

Fig. 1.1: Pakistan solar radiation map [11]

1.4 Justification of research

Photovoltaic technology is best suitable for low solar insolation, small scale electricity generation and no or small-scale storage requirement. But for large systems, when solar insolation increases from a certain level with large storage requirement, photovoltaic technology becomes costly whereas solar thermal technology becomes cost effective. It is commonly believed that plants become economical when solar insolation becomes greater than 5.0 kWh/m²/day [15]. Worldwide more than 58 solar thermal power plants are operational among which 354 MW SEGS (solar energy generating systems) is worth mentioning [16]. Main problem with using solar energy is its irregular nature. Solar intensity is at its peak during noon hours. It starts rising from the start of the day and comes to lowest value during evening hours. Furthermore, clouds also block the solar irradiations during the day. To cater this, a small-scale desalination plant equipped with low energy consumption technology can be used to produce clean portable water only during cloudy or low irradiation hours. Up till now, small-scale RO (reverse osmosis) desalination systems range from 10 m³/day to 1000 m³/day, have been built to yield potable water from brackish or seawater. In this way, we can supply power to grid during most of the day to overcome load shedding and can produce fresh distilled water during cloudy or low irradiation hours. The usage of alternative energy sources for the making of electrical energy and fresh water seems to be a cost-effective way to reduce the dependency on fossil fuels. With the recent developments in solar energy conversion technologies, concentrating solar power (CSP) system attached with desalination technology for power and clean water production has become an attractive solution. The combination of the solar Rankine cycle (SRC) plants with multiple effect desalination (MED) and reverse osmosis (RO) water purification systems was investigated by Iaquaniello et al. [17]. Water purification techniques and their promising combination with CSP and PV electricity power were evaluated by Fiorenza et al. [18]. A thermo economic analysis of dual purpose (SRC/MED and SRC/RO) CSP plants was executed by Ortega-Delgado et al. [19]. Reverse osmosis (RO) is a pressure-compelled method that account for the most of brackish water and seawater desalination capacity on the basis of its comparatively low energy consumption [20]. In reverse osmosis technique, needed form of energy is only electricity. Pumps at various stages in reverse osmosis process are driven by the AC electricity. Specifically for a brackish-water reverse osmosis (BWRO) unit, depending upon the salinity of water energy requirement varies from 1.5 to 2.5 kWh/m³ [21]. This study aims at technical feasibility of medium temperature solar thermal Rankine cycle for energy and water production.

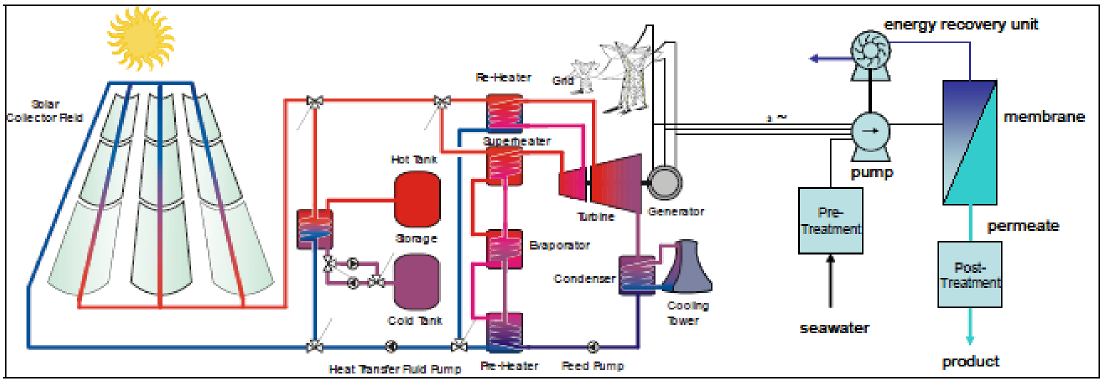

Fig. 1.2: Schematic of a CSP/RO desalination plant [22]

1.5 Advantages of Solar Thermal Power Plant

- Solar energy is freely available everywhere.
- The power generation is environment friendly.
- It is reliable and proven technology and hence involves low technical and financial risk.

- It has less payback period time.
- The cost of power generation is comparable to conventional fossils fuels power plants.
- The possibility of thermal storage and hybrid fueling ensures the power availability around 24 hours.

1.6 Objectives

The central aims of this research are to determine:

- To select the most appropriate location for the installation of Parabolic Trough Solar Thermal Power Plant

- To evaluate the energy production along with thermal behavior of proposed medium temperature Rankine cycle driven by the solar field.

- To determine the most suitable desalination technique to be coupled with above mentioned power plant under climatic conditions of Pakistan.

1.7 Scope and Limitations

This study aims at installing of the medium temperature Rankine cycle driven by the solar energy for the purpose of evaluating the energy production along with thermal behavior of the installation for one year. In this study, a proposed model with output capacity of 15 MW PTSTPP is simulated in TRNSYS software whereas simulations are generated for time period of one year. The model is designed for optimum power output along with energy efficiency measures. A location with highest Direct Normal Irradiance (DNI) is selected whom weather data is available in TRNSYS database. In this work, only the electricity output of the CSP plant would be exploited in order to meet both power and clean water demand because RO desalination technique also requires electricity to operate. The power plant will function only in sun shine hours with DNI greater than 700 $kJ/hr.m^2$ and with no thermal storage. While carrying out simulations, the default parameters of Patnode and Luz System second generation (LS-2) models are considered for solar field [23, 24] and sufficient water availably is presumed. Due to non- availability of weather data of each location of Pakistan, simulation has been carried out for the locations with available weather data.

1.8 Organization of Thesis

- ✓ CHAPTER 1, INTRODUCTION
  - o Pakistan 's energy scenario and clean water stress, Problem Identification, Solar energy potential in Pakistan, Justification of research, Advantages of solar thermal power plant, Objectives, Scope of the research, Limitations of the research
- ✓ Chapter 2, BACK GRAOUND AND LITERATURE REVIEW
  - o Solar thermal power plants, Selection of the technology, Components of Parabolic Trough Collector, Weather data , Solar radiations, Solar angles, Basic working of Desalination system, Solar Desalination process, Existing Methods of Desalination, Selection of most suitable Desalination Technology
- ✓ Chapter 3, RESEARCH METHODOLOGY
  - o Approach of study, TRNSYS , Mathematical Model, Components employed in simulation, Block Flow Diagram of 9 MW PTSTPP

Chapter 4, OUTCOMES AND DISCUSSION

  - o Simulation outcomes, why beam radiation varies? , Required conditions for constructing PTSTPP, Outcomes
- ✓ Chapter 5, CONCLUSIONS AND RECOMMENDATIONS
  - o Conclusions and future recommendations

Summary

Energy importance for economic development of a country and clean water crises of Pakistan has been briefly discussed in this chapter. Several energy sources have been considered but due to associated issues with those sources, solar energy came out as a finest way out to meet power and desalination energy requirement in Pakistan. The usage of high intensity solar irradiations in the country to produce electricity and clean water is discussed. Different solar to electricity generating technologies have been discussed from which solar thermal power generation technology is selected due to its advantages in Pakistan ‘s scenario. Moreover, the objectives, scope and limitations of the research is also stated while at the end, organization of thesis has been discussed in a figurative way.

References

[1] Harijan, Khanji, Muhammad Aslam Uqaili, and Mujeebuddin Memon. "Renewable energy for managing energy crisis in Pakistan." International Multi Topic Conference. Springer Berlin Heidelberg, 2008.

[2] http://atrc.net.pk/resources/pakistan/renewable_energy/pdf (accessed June 30, 2020).

[3] Muneer, T., and M. Asif. "Prospects for secure and sustainable electricity supply for Pakistan." Renewable and Sustainable Energy Reviews 11.4 (2007): 654-671.

[4] http://bukshenergy.com/wp-content/uploads/2012/11/Why-invest-in-Clean-energy- lending-in-Pakistan.pdf (accessed Jan 31, 2020).

[5] Ghaffar, Mohammed A. "The energy supply situation in the rural sector of Pakistan and the potential of renewable energy technologies." Renewable energy 6.8 (1995): 941- 976.

[6] Nabi, G., Ali., Khan, S. et al. Environ Sci Pollut Res (2019) 26:10443.

[7] Raja, Nusrat Kamal, et al. "Design and manufacturing of parabolic trough solar collector system for a developing country Pakistan." J Am Sci 7.1 (2011): 365-372.

[8] Sheikh, Munawar A. "Energy and renewable energy scenario of Pakistan." Renewable and Sustainable Energy Reviews 14.1 (2010): 354-363.

[9] Löf, George OG, John A. Duffie, and Clayton O. Smith. "World distribution of solar radiation." Solar Energy 10.1 (1966): 27-37.

[10] Bhutto, Abdul Waheed, Aqeel Ahmed Bazmi, and Gholamreza Zahedi. "Greener energy: Issues and challenges for Pakistan—Biomass energy prospective." Renewable and Sustainable Energy Reviews 15.6 (2011): 3207-3219.

[11] http://bukshenergy.com/wp-content/uploads/2012/11/Why-invest-in-Clean-energy- lending-in-Pakistan.pdf (accessed Fab 10, 2020).

[12] Farooqi, Anjum Bari, Azmat Hayat Khan, and Hazrat Mir. "Climate change perspective in Pakistan." Pakistan J. Meteorol 2.3 (2005).

[13] Shah, Arvind, et al. "Photovoltaic technology: the case for thin-film solar cells." science 285.5428 (1999): 692-698.

[14] Thirugnanasambandam, Mirunalini, Selvarasan Iniyan, and Ranko Goic. "A review of solar thermal technologies." Renewable and sustainable energy reviews 14.1 (2010): 312-322.

[15] Tsoutsos, Theocharis, Vasilis Gekas, and Katerina Marketaki. "Technical and economical evaluation of solar thermal power generation." Renewable Energy 28.6 (2003): 873-886.

[16] Jensen, C., H. Price, and D. Kearney. "The SEGS power plants: 1988 performance." 1989 ASME international solar energy conference, San Diego, CA. 1989.

[17] G. Iaquaniello, A. Salladini, A. Mari, A.A. Mabrouk, H.E.S. Fath, “Concentrating solar power (CSP) system integrated with MED–RO hybrid desalination,” Desalination, 336 (2014) 121–128.

[18] G. Fiorenza, V.K. Sharma, G. Braccio, “Techno-economic evaluation of a solar powered water desalination plant,” Energy Convers. Manage., 44 (2003) 2217–2240.

[19] B. Ortega-Delgado, L. García-Rodríguez, D.C. Alarcón-Padilla, “Thermo economic comparison of integrating seawater desalination processes in a concentrating solar power plant of 5 MWe,” Desalination, 392 (2016) 102–117.

[20] M. Elimelech, W.A. Phillip, “The future of seawater desalination: energy, technology, and the environment,” Science 333 (2011) 712–717.

[21] Semiat R. “Energy issues in desalination processes, “Environmental Science and Technology 2008; 42(22).

[22] Houda Ben Jannet Allal, “Combined Solar Power and Desalination Plants: Techno-Economic Potential in Mediterranean Partner Countries”, MED - CSD, 2009.

[24] Price, Hank, et al. "Advances in parabolic trough solar power technology." Journal of solar energy engineering 124.2 (2002): 109-125.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Solar thermal power plants

These are power plants which harness solar energy in the shape of thermal energy and then convert it to the electrical energy [1]. It utilizes three types of technologies depending upon the capturing of thermal energy [2].

- Solar power tower
- Dish stirling
- Parabolic trough collector

2.1.1 Solar Power Tower

It utilizes mirror of flat surface called heliostat and equipped with two axis tracking mechanism which focuses solar radiation on a tower called receiver which absorb these radiations and exchanges its heat with working fluid which may be a liquid or gas and that runs the power cycle [3].

Figure 2.1 Solar Power Tower [4]

2.1.2 Dish Stirling

It is a dish shaped mirror that concentrates solar radiation on its focal point where receiver is placed which absorbs these radiations and form steam which runs Stirling engine which is further coupled with generator and thus electricity is produced [5].

Figure 2.2 Dish Stirling [6]

2.1.3 Parabolic trough collector

It comprises of a parabolic shape mirror that focuses the falling solar radiation on its pivotal mark wherever absorber pipe is contemporaneous which collects the heat and handover it towards Heat transfer fluid (HTF) which generates steam and hence electricity is generated [7].

Figure 2.3 Parabolic trough collectors [8]

2.2 Selection of CSP Technology for Current Research

Solar Power Tower is the emerging solar thermal power generation technology and several pilot commercial power plants have been installed worldwide but this is a time-tested technology and needs further maturity whereas Dish Stirling technology is limited to demonstration projects and no commercial power plant with this technology have been mounted yet. Conversely, Parabolic Trough Collector based solar plants are the most matured in market besides around 58 PTSTPP are working worldwide [9]. It involves low technical and financial risk and that's why we have selected parabolic trough collector technology for generation of electricity [10].

2.3 Components of Parabolic Trough Collector

Parabolic trough collector consists of following two main components.

- Heat collection element
- Mirror reflector

2.3.1 Heat collection element

It is a steel tube layered with black chrome or appropriate cermet coating for enhancing solar radiation absorption which is surrounded by glass envelop and made evacuated to limit radiation and conviction losses [11]. The heat is gained by HTF flowing in the tube.

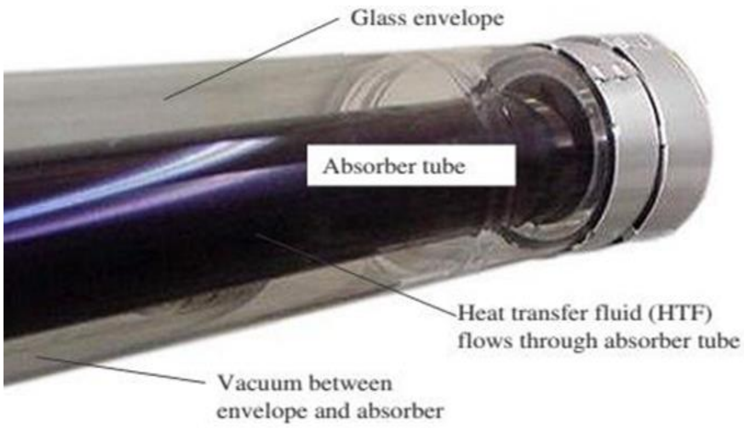

Figure 2.4 Heat collection element [12]

2.3.2 Mirror reflector

It's a parabolic shape mirror of high coefficient of reflection that concentrate solar radiation along its focal line on steel absorber tube.

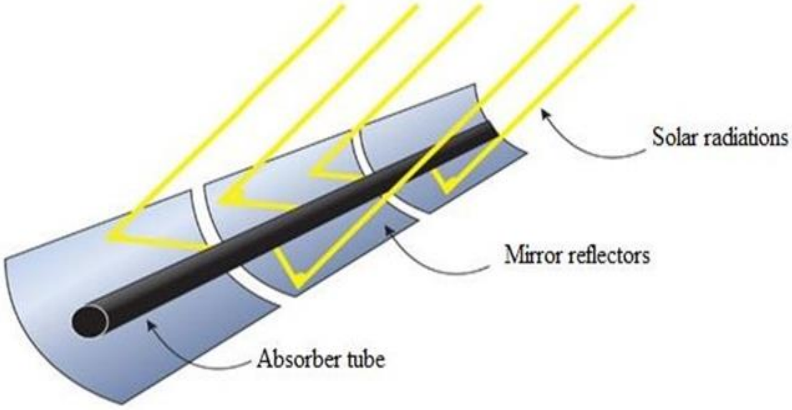

Figure 2.5 Mirror reflectors [12]

The characteristics and losses consideration for LS-2 parabolic trough collector are given in table 2.1 and 2.2 correspondingly.

