

# TRNSYS Modeling and Simulation of a Solar-Fuel Hybrid Thermal Power Plant based on a Central Receiver System

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**Abstract**— Energy plays a key role in the socio-economic development of a country. Although the available potential of solar energy and other renewable sources is sufficient to encounter the energy needs of the world but unfortunately, fossil fuels are used to a large extent for the purpose and this adds a serious problem of unsustainability to the energy market. A solar thermal power plant hybridized with natural gas as fuel is developed and simulated using TRNSYS simulation software to study the parameters and output of the plant. The model was simulated for the 2<sup>nd</sup> January and for the whole year which gives 53.7 Mwh of energy throughout the day and 20717 MWh of energy per annum. Peshawar was considered as a reference location for the plant. A field of 250 heliostats having a total solar reflective area of 25000 m<sup>2</sup> provides the required input energy.

**Keywords**— TRNSYS, hybrid CSP, Brayton cycle, heliostats, Peshawar Pakistan

## I. INTRODUCTION

Energy requirements of the modern world are increasing on daily basis at a rapid rate. Conventional sources of energy like fossil fuels have been under use for the last few decades to cover the energy demands which leads to problems like faster depletion of their limited volume and various environmental threats from their lethal emissions.

To overcome the associated problems with fossil fuels, the world is shifting towards the opportunities of renewable sources which are economical and sustainable. Energy from the sun emerges to be the most auspicious renewable source which could decrease the usage of fossil fuels and emissions of harmful gases like carbon dioxide[1]. Solar Photovoltaic and concentrated solar power are the major entrant technologies in the contest of solar power generation in which CSP has an edge of good efficiency, more life, and economical dispatchability over solar PV [2].

Pakistan is facing an exceptional energy crisis for the past two decades. The gap between electrical power demand and supply has reached 5 GW countrywide, while the rate of electrification has been dropped to seventy-three percent [3].

According to the energy survey of Pakistan for the year 2018, the Energy mix of Pakistan includes sixty-five percent contribution of fossil fuel [4]. Since the country is not self-sufficient in fossil fuels, therefore it is imported from other countries to meet the demand which makes a burden on the state treasury and hence shortfall occurs which causes daily load shedding of more than 10 hours in main cities, while it is up to 18 hours in villages [5]. The geographic position of Pakistan receives direct normal irradiance of 1.9 to 2.2 Mwh/m<sup>2</sup> annually with an average of 10 hours of daily sunshine which makes total solar potential up to 2900 GW [6]. The given statistics are perfect reasons to opt for concentrated solar energy as an alternate source for Pakistan.

The main principle of a CSP plant is based on the reflection of sunlight over an absorbing area with the help of reflecting surfaces to capture solar energy. Based on reflecting mirrors and collectors combinations, CSP has many technological configurations out of which solar power tower is a leading technology in the energy market. Solar power tower carries a receiver at the top of a tower in which a continuously circulating fluid receives the concentrated solar energy reflected by a field of reflecting mirrors around the tower called a heliostat field.

Solar power tower technology has the second-highest concentration ratio after parabolic dish and therefore a temperature of high level can be achieved by the working fluid in the receiver [7]. Power plants using this kind of technology are more economical for large-scale power production.

Solar energy shows transitory behavior and it needs either integration of an energy storage system or hybridization with a fuel source to supply a constant temperature and enthalpy at the inlet of the gas turbine. Moreover, hybridizing with fuel or integrating with an energy storage system increases the availability of energy and reduces the cost of a concentrated solar thermal power plant [8]. Therefore, the combustion chamber is added to a hypothetical Brayton cycle in the current research work and for this purpose, a central receiver-based model is developed using TRNSYS simulation software to simulate the variation of power and energy generated by the solar-fuel hybrid power plant.