Table 2.1 Features of LS-2 Parabolic trough collector [13]

Characteristics	Value/type
Diameter of absorber tube ‘m’	0.070
Concentration ratio	71
Diameter of Pyrex glass envelope ‘m’	0.115
Reflectivity of mirror	0.93
Coefficient of absorption of absorber tube	0.96
Coefficient of emission of absorber tube	0.14
Coefficient of transmission of absorber tube	0.95
Rim angle	70^{o}
Operating temperature(°C)	100-400

Concentration ratio of parabolic trough can be defined as ratio between collector aperture area and the total area of absorber tube. Typical values of concentration ratio are about 20, even though maximum theoretic value is in the order of 70. The temperature level attained during conversion of solar energy into thermal energy depends on the system being utilized. Medium temperature solar concentrators (parabolic trough collectors) can achieve the temperature up to 400 C° while central receiver systems or dish concentrators are employed for high operating temperature. The steel pipe used in typical receiver tube of PTC is on condition that careful coating absorptivity more than 90% and little solar emissions lower than 30% in order to reduce thermal losses from radiations. Reflectors also show a significant role in the performance of PTC because its optical efficiency is related to solar reflectance of mirrors. Durability and solar reflectance of glass mirrors "~0.92" are better than aluminum polished sheets "~0.87" [14].

Table 2.2 Parameters of LS-2 Parabolic trough collector [13]

Length of absorber tube (m)	4.0
Module size (m^2)	(47.1m) *(5m)
Aperture area (m^2)	235
Focal length (m)	1.84
HCE	Evacuated tube
Absorber material	321H
Absorber selective coating	Solel UVAC Cermet

If the working temperature is below 290ºC, a cheap electrically deposited black-chrome or black-nickel coating can be used. For higher temperatures, sophisticated cermet coatings manufactured by physical vapor deposition (PVD) or sputtering are required to achieve a good thermal efficiency (~70%) of the PTC. Due to manufacture constraints, the maximum length of single absorber pipe is less than 6 meters [14].

Table 2.3 Losses consideration for LS-2 Parabolic trough collector [15]

Losses	Value
Cleanliness of solar field	0.95
Heat losses (kW)	257
Penetrating loss/area (W/m^2)	20
TrkTwstErr	0.99
HCEdust	0.98
Belshad	0.97
GeoAcc	0.98

Parabolic-trough collectors are usually installed with their tracking axis oriented either North-South or East-West. The orientation of the tracking axis has a significant influence on the Sun's incidence angle onto the aperture plane of the collectors which, in turn, affects the collector's performance [14]. Losses associated with tracking mechanism are TrkTwtErr, Belshad and GeoAcc.

2.4 Weather data

Typical Meteorological Year (TMY) data has been used in the simulation of solar field. TMY is an average climate condition of a specific site completed in definite span of time. It includes global horizontal irradiations and beam horizontal irradiation along with Direct Normal Irradiations, ambient temperature, and wind speed and sun position with one-hour time step. The TMY meteorological conditions facts are occupied from Meteonorm weather statistics ignoble [16].

2.5 Heat Transfer Fluid (HTF)

HTF is employed to extract heat from the heat collection element of parabolic trough collector. Several varieties of HTF depend on the application and physical condition of a system like temperature etc. In solar thermal application, it must have the following properties.

- Outstanding heat transfer properties
- High temperature stability
- High heat capacity
- Low viscosity
- High freezing point
- High boiling point

Therminol VP-1 have almost all the qualities that's why it has been selected as a HTF in current research. It is a synthetic HTF and has a fusion of Biphenyl (26.5%) with diphenyl oxide (73.5%). Properties of Therminol VP-1 are given in Table 2.3.

Table 2.4 Attributes of Therminol VP-1 [17]

Properties	Value
Form	Clear, water white liquid
Specific heat of HTF at 400 C°	2.62 kJ/kg.K
Kinematic viscosity at 40 C°	2.48 mm^2/s
Liquid density at 25 C°	1060 kg/m^3
Coefficient of thermal expansion at 200 C°	0.000979/C°

The collection of the employed liquid for a planetary arena with parabolic trough collectors is a vital choice in the project point. Current oil is the liquid usually used in parabolic accumulators for high temperature above 200 C° because these operation high temperatures would crop tall heaviness intimate the telephone cylinders and penetrating if usual liquid were rummage-sale. This extraordinary heaviness would require tougher linkages and penetrating, and thus increase the value of the accumulators and whole astral arena [14].

2.6 Solar Angles

The variation in the availability of solar radiations can be best understood from the geometry and the movement of earth around the sun. Earth revolves in elliptical orbit of having its center at offset.

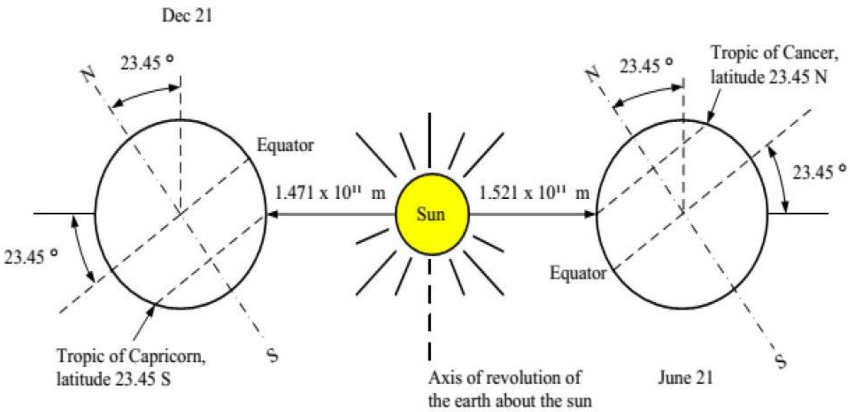

Figure 2.6 Declination angle [18]

Thus, the distances between sun and earth changes from maximum of 1.52 x 1011m at winter solstice (December 21, 22) and minimum of 1.47 x 1011m at summer solstice (June 21, 22) whereas the average distance is 1.49 x 1011m. It is therefore the solar radiations received on earth changes throughout the year. The axis about which earth spins also varies daily between 23.45 and -23.45. This is called tilt which changes daily and constant the whole day. It is the tilt due to which we see seasons on earth. The angle between earth’s equatorial plan and the line linking centers of earth and sun is termed declination angle.

$$\delta = 23.45 \sin[\,360\ (284 + n)/365] \quad \ldots\ldots \text{Eq. (2.1)}$$

Where n is the number of the days.

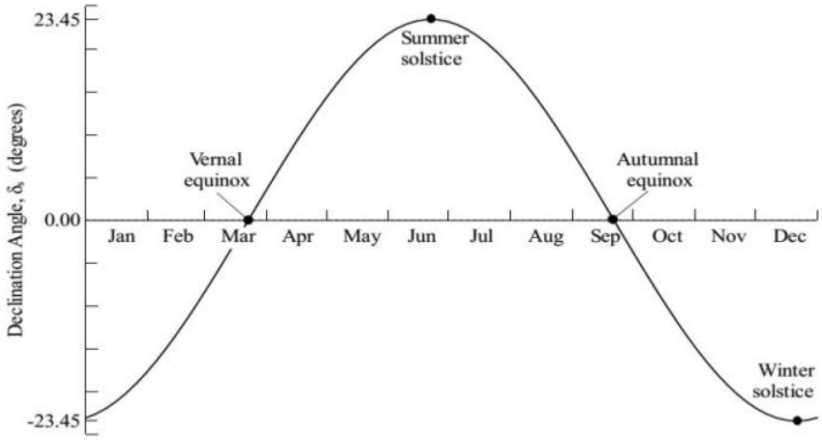

Figure 2.7 Different positions of declination angle in a year [18]

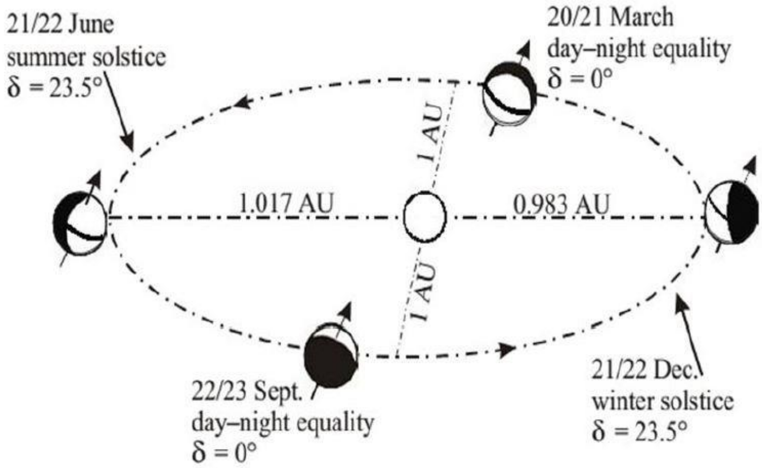

Figure 2.8 Tilt of earth [18]

The sun position is defined by two different angles; altitude and azimuth angle. Solar altitude is the angle between central rays from the sun and horizontal that contains the viewer. It is also called solar elevation angle whereas azimuth is the angle amid due south and projection of ray of horizontal. It is positive west of south and negative east of south. Zenith angle is the angle between vertical line and the sun ray on the specific location.

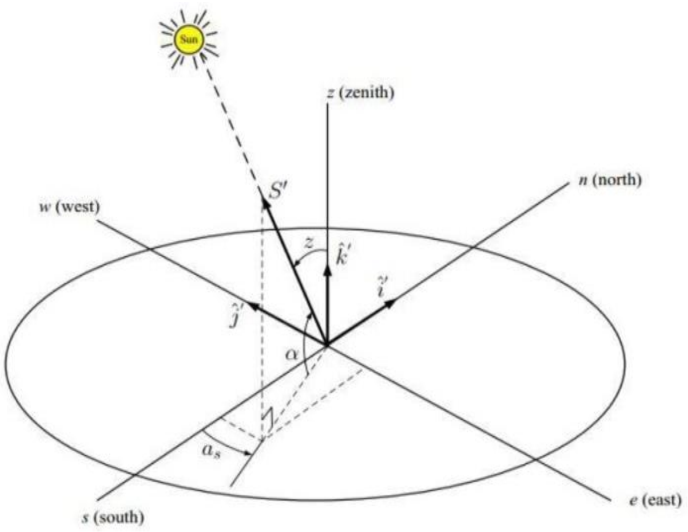

Figure 2.9 Solar angles [19]

2.7 Basic Working of a Desalination System

The process of removal of salts and other impurities from unhealthy water contains of a saline stream going into the arrangement, and a cleansed water stream and a brine stream coming out of the structure. Work is done by the system to start the removal of salts from the freshwater stream, limiting them in the brine stream.

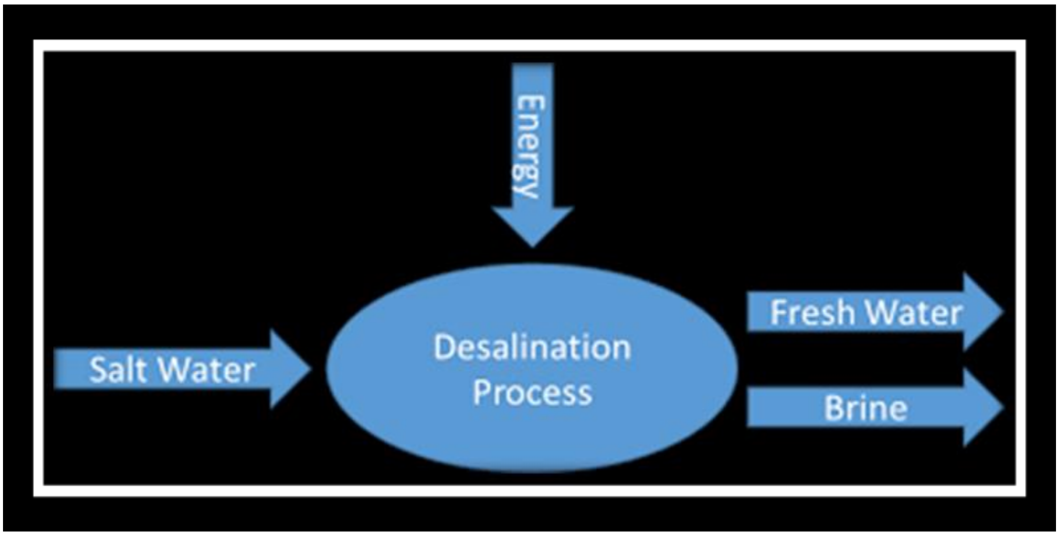

Figure 2.10 Schematic of a Desalination system

2.8 Solar Desalination process

In solar desalination process, the driving force is solar energy which is converted to Thermal energy and fresh water is extracted from a targeted saline water body which can either be surface or subsurface. This process is like the natural water cycle, in the natural water cycle it is observed that solar energy evaporates water from the earth`s surface by converting it into steam. In the same way, solar energy in solar desalination systems functions as a heating source to heat up the feed water in solar collector and evaporate fresh vapors that are further condensed in the form of fresh condensate and are collected for drinking purpose. Following are the two main categories of solar driven desalination.

- Direct Desalination
- Indirect Desalination

2.8.1 Direct Desalination Technologies

Direct solar powered desalination technologies involve the direct employment of solar energy to produce fresh water. The direct desalination technologies mostly involve the utility of solar stills, solar chimneys, solar humidification and de-humidification and freeze thaw desalination systems.

2.8.2 Indirect Desalination Technologies

Indirect solar powered desalination technologies involve indirect processes whereby the solar energy is first converted to selected type of energy which is then employed in desalination, hence employing two sub systems. Several conventional desalination technologies can be used as indirect desalination systems, if the fuel used is replaced with solar energy. Indirect desalination technologies involve:

- Thermal based desalination processes.
- Membrane based desalination processes.
- Chemical based desalination processes.

2.9 Existing methods of Desalination

The following table lists the commonly used desalination systems along with their basic process:

Table 2.5 commonly used desalination systems and their basic processes.

S#	Method	Basic Process
1	Vacuum Distillation	It involves the processing of required liquid Sample under reduced pressure which enables it to boil at a temperature lower than the normal boiling temperature. [20]

2	Multi-Stage Flash Desalination	It involves vaporization of salty water in a vacuum environment having lower temperature whereby it is observed that the vacuum pressure boils the water while using lower energy than usual boiling. [21]
3	Multi-Effect Distillation	It involves reheating of input water at every stage whereby heating takes place by the steam tubes, usually by spraying of saline water on them. Evaporation takes place at each stage as steam flows in each chamber hence heating and evaporating more water. [21]
4	Vapor Compression Distillation	Compressed vaporization technique is used for delivery of heat and generation of vapor in this process. [20]
5	Reverse Osmosis	Involves the usage of a semi-permeable membrane for the removal of ions, molecules other larger particles within the input water stream. [22]
6	Electro-dialysis Reversal	It is a reversal membrane desalination process whereby electric current collects the dissolved salt ions by the usage of an electro dialysis stack which consists of both cationic and anionic ion exchange membranes. [23]

2.10 Selection of Most Suitable Desalination Technique

Purification of brackish water for drinking purpose describes the desalination of saline water with much lesser salt content as compared to seawater, generally from saline wells and river estuaries. Water purification plants throughout the world mostly used Multiple-effect distillation, multi-stage flash and reverse osmosis desalination methods. Among this industrialization of Reverse osmosis technique has been more widespread worldwide because of its comparatively low energy requirements [24]. Following the evaluation of more effective energy recovery devices and upgraded membrane materials, energy consumption of reverse osmosis has been dropped to 3kWh/m^3. Specifically for a brackish-water reverse osmosis (BWRO) unit, depending upon the salinity of water energy requirement varies from 1.5 to 2.5 kWh/m^3 [25]. RO apparatus is normalized containing pumps, motors, pressure gages etc. Thus making learning time for unskilled labor short. Keeping in view the place of installation in Pakistan i-e Quetta city, Reverse osmosis which has 80% portion in overall number of installed desalination plants globally [26], is selected as desalination technique to be integrated with Parabolic Trough Solar Thermal Power Plant.

Summary

Solar thermal power generation utilizes three different technologies i.e. solar power tower, dish Stirling and parabolic trough collector technology. Among these, parabolic trough collector technology is the utmost mature one and thus it involves low technical and financial risk. PTC consists of HCE and parabolic shaped mirror called reflector. Solar radiation is reflected and get concentrated on HCE where it is absorbed. The heat from HCE is then taken by HTF which generates steam from feed water in the heat exchanger. The weather data is taken from Meteonorm whereas Therminol VP-1 is used as a HTF for having an excellent heat transfer properties. The relative position of earth with respect to sun changes and hence its affects the performance of power plant. Meant for the production of water along with power among different desalination techniques, reverse osmosis was chosen as most suitable because it has developed over past 40 years hence it involves low maintenance and technical risks.

References

[1] Schnatbaum, L. "Solar thermal power plants." The European Physical Journal- Special Topics 176.1 (2009): 127-140.

[2] Mills, David. "Advances in solar thermal electricity technology." Solar energy 76.1 (2004): 19-31.

[3] Xu, Chao, et al. "Energy and exergy analysis of solar power tower plants." Applied Thermal Engineering 31.17 (2011): 3904-3913.

[4] http://climatekids.nasa.gov/concentrating-solar/ (accessed July 31, 2020).

[5] Osborn, Bruce, et al. "Dish-Stirling systems: An overview of development and status." (2003).

[6] https://www.cnet.com/news/solar-dish-maker-stirling-files-for bankruptcy/ (accessed July 31, 2020).

[7] Price, Henry. "A parabolic trough solar power plant simulation model." ASME 2003 International Solar Energy Conference. American Society of Mechanical Engineers, 2003.

[8] https://www.flickr.com/photos/44742231@N03/4111626597 (accessed July 31, 2020).

[9] https://en.wikipedia.org/wiki/List_of_solar_thermal_power_stations (accessed July 31, 2020).

[10] Poullikkas, Andreas. "Economic analysis of power generation from parabolic trough solar thermal plants for the Mediterranean region—cases study for the island of Cyprus." Renewable and sustainable Energy reviews 13.9 (2009): 2474-2484.

[11] Huang, Weidong, Peng Hu, and Zeshao Chen. "Performance simulation of a parabolic trough solar collector." Solar Energy 86.2 (2012): 746-755.

[12] http://himinsun.com/1-3-parabolic-trough-receiver.html (accessed July 31, 2020).

[13] H. Price, E. L pfert, D. Kearney, E. Zarza, G. Cohen, R. Gee, R. Mahoney, Advances in Parabolic Trough Solar Power Technology, J. Sol. Energy Eng. 124 (2002) 109. doi:10.1115/1.1467922.

[14] SOLAR ENERGY CONVERSION AND PHOTOENERGY SYSTEMS – Vol. I - Medium Temperature Solar Concentrators (Parabolic-Troughs Collectors) - E. Zarza. Available online at: http://www.eolss.net/sample-chapters/c08/E6-106-05.pdf (accessed Sep 27, 2020).

[16] http://www.meteonorm.com/ (accessed July 31, 2020).

[17] https://www.therminol.com/products/Therminol-VP1 (accessed July 20, 2020).

[18] http://www.itacanet.org/the-sun-as-a-source-of-energy/part-1-solar-astronomy/ (accessed July 31, 2020).

[19] http://www.mpoweruk.com/solar_power.htm (accessed July 31, 2020).

[20] Rief, H., and Alhalabi, W., 2015. Solar powered thermal desalination: its significant Challenges and potential. Renewable and Sustainable Energy Reviews, vol. 48, 152-165.

[21] Dessouky, H., Alatiqi I., and Ettouney, H., 1988. Process synthesis: Multi Stage Desalination System. J. Elsevier: Desalination. Vol: 115 (2), 155-179.

[22] World Health Organization (WHO), Safe drinking water from Desalination, 2011. Available Online at: http://apps.who.int/iris/bitstream/10665/70621/1/WHO_HSE_WSH_11.03_eng.pdf (accessed July 31).

[23] JooLee, H., Sarfert F., Strathmann., H., and HyeonMoon, S., 2017. Designing of an electro dialysis desalination plant. J. Elsevier: Desalination. Vol: 142 (3), 267-286.

[24] Warsinger, David M.; Mistry, Karan H.; Nayar, Kishor G.; Chung, Hyung Won; Lienhard V, John H. (2015). "Entropy Generation of Desalination Powered by Variable Temperature Waste Heat". Entropy. 17 (11): 7530–7566.

[25] Semiat R. “Energy issues in desalination processes, “Environmental Science and Technology 2008; 42(22).

CHAPTER 3

Research Methodology

This section provides the approach which is adopted to carry out the study. The mathematical description of the power plant is also discussed. The steps which are followed for modeling and simulation of the system are shown in figure 3.1

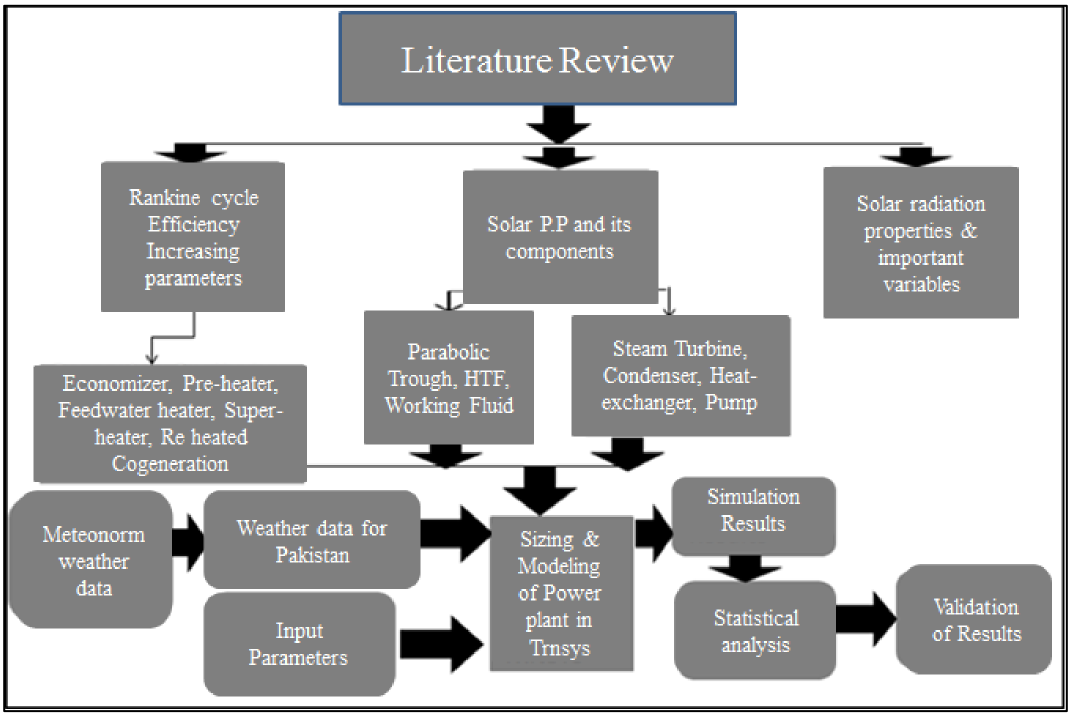

Fig. 3.1: Research Methodology

Literature review is done thoroughly to understand the Rankine cycle efficiency parameters, solar power plant and its components and solar irradiation properties with different variables. Climatic data of the location is taken from Meteonorm weather data base in the form of TMY file. Weather data of only five cities are available i.e. Peshawar, Lahore, Multan, Karachi, and Quetta. A 15 MWe power plant model is produced in TRNSYS using parabolic trough collector. Characteristics of LS-2 parabolic trough collector have been used in simulation of solar field and are given in table 2.1. Therminol VP-1 is selected as a HTF and its characteristics are given in table 2.3. Effects of HTF flow rate on output temperature in solar field are identified. Output power of the Rankine cycle is analyzed by varying the input values of components like super heater, evaporator and condenser etc. Two closed feed water heaters and one open feed water heater (deaerator) are linked to increase the thermal effectiveness of the Rankine cycle. In the end, statistical analysis is performed to validate the simulation results with expected results.

3.1 TRNSYS: The Real Time Simulation Software

TRNSYS is real time simulation software innovated by Solar Energy Laboratory, University of Wisconsin-Madison and is used for the real time simulation of structures as well as multi-zone buildings. It is used by engineers and researchers all over the world to certify new energy models from artless domestic hot water systems to the design and simulation of buildings and their apparatus, including control schemes, occupant performance, alternative energy systems like wind, solar, photovoltaic and hydrogen systems etc. The components are programed in FORTRAN language, and it connects inputs to the outputs using a governing equation. It also allows user to design new type of component by means of all shared program writing dialects like PASCAL, and FORTRAN etc. Furthermore, TRNSYS can be effortlessly connected to several further solicitations for pre- or post-processing or over collaborative appeals all through the imitation. A TRNSYS project is usually formulized by linking elements explicitly in the Imitation Studio. Every single Kind of constituent is defined via a calculated archetypal in the TRNSYS imitation software and has a set of similar Performa's in the Imitation Workshop. The preforma has a black-box portrayal. The key visual interface is the TRNSYS Simulation Studio. Starting here, the user can create projects by tedious and dipping mechanisms to the workspace, linking them in organized manner and selecting the universal simulation constraints. The Solar Thermal Electric Component STEC library framed in thermodynamic quantities (enthalpy, temperature, and pressure) contains proper models for solar field and Rankine cycles. The simulation Studio also contains yield administrator from where one can governor which variables are to be combined permits you to learn in detail what occurred through a simulation [1]. It has several libraries like Thermal Energy System Specialist (TESS) and Solar Thermal Electric Component (STEC) library etc. STEC library is used especially for modeling of solar thermal power plants [2]. TRNSYS applications include:

- Solar systems (solar thermal and photovoltaic)
- Low energy buildings
- Alternative energy systems

- Cogeneration and fuel cells
- Whatsoever that involves dynamic simulation

3.2 Mathematical Model

The size of total aperture area required to produce 15 MW power output is found by the energy balance between HTF and generated steam at reference weather conditions. Fixing the aperture area of single parabolic trough collector, overall number of solar collectors can be found by:

$$N = Aapp \div Ac \quad (1)$$

Where Ac and Aapp are the area of single PTC and total aperture of the solar field.

The number of radiations absorbed by HTF is given by:

$$Q = G\cos(\theta) \cdot IAM \cdot RowShadow \cdot Endloss \cdot \eta(field) \cdot (HCE) \cdot SFAvail \quad (2)$$

Where G is the solar radiation flux in W/m², ‘θ’ is incident angle, Row Shadow represents the factor which stands for shared shading of parallel collector rows, End loss describe the losses from end of HCEs, η (field) is field effectiveness that accounts for losses due to mirror optics and deficiencies, η (HCE) is HCE effectiveness that shows losses due to HCE optics and deficiencies. While SFAvail is the portion of field that is available and following the sun and IAM is incidence angle modifier which is given by [3]:

$$K = cos(\theta) + 0.000884(\theta) + 0.00005369(\theta) \quad (3)$$

Here ‘ɵ’ is the angle of incidence of solar radiations. Adopted values of optical properties are given in Table 1.

The solar energy gain by HTF is given by:

$$Qabs = I \cdot Aaperture \cdot [LMS \cdot (A + B) \div 2 \cdot (\Delta Ti + \Delta To)] + \frac{C(\Delta Ti + \Delta To)}{2I} + D \cdot (\Delta Ti - \Delta To)^3/2I \cdot (\Delta Ti + \Delta To) \quad (4)$$

Where A, B, C and D are empirical factors which describe the properties of PTC, and its values are given by Lippke [4]. While M is the incidence angle modifier, L is the losses associated with PTC and S represents the shading of parallel rows. The end losses of PTC are given by:

$$Endloss = 1 - f \tan\theta / Lsca \qquad (5)$$

Where 'f' is the focal length of PTC and 'L_{SCA}' is the single collector assembly length.

Shading of parallel rows is given by:

$$RowShadow = (Lspacing/W) \cdot (\cos\theta z \,/\, \cos\theta) \qquad (6)$$

Where is 'θ_z' Zenith angle.

The net heat absorbed by the HTF is given by:

$$Qnet = Qabs - Qpipe \qquad (7)$$

Where Qpipe is the thermal losses for the pipes

Requisite mass flow rate of heat transfer fluid in order to meet set point temperature is given by:

$$M = Qnet/Cp(Tout - Tin) \qquad (8)$$

Where Cp is the specific heat of HTF.

Thermal efficiency of PTC is given by [5]:

$$\eta th = K[A + B(\Delta T)] + C(\Delta T/I) + D(\Delta T/I)^2 \quad \text{General equation} \qquad (9$$

A, B, C, D = Thermal performance coefficients of parabolic trough collector as tabulated in Table 3.1.

ΔT= temperature difference between HTF and ambient in degrees

K= incidence angle modifier, which is a function of incident angle

Table 3.1 LS-2 Thermal performance Coefficients [6]

Material Type	A	B	C	D
Cermet, Vacuum	73.3	-0.0007276	-0.496	-0.0691

Cermet, Air	73.4	-0.004683	-14.40	-0.0637
Black Chrome, Vacuum	73.6	-0.004206	7.44	-0.0958
Black Chrome, Air	73.8	-0.006460	-12.16	-0.0641

Different values of thermal performance coefficients of parabolic trough collector are shown above. First with the combination of Cermet with vacuum and air then black chrome with vacuum and air. For simulation purposes values of thermal performance coefficients were taken from cermet with vacuum case.

3.3 Components employed in simulation [2]

Parabolic trough: The parabolic trough collector is created on Lippke model of [4] and practices a combined efficiency equation to justify for various fluid temperatures at the collector field inlet and outlet. It computes the investigated mass flow rate of the heat transfer fluid to attain a user-defined outlet temperature.

Economizer: A zero capacitance sensible heat exchanger is modeled in counter flow mode. The cold side input is presumed to be water/steam subjected on quality. The corresponding specific heat of cold side fluid is considered from water/steam property records.

Evaporator: This model drives a water evaporator, giving outlet temperatures and flow rates of hot and cold streams as well as requesting for a certain water inlet flow rate to obtain total evaporation. The cold side is presumed to be water/steam depending on the quality. Water/Steam conditions are given by temperature, pressure and quality.

Turbine stage: This turbine stage model determines the inlet pressure of the turbine stage from the outlet pressure, the steam mass flow rate and reference values of inlet and outlet pressure and mass flow rate using Stoidola's law of the ellipse. It assesses the outlet enthalpy from the inlet enthalpy and inlet and outlet pressure using an isentropic efficiency.

Feed Water Heaters: The feed water heaters are heat exchangers that condense steam extracted from the turbine to heat feed water before it enters the economizer, thus aggregating the Rankine cycle efficiency. Two TRNSYS constituents were used to model the feed water heaters, the pre-heater and the sub-cooler. The pre-heater model assumes water of constant heat capacity on the cold side and condensing steam on the hot side. It decides the required steam mass flow rate that would keep the water level in the heat exchanger constant using the effectiveness method to calculate heat transfer.

Deareator: The deareator is a type of feed water heater where steam is combined with sub-cooled condensate to produce saturated water at the outlet. This helps removal of oxygen from the feed water, governing corrosion. Conservation of energy and mass are used to calculate the requisite steam flow rate from a turbine extraction to attain this process.