### 1) Working principle of power tower technology

The tower is installed in a field of reflecting mirrors called heliostats which concentrates solar energy over a receiver mounted at the top of a tower. Fluid flowing through the receiver gain energy and as a result its temperature raises. The fluid of high temperature gives its energy to rotating machinery called turbine and the mechanical energy of rotating shaft of turbine converts into electrical energy in a magnetic field. Hence solar energy received at the heliostat field is delivered as electrical energy at the generator end of the plant.

### 2) Main Components of the plant

a) *Heliostat:* A large number of mirrors are configured around a central in such a way that they continuously track the sun to focus the sunlight over a small area of the absorber. Heliostat needs to have excellent reflectivity, precisely tracking ability and high strength to resist against winds [9].

b) *Tower:* The tower is used to support the receiver at a greater height and it is prepared either from hard metallic structure or concreted construction. The length of the tower is one of the most important design factors which can be selected according to the heliostat field layout and plant total electrical capacity[20].

c) *Energy receiver/ Absorber:* This is the receiver part for input energy to the plant. solar radiant energy gets absorbed in this part of the plant and transformed into thermal energy of the fluid which can be either directly utilized in power conversion unit or used to produce steam for turbine operation [10]. Receiver types include an external receiver that has no covering for insulation purposes and a cavity receiver consist of one or two cavities with tubes fixed inside the cavity. Due to more convection losses, the external receiver has low productivity than the cavity receiver.

d) *Power conversion block:* This is the core area of the plant which uses turbines to convert the thermal energy of working fluid into the mechanical energy of rotating shaft using turbines that work on the principles of a thermodynamics cycle. The Rankine cycle is the thermodynamic cycle with steam as a working fluid, the Brayton cycle uses gas as working fluid while the combined cycle is the combination of both these cycles [11]. A complete schematic diagram of a central receiver system with the Brayton cycle is shown in Figure-1.

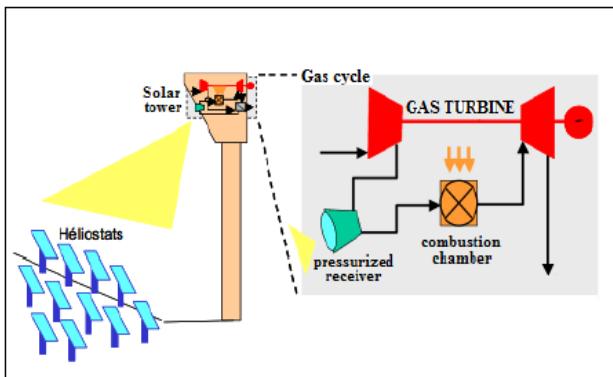


Figure 1. Central receiver system using Brayton power cycle [12]

## II. METHODOLOGY

The model of the plant is based on the Brayton cycle which is modeled and simulated in TRNSYS simulation software developed by WISCONSIN University USA [13]. TRNSYS software is a simulation package with good flexibility due to the facility of addition mathematically developed models, the easily accessible supplementary modules, and the capability of interfacing with additional programs of other simulating software. TRNSYS has a wide range of applications which include solar energy systems, heating ventilation and air conditioning systems, domestic and commercial buildings, hydrogen systems, and various kinds of transient systems. An individually Programmed Model of each component called "Type" can be found in the libraries of TRNSYS and the desired Types needs to be connected in the graphical user interface to simulate a complete system. Types of all the components required in the complete model of the plant under study are present in the standard and STEC library of TRNSYS [14]. Figure-2. shows the picture of the simulation model.