Condenser: Steam departing the turbine is condensed so that it can be pumped through the steam generation system. Moreover, portion of condensed extraction steam leaving from the feed water heaters is bound for the condenser to be reused. The condenser model assumes a constant temperature variance between the condensate and the cooling water as well as a constant rise in cooling water temperature. Therefore, the condensing pressure hangs on only on the condensate inlet temperature.

3.5 Block flow diagram of proposed PTSTPP

4 HTF is flowing inside solar field and when the set point temperature is achieved, it starts flowing from super heater, steam generator and finally from pre-heater and again comes back to solar field for reheating after exchanging heat with feed water to generate super- heated steam. The super-heated steam has a pressure of 100 bars while range of temperature lies in 350 to 400 C° depending upon the intensity of DNI at the time.

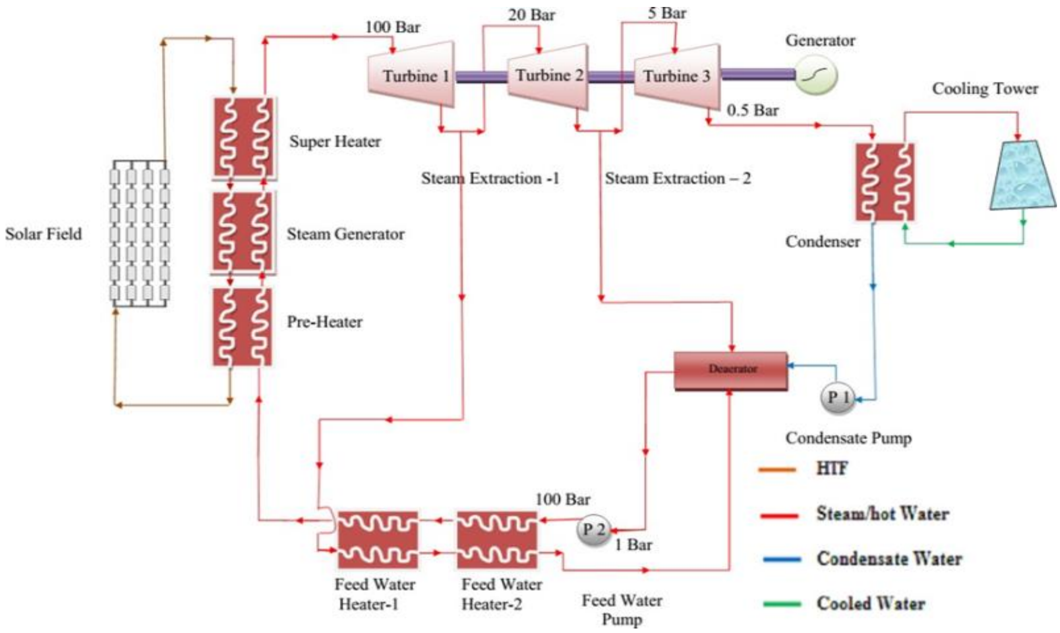

Fig. 3.2: Block Flow Diagram of proposed PTSTPP

Firstly, the super-heated steam is allowed to pass through high pressure turbine and exists at 20 bars. Steam is taken from the high pressure turbine of 10% of total steam for pre- heating of water in feed water heaters while remaining steam is allowed to pass through medium pressure turbine which exists at 5 bar pressure. Here again 10 % of the steam is extracted for deaerator while remaining steam is allowed to pass through low pressure turbine which exists at the condensing pressure of 0.5 bar. The condenser receives a steam at saturated state which is a mixture of steam and water vapor. The steam must be condensed to otherwise it would damage the pump as it couldn‘t handle two phase working fluid simultaneously. Thus the saturated steam is condensed by using the flow of cooling water in counter flow heat exchanger called condenser. The cooling water temperature is made lowered using cooling tower. The condenser is working at negative pressure in order to get larger pressure drop from low pressure turbine and hence we get larger work output [7]. The negative pressure is maintained in condenser by using suction pump which maintains the set point pressure. Moreover, there is a condensate pump which takes the condensed steam from condenser and sends to deaerator so that dissolved gases comes out from the condensed steam, otherwise it would damage the blades of turbine. The deaerator is an open feed water heater which also serves as pre- heater. The condensed pre-heated water is passed through series of two closed feed water heater using feed water pump which results in raising its pressure. The cycle is repeated and is called Rankine cycle.

The TRNSYS model of intended parabolic trough solar thermal power plant is shown in simulation environment in following figure 3.4.

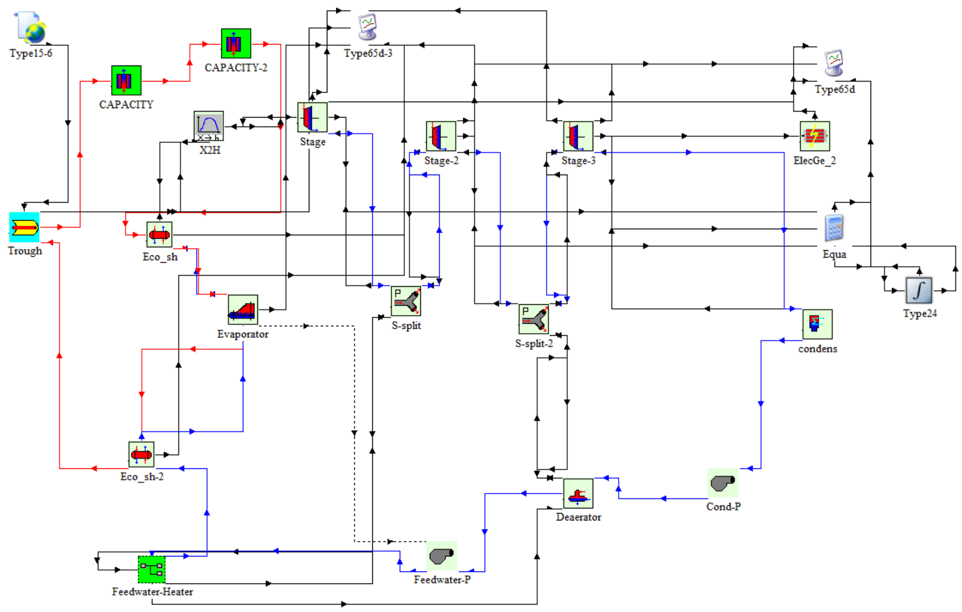

Fig. 3.3: TRNSYS Model of 15 MW PTSTPP

In TRNSYS, the inputs variables of a component are defined gives output by a central governing equation. The yield of this component is made the input of the followed by component along with the defining of necessary inputs which gives outputs using governing equation which are made the inputs of the next components and thus the simulation of the whole system is generated. The weather data is taken from Metronome weather database, and it is responsible for the variation of results with respect to time. The output component displays the results in the form of graph for the stipulated time whereas the printer saves the calculated values of different quantities at each time step in the form of Excel sheet. Table 3.2 shows the values of different pump efficiencies throughout the power cycle which are taken from [4].

Table 3.2 Pump efficiencies

Description	Pump efficiency	Motor efficiency
Condensate pump	0.75	0.95
Feed water pump	0.75	0.95
HTF pump	0.75	0.95
Cooling water pump	0.75	0.95

Summary

Solar radiation varies throughout the day and year due to changing position of earth with respect to sun. The solar radiations properties and solar angles help in harnessing the maximum number of solar radiations. From literature review, the factors affecting the performance of power plant are identified. Effects of HTF flow rate on output temperature in solar field are acknowledged. Output power of the Rankine cycle is analyzed by varying the input values of components like super heater, evaporator and condenser. The proposed power plant is modeled in TRNSYS simulation studio whereas simulation is carried out for the location of Quetta to analyze the thermal behavior and technical feasibility of system. Furthermore, statistical analysis is performed to validate the simulation results with expected results.

References

[1] http://www.trnsys.com/ (accessed July 31, 2020).

[2] http://sel.me.wisc.edu/trnsys/trnlib/stec/stec.htm (accessed July 31, 2020).

[3] D. Sauceda, N. Velzquez, O. Garca-Valladares, R. Beltrn, Numerical simulation and design of a parabolic trough solar collector used as a direct generator in a solar-GAX cooling cycle, J. Mech. Sci. Technol. 25 (2011) 1399–1408.

[4] F. Lippke, Simulation of the part-load behavior of a 30 MWe SEGS plant, Other Inf. PBD Jun 1995. (1995) Size: 58 p. doi: SAND95-1293.

[5] S.D. Odeh, G.L. Morrison, M. Behnia, Modelling of parabolic trough direct steam generation solar collectors, Sol. Energy. 62 (1998) 395–406. Doi: 10.1016/S0038- 092X (98)00031-0.

[6] A. M. Patnode, Simulation and performance evaluation of parabolic trough solar power plants [Ph.D. thesis], University of Wisconsin, Madison, Wis, USA, 2006.

[7] Nag, P. K. Power plant engineering. Tata McGraw-Hill Education, 2002.

CHAPTER 4

Results and Discussion

4.1 Simulation Outcomes

The following input statistics have been used in performing simulations for one complete year to determine the technical feasibility of PTSTPP using TRNSYS software.

Table 4.1 Input data

Variable	**Value**
Maximum steam temperature (C°)	390
Turbine inlet pressure (bar)	100
Condensing pressure (bar)	0.5
Isentropic efficiency of turbines	0.8
Isentropic efficiency of generator	0.9
Isentropic efficiency of pumps	0.8
Specific heat of water at 25 C° (kJ/kg.K)	4.18
Specific heat of HTF at 400 C° (kJ/kg.K)	2.62 [1]

The results and behavior of important variables are shown in the form of graph with respect to time with one-hour time step intended for the whole year. The power plant will work as long as the temperature of HTF is in the range of 350 to 400 C° and minimum flow rate of HTF is greater than 1 kg/sec while these conditions will meet only when DNI is greater than 700 kJ/hr/m² else the power plant will remain OFF. This threshold value of DNI is found from simulation results, checked at different time intervals. Figure 4.1 shows the solar irradiation in Quetta city over the span of one year with one hour time step. High value of irradiations can be easily seen in summer months. Figure 4.2 shows different temperatures of important variables in the system. Red line: HTF temperature at solar field, Blue line: HTF temperature at super-heater, Pink line: Water temperature at evaporator, Orange line: Water temperature at condenser. Outlet temperature of solar field is higher than its limit of 390 C° for the months of May, June, and July. It is mainly due to high concentration of irradiations during these months. Figure 4.3 shows the generated output power in watts for the timespan of one year with highest value of 15 MW as capacity of the proposed system. Figure 4.4 shows the annual generated energy in GWh during the simulation period with total generation around 25.6 GWh per annum.

Following figure is showing the transient performance of Total irradiation on horizontal plane and beam radiations for the selected location. Beam irradiation is actually the part of total available irradiation which is conventionally considered for concentrated solar power.

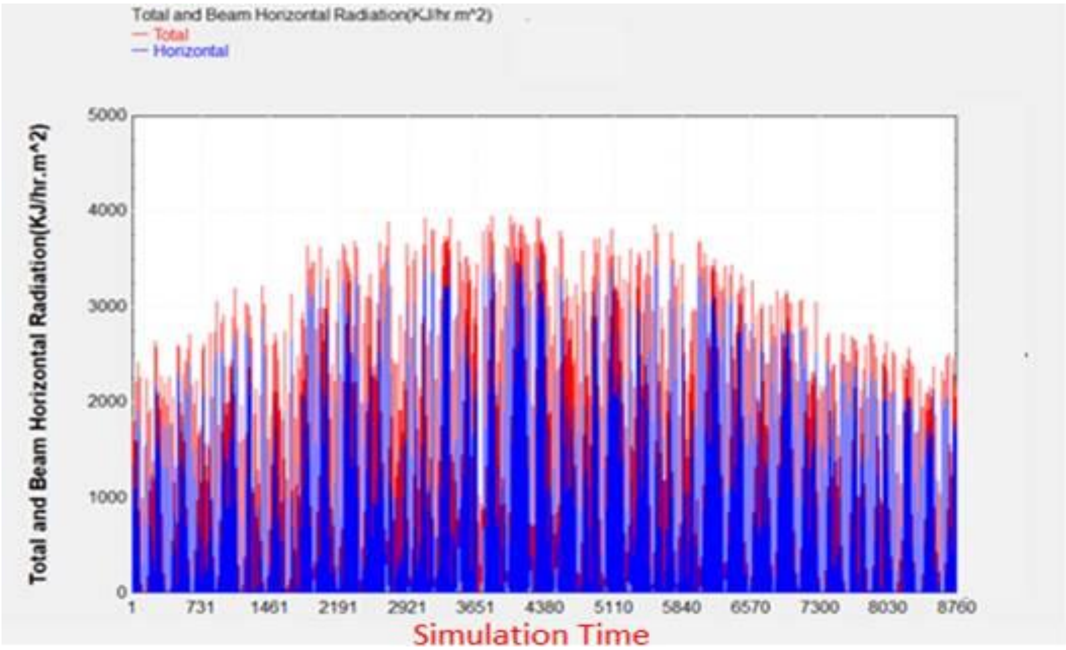

Figure 4.1 Total and Beam Horizontal radiations

Figure 4.2 shows different temperatures of important variables in the system. In given figure transient effect of HTF and working fluid is showed at solar field outlet and Outlet temperature of solar field is higher than its limit of 390 C° for the months of May, June and July. It is mainly due to high concentration of irradiations during these months. Red line is showing effect of solar irradiations in form of heat gain by HTF while passing through solar field during the day time throughout the year. Pink line is showing increase in temperature of working fluid at super-heater heat exchanger by exchanging heat with heated HTF. Green line is showing behavior of working fluid at saturated temperature in evaporator heat-exchanger during changing its phase from saturated liquid to saturated vapor. Pressure drop over the evaporator section is taken as zero in the simulation process.

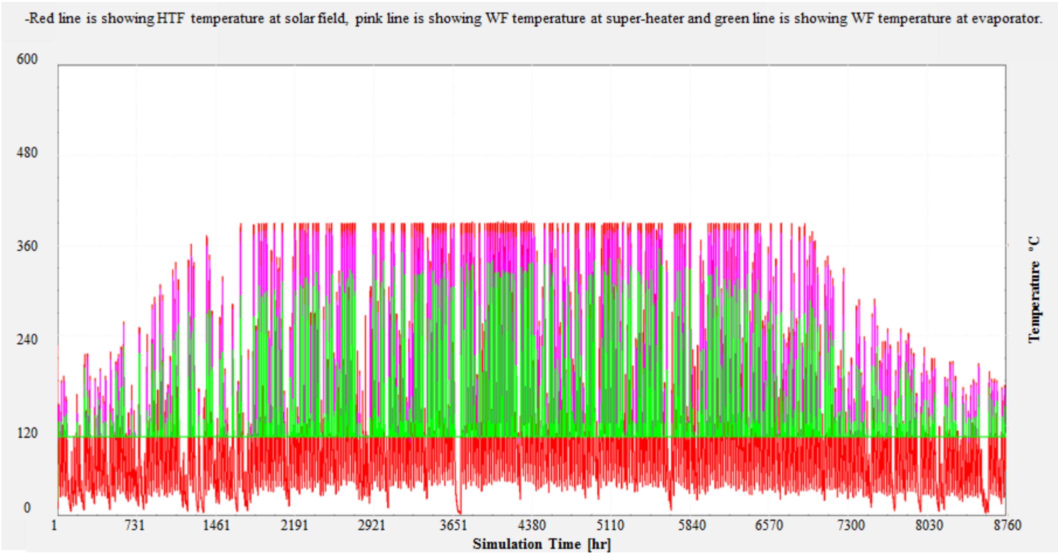

Figure 4.2 Temperature gain of system

Figure 4.3 shows the generated output power in mega-watts for the timespan of one year with highest value of 15 MW. Blue line is showing the transient output in terms of power produced from proposed solar thermal system at chosen site. Highest value of output power is depicting the capacity of the proposed system. Gradual increase in output power is clear as the period of year turns to summer after winter period. Output power is lowest for the months of December and January. For almost 8 months of the year produced power remains higher than the 6.4 MWs as can be seen in graph. During the summer season of the year suggested plant continues to give more than 9.6 MWs in terms of useful power. Overall behavior of output power for the time period of one year is representing good solar potential which can be utilized to cater energy demand in the nominated city.

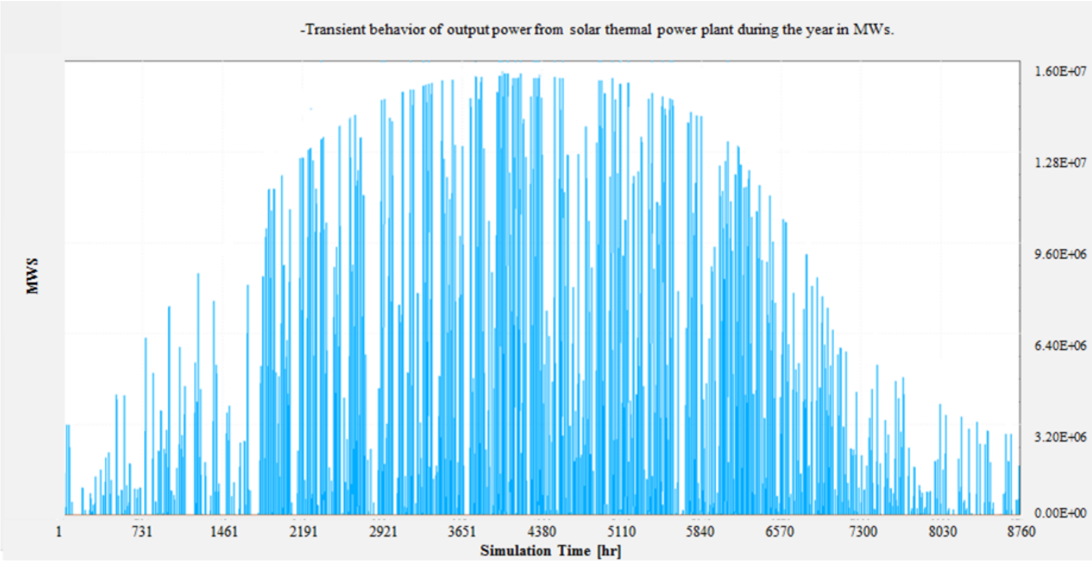

Figure 4.3 Output power

Figure 4.4 shows the annual generated energy in GWh during the simulation period of one year with total generation around 25.6 GWh. Incline in energy generation is clear during sunny months of the year. During first and last three months rise in energy is much smaller as compared to the increase in energy during the six months of summer in the year. Without accumulating the carbon in our atmosphere we can use this amount of energy to meet our needs. Energy curve is smoothly increasing throughout the year depicting advantage of harnessing solar energy.

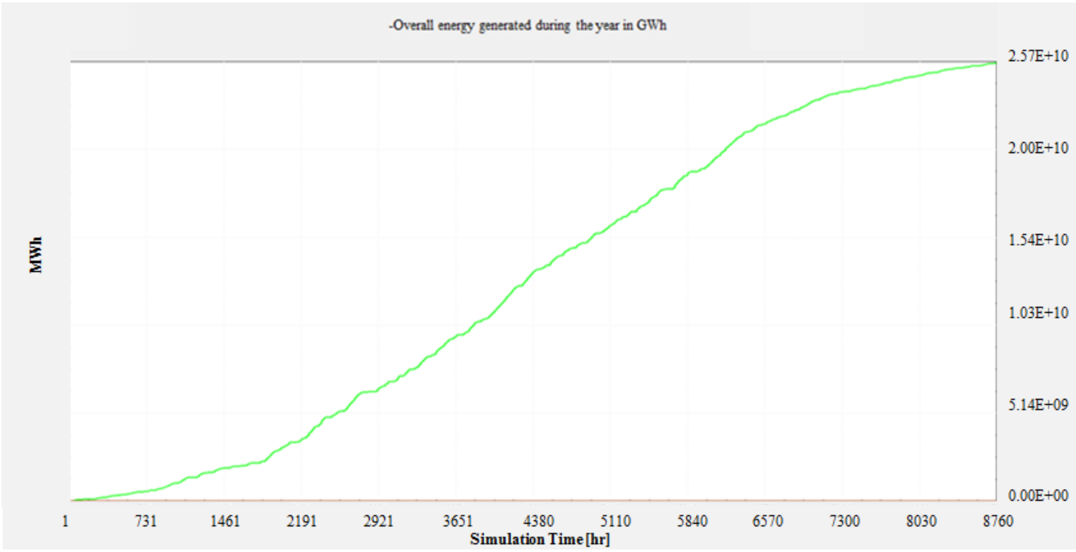

Figure 4.4 Generated energy per annum

Figure 4.5 is showing particularly the effect of solar irradiation on HTF temperature. Throughout the year solar field model tries to maintain the upper defined limit for the temperature of HTF which is defined by the user i-e 390 °C. During summer months in which the solar irradiation is higher than usual usually during noon hours; HTF temperature crosses its limit of 390 °C. The reason behind it; flowrate of HTF cannot be further increased so it crosses it`s defined limit during peak irradiation hours of the day. Figure 4.6 describes the effect of solar irradiations on important variables of system. Here red line: HTF temperature at solar field, pink line: Temperature of working fluid at super-heater, green line: working fluid temperature at evaporator section. Figure 4.7 gives detail about the output power of system in watts. Following figure shows the behavior of solar irradiations for particular day of June. Solar irradiation is superior to the value of 2000 KJ/hr.m² for around 6-8 hours which is showing massive solar potential to harness.

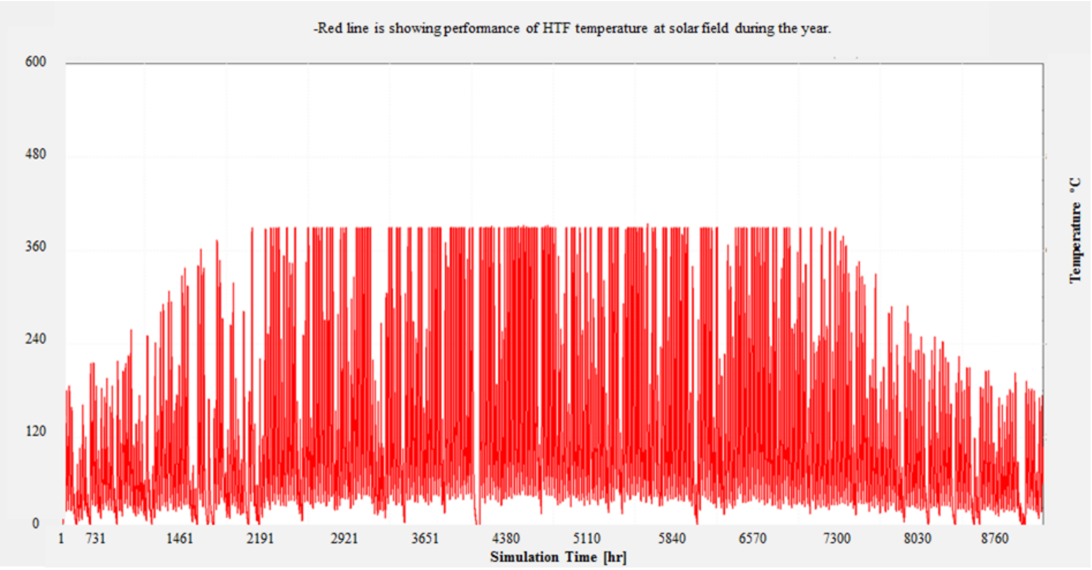

Figure 4.5 Solar impact on HTF temperature

Figure 4.6 illustrates the influence of solar irradiations in heating important variables of system. Here, Red line is showing HTF temperature for 21st of June, pink line is showing heat gained by working fluid by exchanging heat with HTF at super-heater and green line is showing transient behavior of working fluid in vapor state while passing through evaporator heat-exchanger. For the selected day, HTF temperature upheld its limit of 390 °C for almost 10 hours during simulation period depicting immense solar potential for the selected location. Temperature of working fluid at super-heater and evaporator heat exchangers started to rise after the increase in HTF temperature during the day. This is due to the use of capacity models in the STEC model to shun away the high computational gains during the simulation process.

Temperature at super-heater rises up to 380 °C whereas for evaporator section it touches the value of 320 °C.

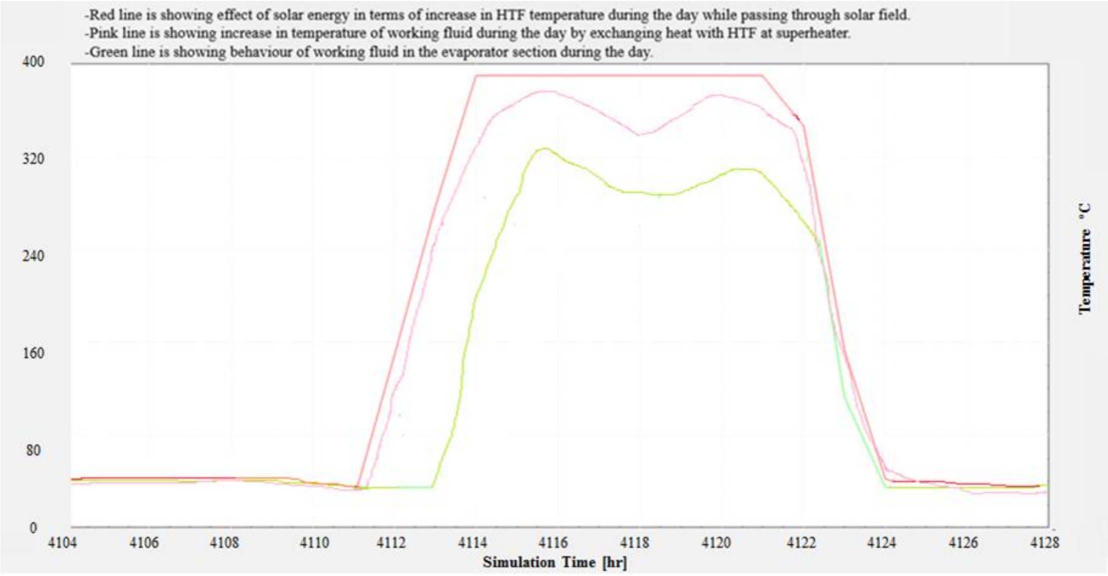

Figure 4.6 Performance of system for 21st of June

Figure 4.7 is showing transitory behavior of working fluid flowrate while passing through steam heat-exchangers. Blue line is showing flow rate of working fluid demanded by the evaporator section. Working fluid flowrate demanded by evaporator sets the upper limit of flowrate of working fluid in whole of Rankine cycle. Higher the demanded flow-rate higher will be the working fluid flowrate in all other components of Rankine cycle. Black and pink lines are showing the transient movement of flowrate through the super-heater and pre-heater sections.

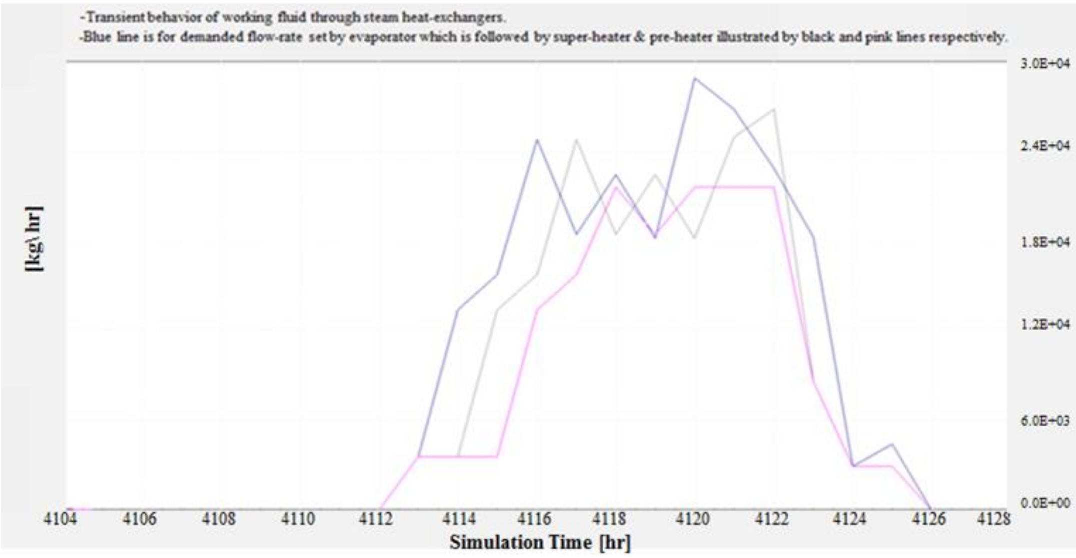

Figure 4.7 Behavior of working fluid through Steam heat-exchangers for 21st of June

Figure 4.8 gives detail about the output behavior of power produced by the proposed system in mega-watts. Here, violet line is showing overall value transient response of energy generated by Rankine cycle. Red line is showing transient response of High pressure turbine in terms of power during the day, blue line is expressing behavior of output power resulted from medium pressure turbine in the cycle whereas pink line is illustrating performance of power given by low pressure turbine on each moment during the day. Overall Value of output power on any given moment is simply the addition of output power from mentioned turbines in the cycle during the simulation period. For 21st of June highest value touched by generated power is 15 MWs showing the output capacity of suggested system. By comparing output power behavior with above figs 4.6 & 4.7 we can conclude transient behavior of output power is depending upon temperature increase in HTF at solar field and working fluid flow-rate demanded by evaporator section. Higher the temperature increase in HTF at solar field higher will be increase in working fluid temperature at steam heat-exchangers section of cycle. Temperature increase in HTF at solar field is highly dependent of HTF flow-rate through the solar field. Low value HTF flow-rate makes the gain in HTF temperature higher but results in lower output power from Rankine cycle. Whereas high value of HTF flow-rate results in decrease of HTF temperature at solar field but give higher output power from Rankine cycle. Same is true for working fluid flow-rate limit set by evaporator section. Larger the flow-rate demand set by evaporator for working fluid larger will be the output power produced by Rankine cycle.