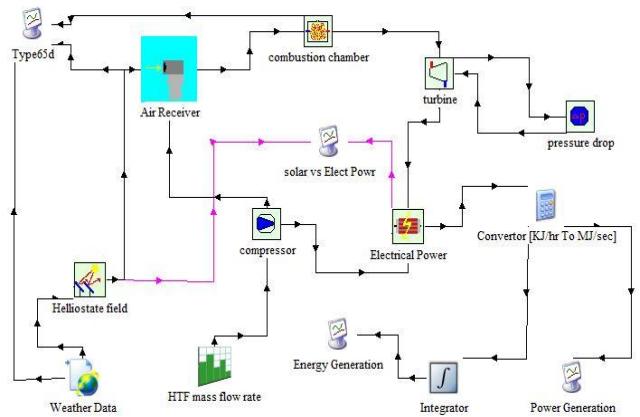


Figure 2. TRNSYS Model of Solar-fuel hybrid model

### 1) Location of the plant:

The prime level for considering a concentrated solar thermal plant is to choose the site for installation which is feasible from both economic and technical points of view. The site depends upon many factors out of which the average value of direct normal radiation (DNI) is the absolute necessary requirement which needs to exceed 5 Kwh/m<sup>2</sup> per day [15]. The slope of the land greatly affects the efficiency of the plants due to associated shading consequences. higher slopes of the lands decrease the efficiency and flattening of area results in higher efficiency, therefore the recommended slopes for a CSP is less than three percent [16] and the wind velocity should not exceed 15.6 m/s [17]. DNI of some regions in Pakistan may reach up to 6 KWh/m<sup>2</sup>/day and the selected site for this work is Peshawar which has rich DNI approaching almost 4.5 - 5 Kwh/m<sup>2</sup>/day [18]. Weather data of Peshawar is available in the TRNSYS weather library in TMY2 format.

## 2) HTF

HTF stands for heat transfer fluid used as a working medium for energy exchange in the plant. Molten salt, man-made oils, water, and air are some of the common heat transfer fluids used in CSP [19]. The model under the study uses gas as heat transfer fluid.

## 3) Parameters of the Model

Parameters of a fictive Brayton cycle with steady state capacity of 5MW are taken as a reference set of values in the power conversion portion of the model which are given in table-I.

TABLE I. INPUT VALUES OF THE BRAYTON CYCLE

Parameter	Value (unit)	Parameter	Value (unit)
HTF mass flow rate	60120 (kg/hr)	Compressor inlet temperature	25 (C°)
Water mass flow rate	18000 (kg/hr)	compressor outlet temperature	372.85 (C°)
Turbine inlet pressure	15 (bar)	Pressure ratio	15 (unitless)
Turbine inlet temperature	926 (C°)	Heat rate	6333 Btu/kWhr
Turbine outlet temperature	280.35 (C°)	Fuel mass flow rate	0.166 kg/sec

Brayton cycle receives input energy from both a combustion chamber with natural gas as fuel and a solar field which consists of heliostats and a power tower with necessary frames, wirings, and pipes. Parameters of the solar field are given in tale-II.

TABLE II. SOLAR FIELD PARAMETERS

Parameters	Value (unit)	Parameters	Value (unit)
Reflectivity of mirrors	0.96	Absorber emissivity	0.80
Surface area of a mirror	100 (m <sup>2</sup> )	Absorber fraction	0.85
No of azimuth data points	9	Aperture of receiver	15 (m <sup>2</sup> )
No of zenith data points	7	Hot gas piping emissivity	0.80
Receiver optical efficiency	0.82	Design inlet pressure	15 bar

## III. RESULTS AND DISCUSSION

The model is receiving input energy from both solar and conventional fuel and the solar energy is dependent upon the local DNI which varies through the course of the day. Simulation results show that fuel consumption decreases in the times when the DNI increases. Figure-3 is the simulation plot

of various output values of the model for the second January of a typical metrological year where the blue line shows the DNI of that specific day and the green line is for fuel consumption. It can be seen from the figure that the line of fuel consumption is at the lowest position when the line of DNI passes through the highest point and at the end of the day when the graph of DNI falls down, an increasing trend of fuel consumption can be observed in the graph. Moreover, the yellow line exhibits the temperature at the inlet of the turbine which goes constant due to fuel supply in the time of insufficient solar energy.