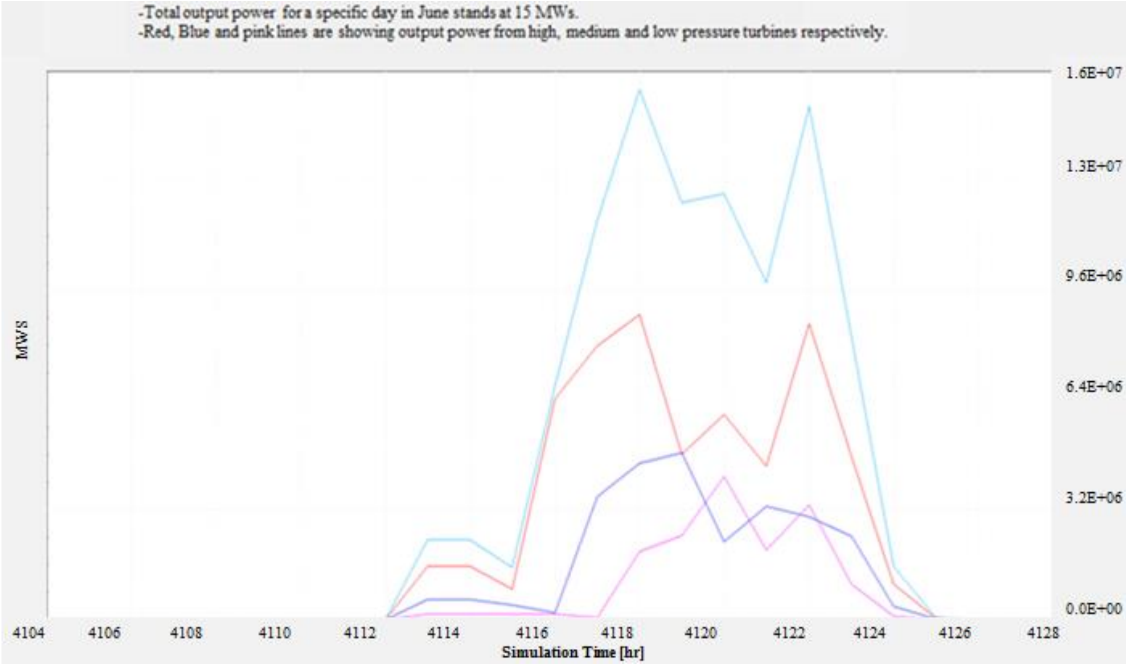

Figure 4.8 Output power for 21st of June

For winter season, Second last day of December with output power of 1.5 MWe was chosen to describe system transient behavior as shown in Fig. 4.8. Low irradiation and cloudy sky shows excessive variation in output power during operation of the selected day as compared to selected summer day. During the first phase of the day, output power remains lower than 640kW, it rise up to the value of 1.5MW in last three hours of operation. Increase in temperature of HTF and working fluid for winter day is up to 320 C° as shown in Fig. 4.9 whereas for chosen summer day it was above the limit of 390 C°. Last day of December was chosen to describe system transient behavior for winter season as shown in Fig. 4.8. Low intensity of irradiations shows slow temperature gain of HTF and sharp fall once it touches the maximum value of 320 C°. Increase in temperature of HTF and working fluid for this winter day is up to 320 C° whereas for chosen summer day it was above the limit of 390 C°.

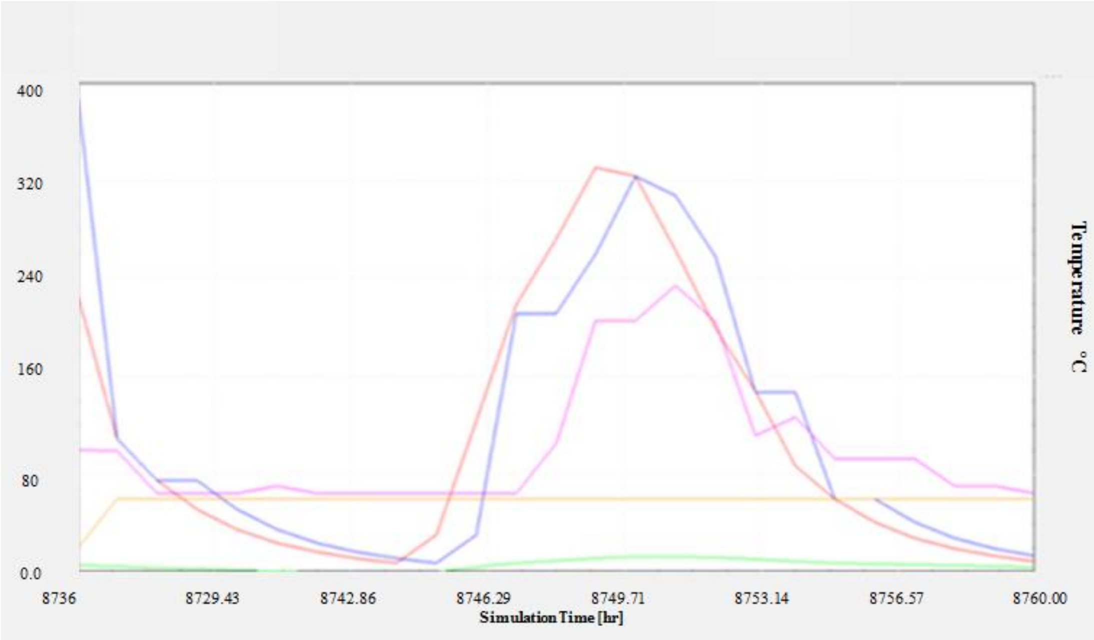

Figure 4.9 Thermal performance for a specific day in December

Low irradiation and cloudy sky shows excessive variation in output power during operation of the selected winter day as compared to selected summer day. During the first phase of the day, output power remains lower than 640kW, it rise up to the figure of 1.5MW in last three hours of operation. Availability of output power decreases down to 5-7 hours.

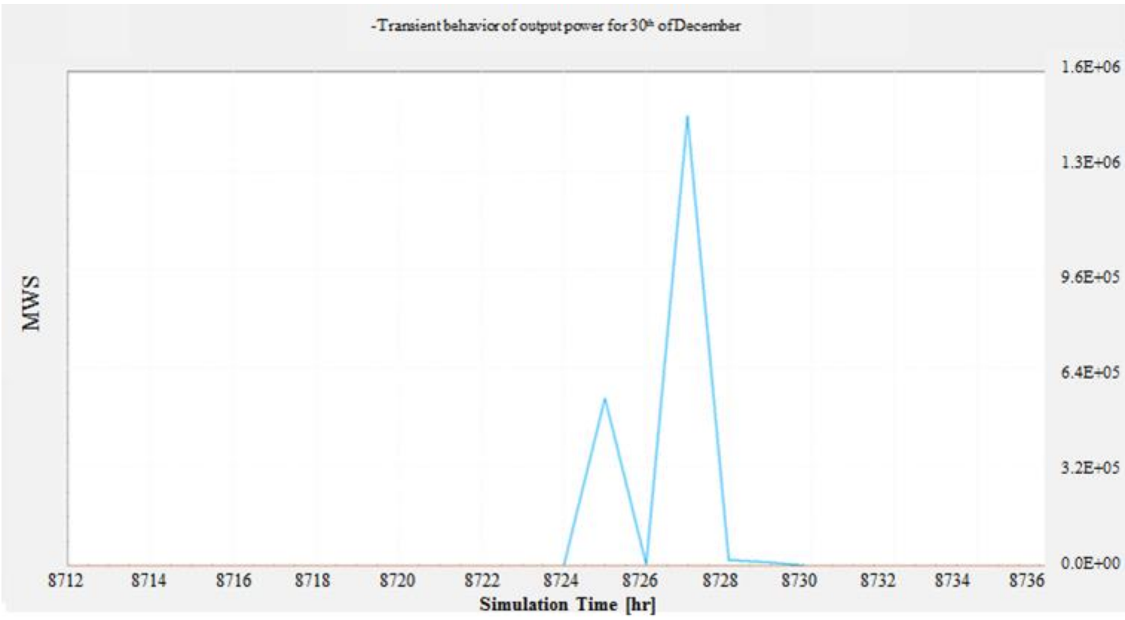

Figure 4.10 Output power for 30^{th} of December

From the simulations results, it can be easily deduced that when DNI varies, it varies the steam outlet temperature which in turn changes the steam flow rate so as to maintain the steam temperature at maximum value and hence the power output changes. More is the intensity of DNI at receiving plan, more power output will be generated and vice versa. In other words, DNI has a direct linkage with power output.

4.2 Validation of results

Following figure is showing predicted result of Rhodes Island for two typical days during the year. Blue line is showing temperature of HTF at solar field, pink line is showing temperature of working fluid at super-heater. Orange line is showing temperature of working fluid at evaporator section. First day is sunny in nature whereas second day is illustrating the behavior of cloudy day in simulation. During the sunny day temperature gain in HTF and working fluid at solar field and super-heater is around 390 °C. For the cloudy day defined limit of HTF temperature set by user is not met for the major period of day due to low irradiation.

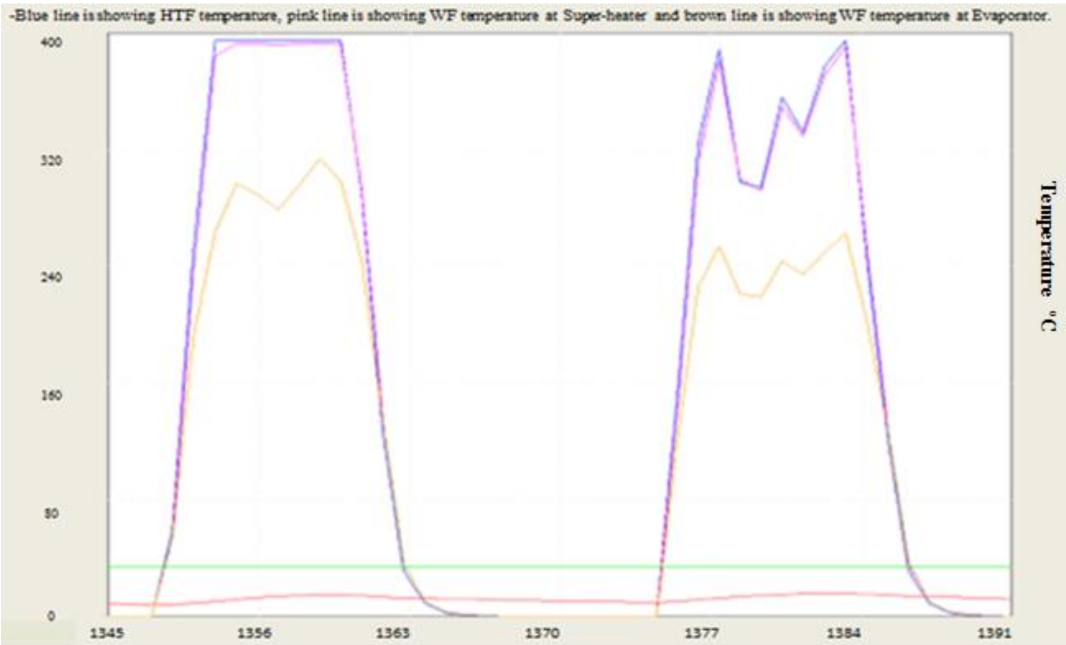

Figure 4.11 Predicted temperature result for Rhodes Island in the literature

Fig 4.12 is showing calculated result for validation purpose with the same parameters of system for Rhodes Island. Simulation time period is same for both figures depicting behavior of sunny & cloudy day. Rise in temperature of HTF & working fluid during sunny day in calculated results is following almost the same fashion of predicted results. Temperature limit of HTF set by user is met during the major portion of chosen day which result in heating of working fluid up-to the temperature of 380 °C.

For cloudy day HTF temperature touches the limit of 390 °C for a brief period during the day following the same course in predicted results.

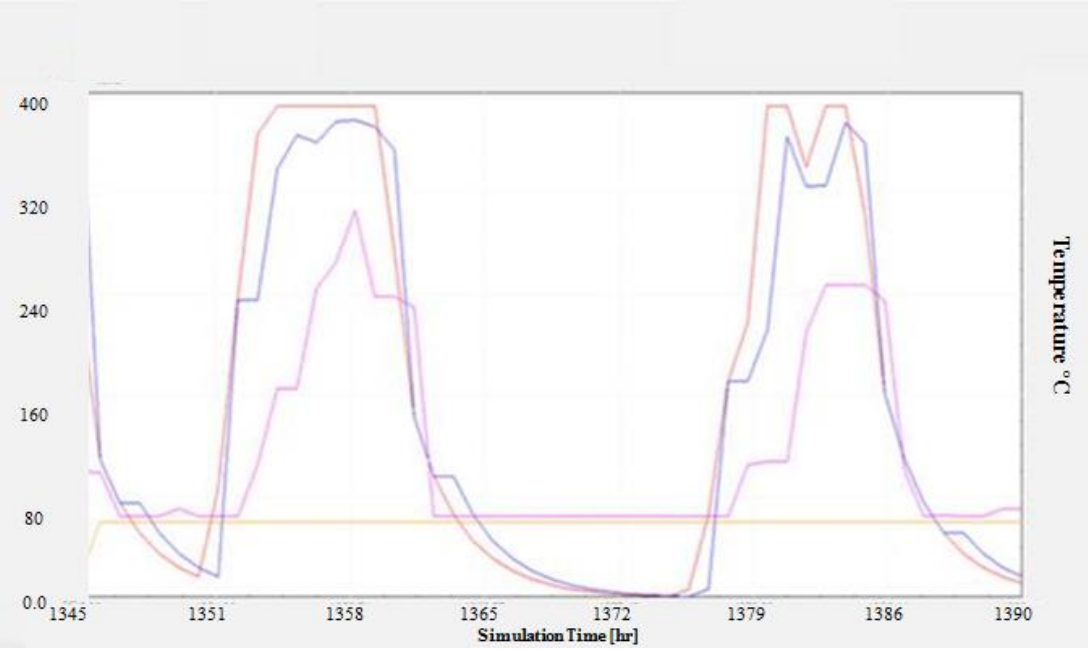

Figure 4.12 Calculated temperature result for validation

4.3 Why output power varies?

DNI varies at each instant of the day and year. The reason for variation throughout the day is solar altitude angles which varies throughout the day that alters the air mass and hence beam radiations alters due to the inducing of diffuse component of radiations [2]. Thus greater is the solar altitude angle, lesser will be the air mass and more will be the intensity of radiations. Similarly, when solar altitude angle is less, higher will be the air mass and less will be the intensity of solar radiations. The reason for DNI variation throughout the year is declination angle which varies each day with a maximum of plus minus 23.5 degrees [3]. Tilt of the earth is changed by the declination angle. When the tilt is towards the sun, more radiations are received on earth surface and hence the intensity of radiations is greater and when the tilt is away from the sun, less no of radiations are received on earth surface and hence the intensity is lower.

4.4 Required conditions for constructing PTSTPP

Direct Normal Irradiation (DNI) > 1900 kWh/m2/year (5.2 kWh/m2/day) [4]

- To take full advantage of the incident solar radiation one axis sun tracking is required.

- Total gradient of flat land area should be smaller 3% [5]

The concentration of irradiations is basically governed through the pounded incline happening a positive site [6]. The terrestrial incline provides growth to aspects alike of shadowing and shading cast by the neighboring land which considerably decreases the quantity of radiation captured by the collectors. Henceforth land with greater slope disturbs the efficiency of a solar plant.

- Wind speed < 15.64 m/s [7]

The grounded support of solar collector structure is considered to endure firm wind load. Structural design and efficacy of solar field are vulnerable to strong winds. Therefore high-wind locations bound the potential of the solar plant by affecting its performance. [7]

- Accessibility of appropriate grid connection
- Accessibility of aquatic assets
- Accessibility of worthy transport services
- Accessibility of back up fuel (elective)

4.5 Outcomes

Fixing the aperture area of single parabolic trough collector, total number of loops are found to be "40" with "24" solar collectors within per loop. These solar collectors are connected in loops to form the total aperture area of solar field. Total aperture area of solar field required to produce power output of 15 MW is 60,000m². Total power generation is around 25.6 GWh which shows the capacity factor of 19.5 percent, whereas capacity factor designed for solar concentrated projects in southern Baluchistan of Pakistan given by solar world map is ≥18 percent. During summer season power production span is more than 8 hours during the day which is dropped to 5-7 hours in winter season due to low concentration of irradiations.