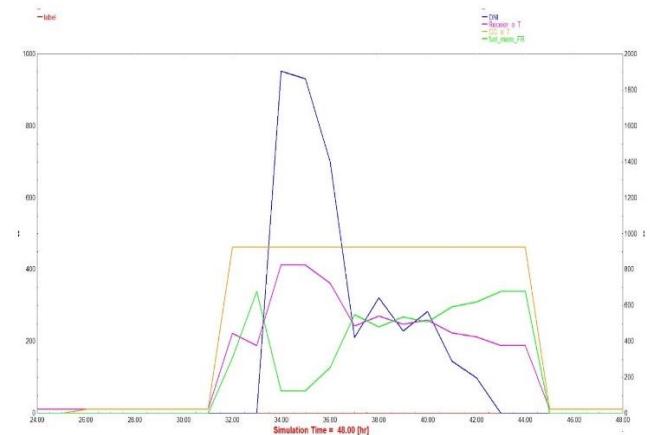


Figure 3. Simulation of model for Various parameters on 2<sup>nd</sup> January

The total energy generated when the model was simulated for the day of 2nd January of a typical metrological year is 53.6 Mwh which can be seen from Figure-4.

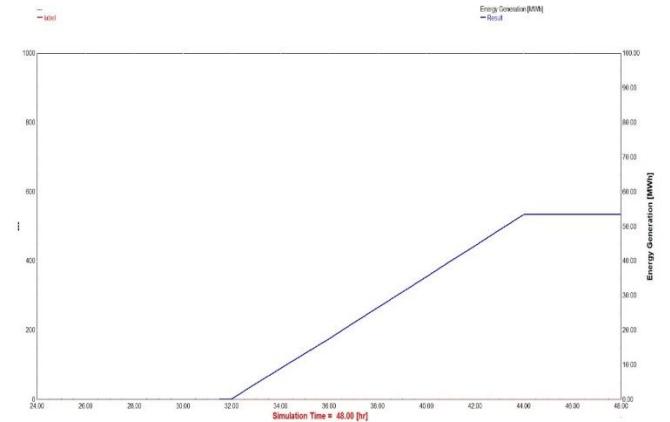


Figure 4. Total energy generated on 2<sup>nd</sup> January

The model was simulated for a typical metrological to find the energy generated for the whole year. Figure-5 shows the plot of energy produced. It can be noted from the figure that a total amount of 20717 MWh of energy can be obtained from the plant for the whole year.

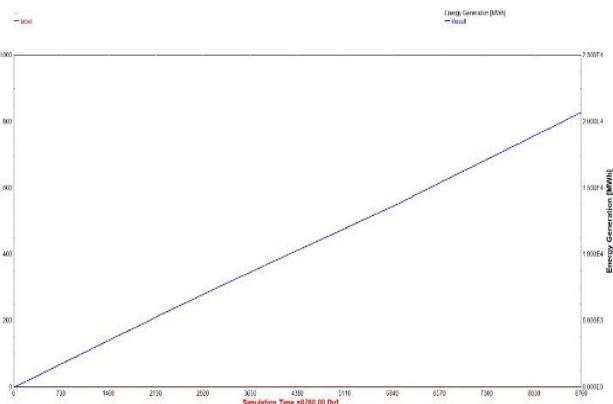


Figure 5. Annual energy generated by the model

Solar energy has a major share in the generated electrical energy and a total of 250 heliostats with an area of 100 m<sup>2</sup> per heliostat are utilized in acquiring the solar input.

## CONCLUSION

The solar thermal power plant with a total electrical capacity of 5 MW having a hypothetical Brayton cycle hybridized with natural gas as input energy was modeled and simulated for the weather data of Peshawar using TRNSYS simulation software. complete Typical metrological year and 2nd January of the same year were the reference time axes used to plot the varying energy generated from the simulation of the model.

Simulation results show that the temperature at the inlet of the turbine remains constant during low DNI hours by the utilization of natural gas as input energy. The conclusion of the current research can be summarized as that although solar energy is available in sufficient amount but its nature is transient which can be covered by adding fuel as input to a solar thermal power plant.

## REFERENCES

- [1] T Tsoutsos, N Frantzeskakib, and V Gekasb, "Environmental impacts from the solar energy," ELSEVIER Energy, vol. 33, pp. 289-296, 2005
- [2] s. G.T Machinda, "Concentrating Solar Thermal Power Technologies: A review," in 2011 Annual IEEE India Conference, Hyderabad, India, 2011
- [3] "Sustainable Development Policy Institute ("SDPI") (Pakistan Energy Vision 2035)."
- [4] Report of " Pakistan Economic Survey 2018-2019"
- [5] "Asian Development Bank (Pakistan Solar Rapid Assessment June 5, 2017)."
- [6] "Solar Thermal Power 2020 | Greenpeace International."
- [7] Kalagirou, S. A. (2009). Solar Energy Engineering Processes and Systems (2nd ed.).Massachusetts: Elsevier
- [8] H Muller-Steinhagen, Freng Tried, and Franz Trieb, "Concentrating Solar Power," *A review of the technology*, no. 18, February 2004
- [9] Price, H., Lu"pfert, E., Kearney, D., Zarza, E., Cohen, G., Gee, R. and Mahoney, R., 2002. Advances in parabolic trough solar power technology. *J. Sol. Energy Eng.*, 124(2), pp.109-125.
- [10] H. A. Raza, S. Sultan, S. ul Haq, A. Hussain, A. K. Janjua, and A. Bashir, "Modeling of 1 MW solar thermal tower power plant using TRNSYS," in 2018 1st International Conference on Power, Energy and Smart Grid (ICPESG), 2018,
- [11] R Sioshansi and P Denholm, "The Value of Concentrating Solar Power and Thermal Energy Storage," *IEEE Transactions on Sustainable Energy*, vol. 1, no. 3, pp. 173-183, October 2010
- [12] Garcia, P., Ferriere, A., Flamant, G., Costerg, P., Soler, R. and Gagnepain, B., 2008. Solar field efficiency and electricity generation estimations for a hybrid solar gas turbine project in France. *Journal of Solar Energy Engineering*, 130(1).
- [13] WISCONSIN. [Online]. Available: <http://sel.me.wisc.edu/trnsys/index.html>. [Accessed 6 april 2021].
- [14] STEC [online] Available : <https://sel.me.wisc.edu/trnlib/stec/stec.htm> [Accessed 10 april 2021].
- [15] "K. Kaygusuz, Prospect of concentrating solar power in Turkey: the sustainable future, *Renew. Sustain. Energy Rev.* 15 (2011) 808–814."
- [16] "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."
- [17] "Nusrat Kamal Raja, M. Shahid Khalil, Design and Manufacturing of Parabolic Trough Solar Collector System for a Developing Country Pakistan, *Journal of American Science*, 2011."
- [18] National Renewable Energy Lab; [http://www.nrel.gov/analysis/tech\\_cap\\_factor.html](http://www.nrel.gov/analysis/tech_cap_factor.html), National Renewable Energy Lab USA, September (2010).
- [19] S.Bonnet, M. Alaphilippe, P. Stouffs. "Thermodynamic solar energy conversion: Reflections on the optimal solar concentration ratio". *International Journal of Energy, Environment and Economics*, vol12, pp141-152., 2006.
- [20] Burghartz, A.K., von Reeken, F. and Balz, M., 2018, November. Economic evaluation of towers for central receiver systems. In AIP Conference Proceedings (Vol. 2033, No. 1, p. 090004). AIP Publishing LLC.

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The author was born in District Khyber of KPK, Pakistan. After his undergraduate in Mechanical engineering from UET Peshawar, The author got a scholarship for an MS degree in US-Pak Center for advanced studies in energy, UET Peshawar, from where he has defended his research work successfully. The current paper is a part of his Master's thesis in thermal System Engineering at the United States Pakistan Center for Advanced Studies in Energy USPCAS E, University of Engineering and Technology Peshawar. The thesis is focused on the simulation of a solar thermal power plant using TRNSYS simulation software.

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