4.6 Assessment of proposed power plant with respect to previous work done in literature

Table 4.2 Fraction of prior work carried out for Pakistan and World

[8]	A Parabolic trough solar thermal power plant without any thermal storage is simulated for the location of Nawabshah in Pakistan. Designed plant can

	produce 31MW on average day of June with capacity factor of 20.5%. Selected aperture area of solar field is 200000m². A 30MW net effectiveness of 0.96, turbine efficacy = 0.37, solar field piping loss = 6.2 MWth needs a total of 54 solar loops to generate such power.
[9]	A solar thermal power plant with parabolic trough collector technology is simulated having output capacity of 1MW. Total field area selected is 8175m² with thermal storage availability for the region of Gurgaon in India. Length of solar collector assembly = 120m with loss coefficient parameters: A=73.6, B=0.0042, C=7.40 is selected in PTC modeling. High/Low storage temperature tank with volume= 20m³ were added to optimize output power.
[10]	A Trnsys vibrant imitation archetypal for a parabolic plant is designed for weather conditions of Algeria. Solar field with total area of 200000m² having natural gas as auxiliary fuel shows the least effectiveness of talent is 14% for wintertime dated. Length of SCA (m) = 14.37, Aperature width of SCA (m) = 1.52, Focal Length of SCA (m) = 0.45, Row spacing (m) = 4.54 Total Field Area (m²) =200000.
[11]	A small scale PTC power plant with output capacity of 20kW is simulated for the location of Lahore in Pakistan. Total solar field area is 580m² with aperture area of 348m².
[12]	A 20MW parabolic trough based solar power plant with six hours thermal energy storage is designed and simulated under climatic conditions of Quetta in Pakistan. Parameters of solar field: Solar multiple=2, Collector assembly length=115m, Area of solar field= 107 acre. Thermal storage hour=6, Storage volume=4559.35m³, Storage HTF type= Solar salt.

- Parabolic trough collector based power plant simulated in this work is designed to produce output power without any thermal storage in the absence of auxiliary fuel. The proposed system of 15 MW for Pakistan is analyzed in Trnsys environment with detailed transient behavior whereas in literature, medium size PTC based solar thermal power plant having capacity of 10-20MW intended for the locations in Pakistan is only available in SAM software. Total area of Solar field in proposed power plant = 60,000m^2, length of module = 12.5m, width = 5m, Operating temperature = 100C°-400C°, Piping heat loss/area (W/m^2) = 20 with Concentration ratio = 71. In calculating tariff, national electricity production regulatory authority (NEPRA) has employed benchmark capacity factors for solar power plant projects. In 2016 tariff, these are 17% for northern Pakistan and 18% for southern Pakistan. Southern Pakistan consists of Baluchistan, Sindh and southern Punjab whereas northern Pakistan takes into account the rest of the country [13].

Summary

Simulation results of proposed parabolic trough solar thermal power plant intended for the location of Quetta are concisely discussed here. Results show that power plant is working only in sun shine hours with DNI greater than 700 $kJ/hr.m^2$. The annual power generation of solar power plant is around 25600 MWh with output capacity of total 15 MWe. During summer season power production is maintained around 8-10 hours but power production time is dropped to 5-7 hours in winter season due to low concentration of irradiations. The total number of LS-2 parabolic trough collectors required is 960. The real time analysis of proposed project indicates the practical viability of solar thermal power plant with medium generation capacity for arid regions in Pakistan.

References

[1] https://www.therminol.com/products/Therminol-VP1 (accessed July 31, 2020).

[2] http://www.pveducation.org/pvcdrom/properties-of-sunlight/elevation-angle (accessed July 31, 2020).

[3] http://www.usc.edu/dept-00/dept/architecture/mbs/tools/thermal/solarbasic.html (accessed July 31, 2020).

[5] Bin Yang; Jun Zhao; Wenbin Yao; Qiang Zhu; Hang Qu, Feasibility and Potential of Parabolic Trough Solar Thermal Power Plants in Tibet of China, APPEEC 2010, Asia-Pacific Power and Energy Engineering Conference 2010.

[6] Richard G. Allen, Ricardo Trezza, Masahiro Tasumi, Analytical integrated functions for daily solar radiation on slopes, Agricultural and Forest Meteorology 139 (2006) 55–73.

[7] Nusrat Kamal Raja, M. Shahid Khalil, Syed Athar Masood, Muhammad Shaheen, Design and Manufacturing of Parabolic Trough Solar Collector System for a Developing Country Pakistan, Journal of American Science, 2011.

[8] Engr. Shahrukh Saleem, Prof. Dr. Azzam ul Asar, Analysis & Design of Parabolic Trough Solar Thermal Power Plant for Typical Sites of Pakistan, IOSR-JEEE Volume 9, Issue 3 Ver. I (May – Jun. 2014).

[9] Jignasha Bhutka, Jaymin Gajjar, T. Harinarayana, Modelling of Solar Thermal Power Plant Using Parabolic Trough Collector, Journal of Power and Energy Engineering, 2016, 4, 9-25.

[11] A. Rehman, I. A. Chaudhry, T. Khan, Design and Simulation of Solar Parabolic Trough with TRNSYS, Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan, Vol. 19 No. IV-2014.

[12] Muhammad Raheel khan, Muhammad Arif khattak, Muhammad Yousaf , Abidullah1, Lutf ur Rahman, Performance Analysis of a Parabolic Trough Concentrated Solar Power Technology in Pakistan, International Journal of Engineering Works.

[13] International Finance Corporation. 2016. A Solar Developer's Guide to Pakistan. Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/25355 License: CC BY-NC-ND 3.0 IGO.

Chapter 5

Conclusions and Recommendations

5.1 Conclusion

After the practical examination, it is noticeable that proposed solar thermal power plant is ample practicable in location where DNI is great and great leftover terrestrial is obtainable. Moreover, region under consideration is designated as second highest among world regions in terms of available solar resource [1]. Simulation results show that output capacity of proposed parabolic trough power plant is 15MW with almost 11.5GWh of annually generated energy. Performance evaluation of the system specifically under the medium and low-level solar radiations shows good potential with daily average power availability of around 7.1 hours. Impact of solar field flow rate is crucial in output behavior of system and produced energy. E.g. high flow rates improve the heat transfer coefficient HTF-steam heat exchangers but result in lower solar field outlet temperatures. Conversely, low flow rates will result in high solar field outlet temperatures but reduce the heat transfer coefficient in HTF-steam heat exchangers. Such kind of independent medium scale solar based power plants can mitigate the gap between energy produced and energy demand and upon attached with proper desalination technology can best serve as a solution to power and fresh water shortage in our country. Especially in areas of Sindh and Baluchistan, where energy demands is high and quality of fresh water is low.

5.2 Future Recommendations

- Further investigation is required to check the economic feasibility of the power plant.
- Output energy and economic indicator of abovementioned project should be analyzed with the addition of thermal storage.
- Research study should be conducted on hybrid fueling of the power plant for non-sunshine hours like natural gas or coal heating for increasing of capacity utilization and its effect on economics of the power plant.
- Investigation is still required to increase the thermal performance of the cycle by extracting extra heat from solar field using Organic Rankine Cycle (ORC)

which can run the power plant even from low temperature gradient source. This would increase the power output from the same heat input source.

- Research should also be carried out on air cooled condenser incase water is not available for cooling and its effect on the cost and routine of the power plant.

Annexure*

Umer Saleem[1], Adeel Waqas[2], “Modeling and Simulation of a medium temperature Solar Thermal Rankine cycle for arid regions of Pakistan for Energy and Clean water production” presented at International Conference ‘Pakistan Renewable Energy Summit 2019’ organized by World Wind Energy Association (WWEA) and Global 100 % Renewables.

Modeling and Simulation of medium temperature Solar Thermal Rankine cycle for arid regions of Pakistan for Energy and Clean water production

Umer Saleem[1], Adeel Waqas[2]

[1,2] U.S. Pakistan Center for Advanced Studies in Energy National University of Science & Technology Islamabad, Pakistan

Email: umersaleem425@gmail.com

Abstract

The use of renewable energy sources to produce electrical energy and fresh water seems to be a cost-effective way to reduce the dependency on fossil fuels. To reach the objective of achieving 30% renewable energy by 2030 it would be beneficial to tap enormous solar potential of Pakistan, especially in the arid regions. With the recent developments in solar energy conversion technologies, concentrating solar power (CSP) system attached with desalination technology for power and clean water production has become an attractive solution.

Currently, CSP systems using Parabolic Trough Collectors (PTCs) are dominating the global CSP market since these are the most mature technology and the most installed CSP systems in the world. The much lower primary energy consumption of reverse Osmosis (RO) compared to other desalination techniques suggests that RO is the

preferred desalination technology. In this paper, only the electricity output of the CSP plant would be exploited to meet both power and clean water demands because RO is the only desalination technique which requires electricity to operate. Therefore, Simulation of a proposed solar power plant is executed using the TRNSYS software under climatic conditions of Quetta valley in Pakistan which results in power output of 15 MW. Quetta is selected due to high direct normal radiation and scarcity of the clean water.

Keywords: TRNSYS, Solar Thermal Electric Components (STEC), Reverse Osmosis (RO), Renewable Energy, Concentrated Solar Power (CSP), Heat Transfer Fluid (HTF), Desalination.

1. Introduction

It is widely acknowledged that energy from sun is advantageous source of clean energy and essential for countries such as Pakistan, which lies on sunny belt with annual mean daily solar insolation 5.5kWhm^{-2} for the whole country [1]. The application of the solar thermal power to yield, electricity and fresh water is a favorable technology which leads to a significant decline in fuel energy consumption. While, several other solar technologies have been displayed, parabolic trough solar thermal electric power plant is reasonable clean energy option available today. Parabolic trough plants producing over 350 megawatts (MW) of electricity are in operation in the California Mojave Desert [2]. Parabolic trough has proven to be the most established and cost-effective technology presently available [3]. Three different solar power plants (photovoltaic [PV], CSP and PV/CSP) with the same electricity generation rate of 50 MW were investigated by Parrado et al. [5]. The combination of the solar rankine cycle (SRC) plants with MED and RO water purification systems, was investigated by Iaquaniello et al. [6]. Water purification techniques and their promising combination with CSP and PV electricity power were evaluated by Fiorenza et al. [7]. A thermo economic analysis of dual purpose (SRC/MED and SRC/RO) CSP plants was executed by Ortega-Delgado et al. [8]. In this paper a proposed Solar Electric Generation (SEGs) power plant having a capacity of 15 MW is discussed to meet energy and fresh water demand of Quetta city in Pakistan.

2. Description of solar thermal power plant

Solar field involves a collection of troughs in side by side queues lined up on north-south axis. In this way, one dimensional parabolic collectors follow the path of sun during the whole day from east to west to make sure that receiver is constantly aiming at the sun. Sun’s energy is concentrated on a receiver pipe which lies on the focal point of the trough collectors. Through receiver pipe heat transfer fluid (HTF) flows which gets heated because of concentrated solar energy and this heated HTF is then used to generate electricity as shown in Fig. 1. The transference watery was selected conferring to its physicochemical assets. Heat is transferred from HTF to working fluid using heat exchangers which turns working fluid into steam. Steam is then induced to steam turbine and finally electricity is created using a generator linked to steam turbine.

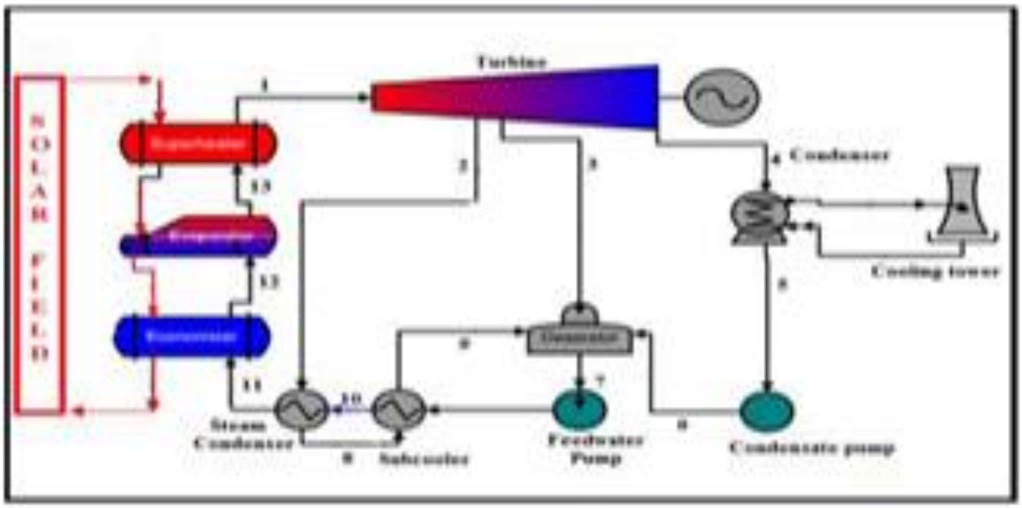

Fig. 1. Schematic diagram of CSP

3. Methodology

To carry out simulation work, Transient Systems Simulation (TRNSYS) software is selected due to its simplicity and flexibility. The Solar Thermal Electric Component STEC library framed in thermodynamic quantities (enthalpy, temperature and pressure) contains proper models for solar field and rankine cycles [9]. ‘Capacity’ model is used in simulation study of solar thermal power plant to shun away the massive gain in computational difficulty of a full transient model. The configuration of Concentrated Solar Thermal Power Plant (CSTPP) in TRYNSYS environment is shown in Fig. 2.

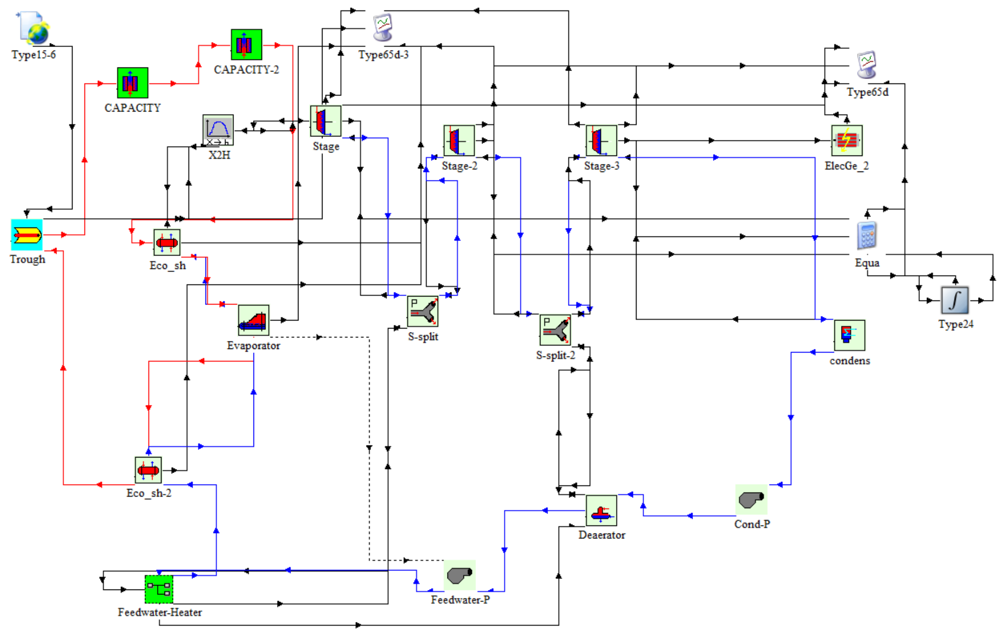

Fig. 2. CSP plant in TRNSYS

The connections among components consider two fluid channels: HTF channel and steam channel. In the heat transfer fluid channel, temperature and mass flow rate are linked from the output of the component in the flow direction to the input of the next component. On the other hand, in steam circuit instead of temperature, pressure is used. Pressure information is attached opposite to the flow direction of temperature and mass flow information.

4. Results

Simulation results for one year are shown in Figs. 3 and 4. Weather data for the location of Quetta was taken from TRNSYS weather database and the elementary factors of solar field are given in table 1.

TABLE 1. BASIC PARAMETERS OF PARABOLIC TROUGH FIELD [10]

S. No	PTC module parameters	Value
1	HTF specific heat	2.303kJ/kg. K
2	Clean reflectivity	0.95
3	Total field area	60,000m^2
4	Aperture width of SCA	5m
5	Length of SCA	12.5m

Figure 4.2 shows different temperatures of important variables in the system. Outlet temperature of solar field is higher than its limit of 390 C° for the months of May, June and July. It is mainly due to high concentration of irradiations during these months. Red line is showing effect of solar irradiations in form of heat gain by HTF while passing through solar field during the daytime throughout the year. Pink line is showing increase in temperature of working fluid at super-heater heat exchanger by exchanging heat with heated HTF. Green line is showing behavior of working fluid at saturated temperature in evaporator heat-exchanger during changing its phase from saturated liquid to saturated vapor.

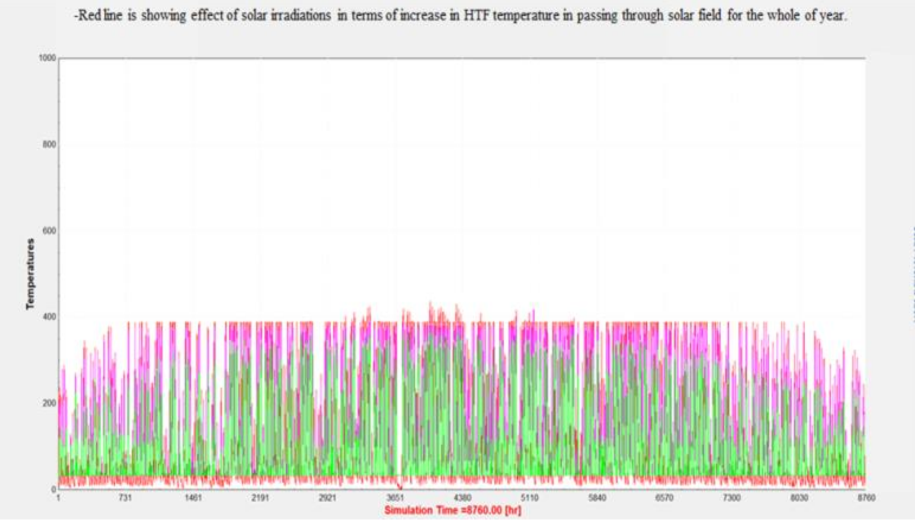

Fig. 3. Different temperature of system throughout the year

In Fig. 4, horizontal axis shows simulation time for one year whereas vertical axis represents generated energy throughout the year. Yearly produced energy is around 25.6 GWh and maximum output power of solar plant is 15 MW.

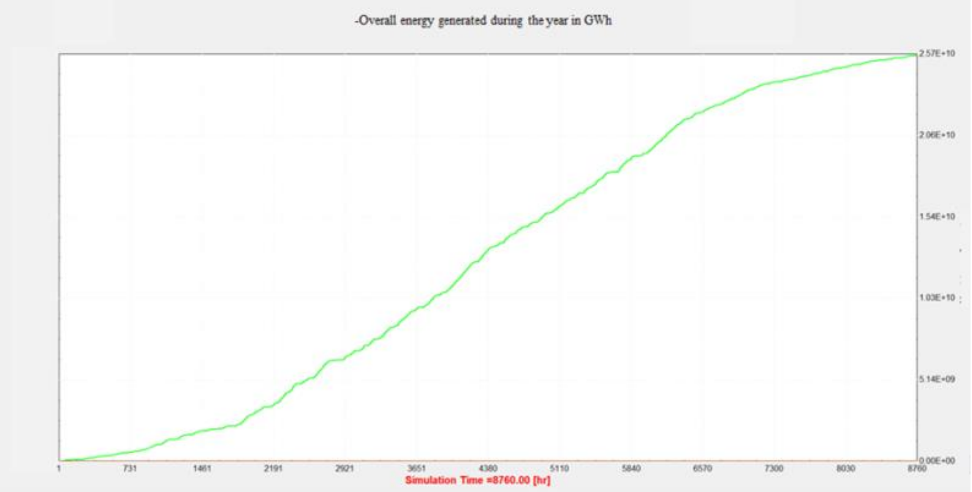

Fig. 4. Energy generated annually

A) Summer season

A particular day of June is chosen to demonstrate output power and transient behavior of system in summer season. Effect of clear sky and high irradiation can be seen in Figs. 5 and 6 which are showing output power in watts and temperature increase in HTF and working fluid, respectively. Variations in generated power throughout the day are quite low and system continued to generate power using solar irradiations for more than 8 hours which is showing good solar potential.

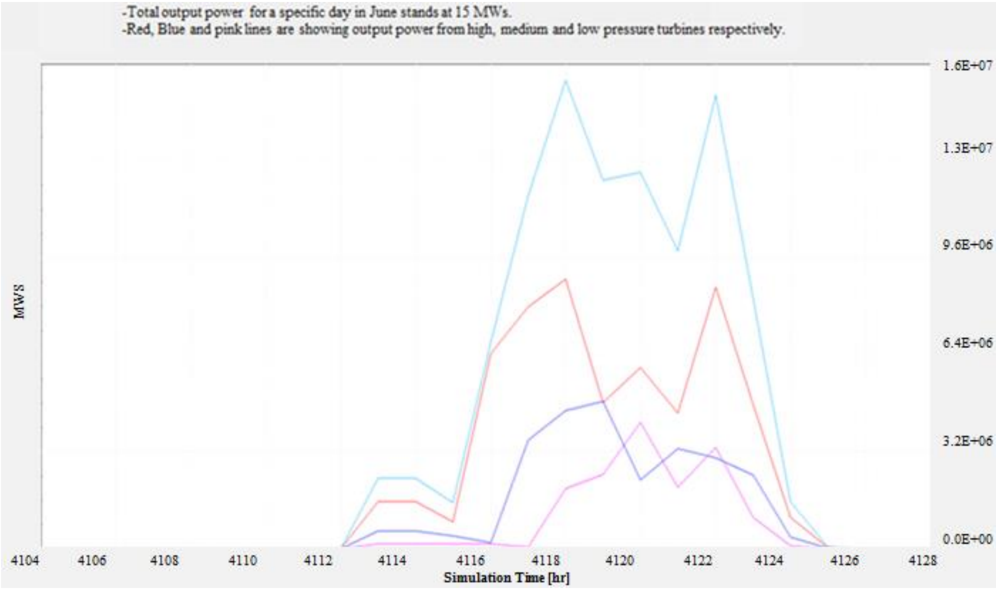

Fig. 5. Power generated for 21st of June

Fig. 6. Thermal behavior of system

B) Winter season

For winter season, second last day of December with output power of 1.5 MW was chosen to describe system transient behavior as shown in Fig. 7. Low irradiation and cloudy sky show excessive variation in output power during operation of the selected day as compared to selected summer day. During the first phase of the day, output power remains lower than 640kW, it rises to the value of 1.5MW in last three hours of operation. Increase in temperature of HTF and working fluid for winter day is up to 320 C° as shown in Fig. 8 whereas for chosen summer day it was above the limit of 390 C°.

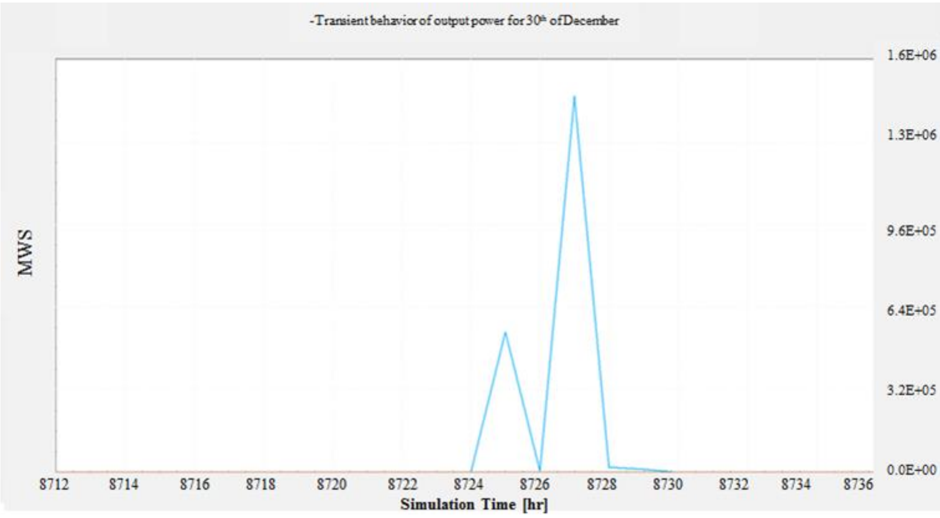

Fig. 7. Power generated for chosen day of December

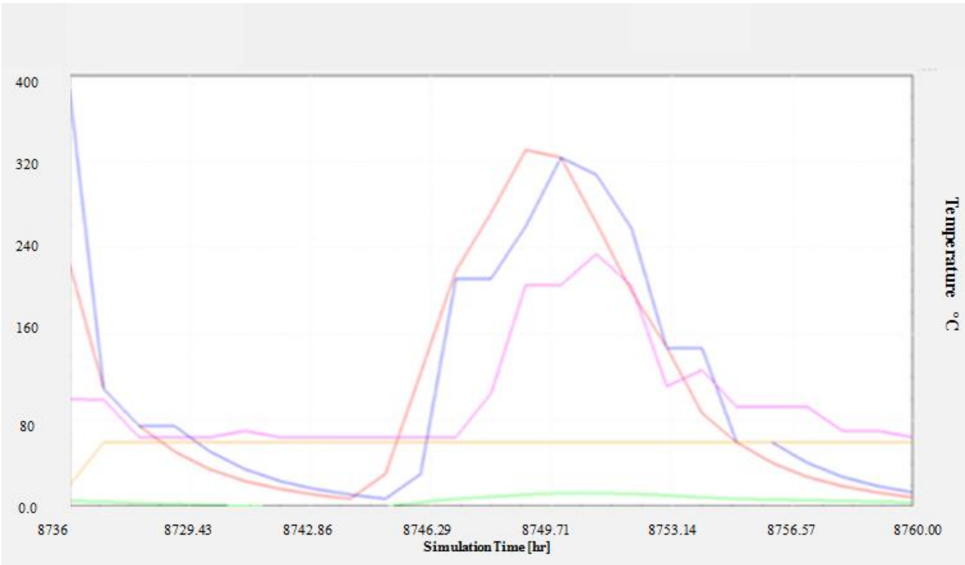

Fig. 8. Thermal behavior of system

5. Desalination

Main problem in using solar energy is its irregular nature. To cater this, a small-scale desalination plant equipped with low energy consumption technology can be used to produce potable water only during cloudy or low irradiation hours. Up till now, small-scale RO (reverse osmosis) desalination systems range from 10 m³/day to 1000 m³/day have been built to yield potable water from brackish or seawater [11]. Reverse osmosis (RO) is a pressure-driven method that account for the most of brackish water and seawater desalination capacity based on its comparatively low energy consumption [12]. In reverse osmosis technique, needed form of energy is only electricity. Pumps at various stages in reverse osmosis process are driven by the AC electricity. Specifically for a brackish-water reverse osmosis (BWRO) unit, depending upon the salinity of water energy consumption varies from 1.5 to 2.5 kWh/m³ [13]. Possible integration of CSP and Desalination plant is shown in Fig. 9.

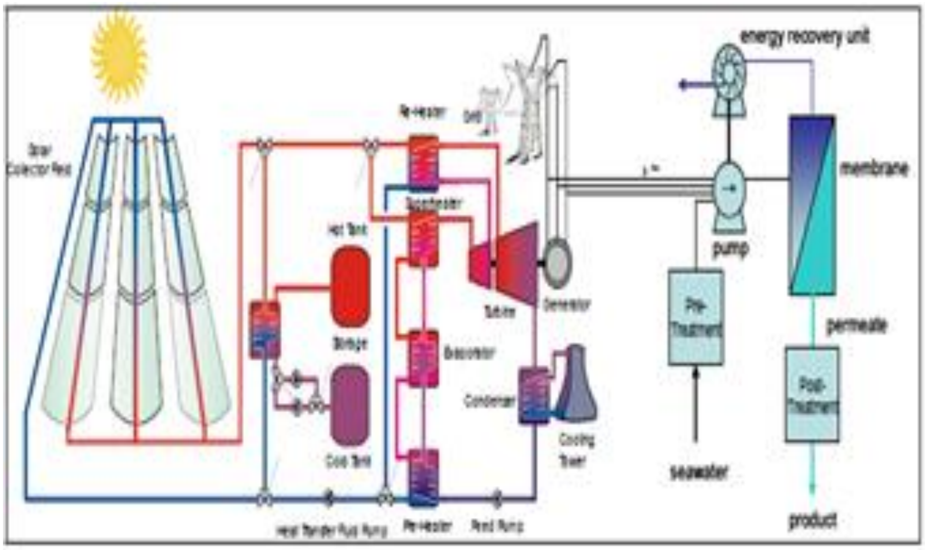

Fig. 9. Schematic of a CSP/RO desalination plant

6. Deduction

This item targets at the revision of a connection of the medium temperature Rankine sequence driven by the planetary arena through a molding accepted out in TRNSYS software. The climatic circumstances of Quetta were used to evaluate the energy production along with analyzing thermal behavior of the installation for one year. The technical results talk about the time of availability of power, annual power production and output capacity of the power plant. Reverse osmosis technology is found to be most appropriate for production of distilled water due to low energy requirements and matured market. Desalination attached with solar power plant is the most cost-effective scheme to meet power and clean water demand especially in arid regions of Pakistan.

7. References

[1] Sukhera M, Pasha M. “Solar radiation maps for Pakistan,” Sol Wind Technol 1987;4:229-38.

[2] Energy Efficiency and Renewable Energy. “Parabolic trough solar thermal electric plants,” US Department of Energy; 2006. DOE/GO 102006-2339.

[3] Al-Nasser, A.M, “Performance and Economics of a Solar Thermal Power Generation Plant in Jubail, Saudi Arabia: Parabolic Trough Collector,” IEEE International Energy Conference and Exhibition (EnergyCon), 2010.

[4] Al-Soud Mohammed S, Hrayshat Eyad S. “A 50MW concentrating solar power plant for Jordan.” J Clean Prod 2009; 17:625-35.

[5] C. Parrado, A. Girard, F. Simon, E. Fuentealba, 2050 LCOE (Levelized Cost of Energy) projection for a hybrid PV (photovoltaic)-CSP (concentrated solar power) plant in the Atacama Desert, Chile, Energy, 94 (2016) 422-430.

[6] G. Iaquaniello, A. Salladini, A. Mari, A.A. Mabrouk, H.E.S. Fath, “Concentrating solar power (CSP) system integrated with MED–RO hybrid desalination,” Desalination, 336 (2014) 121-128.

[7] G. Fiorenza, V.K. Sharma, G. Braccio, “Techno-economic evaluation of a solar powered water desalination plant,” Energy Convers. Manage., 44 (2003) 2217-2240.

[8] B. Ortega-Delgado, L. García-Rodríguez, D.C. Alarcón-Padilla, “Thermo economic comparison of integrating seawater desalination processes in a concentrating solar power plant of 5 MWe,” Desalination, 392 (2016) 102-117.

[9] Schwarzbozl P. “A TRNSYS model library for solar thermal electric components (STEC),” Release 3.0; 2006.

[10] G.C. Bakos, D.A. Petroglou, “Simulation study of a large-scale line-focus trough collector solar power plant in Greece,” Renewable Energy 71 (2014) 1-7.

[11] June-Seok Choi, Sangho Leea, Jin-Min Kim, Suingil Choi, “Small-scale desalination plants in Korea: Technical challenges,” Desalination 247 (2009) 222-232.

[12] M. Elimelech, W.A. Phillip, “The future of seawater desalination: energy, technology, and the environment,” Science 333 (2011) 712-717.

[13] Semiat R. “Energy issues in desalination processes,” Environmental Science and Technology 2008;42(22).