Available online at www.sciencedirect.com

ScienceDirect

Procedia - Social and Behavioral Sciences 195 (2015) 2382 – 2390

Procedia
Social and Behavioral Sciences

World Conference on Technology, Innovation and Entrepreneurship

The Impact of the Solar Irradiation, Collector and the Receiver to the Receiver Losses in Parabolic Dish System

Rosnani Affandi[a*], Mohd Ruddin Ab Ghani[a], Chin Kim Ghan[a], Liaw Geok Pheng[a]

[a]*Faculty of Electrical Engineering, University Technical Malaysia Malacca,76100 Durian Tunggal, Melaka, Malaysia*

Abstract

Parabolic Dish (PD) is one of Concentrating Solar Power (CSP) technologies that convert sunlight to electricity. PD has shown the highest efficiency by converting nearly 31.25% of solar radiation into electricity and PD has emerged as one of reliable and efficient Renewable Energy (RE) technology. However, the evaluation for the PD system performance by using experimental approach is costly and time consuming. Therefore, a model has become necessary to predict the system performance under several of operating conditions. Nevertheless, current literature on PD modelling is scattered, focusing on individual components and rarely organised in one cohesive report. This paper is to study on the impact of the Direct Solar Irradiance (DNI), collector and receiver to the value of heat transfer to the receiver; solar power intercept by a receiver as well as the receiver loses in 25kW PD system. This study is using a simulation approach and Matlab Simulink was used as the simulation tool. The irradiation data were downloaded from the Meteonorm 7 Software and George Town, Penang in Malaysia has been selected as the location for simulation. Meanwhile, the aluminium and silver was used as the reflective material and the intercepted factor used for the simulation is in the range of 0.9 to 1.0. As a conclussion, the simulation result has shown that variations of the solar irradiation on the site, reflective material and the intercept factors influence the value of the value of the rate of heat transfer to the receiver; solar power intercept by a receiver as well as the receiver loses.

Keywords: Parabolic Dish (PD); Concentrating Solar Power (CSP); Direct Normal Irradiation (DNI); receiver losses

1. Introduction

Concentrating Solar Power (CSP) is technologies that use direct sunlight as a heat source to generate the electricity. Most of the technologies are located in the areas that is hot and dry with excellent solar radiation (G T Machinda, S Chowdhury, S P Chowdhury, 2011). Meanwhile, in order to be economically feasible, it is essential to

doi:10.1016/j.sbspro.2015.06.220

select the site with higher solar irradiation (Arvizu et al., 2011). For this aim it is needed to know the DNI for the suggestion of the installation site (Silvano Vergura, 2012).

Generally, CSP has four technologies which are; Parabolic Troughs, Linear Fresnel, Parabolic Dish and Power Tower (Refer Fig.1). All of the technologies have different structure; therefore it will produce a different outcome on the rate of heat transfer to the receiver, solar power intercepted by the receiver and the receiver loses.

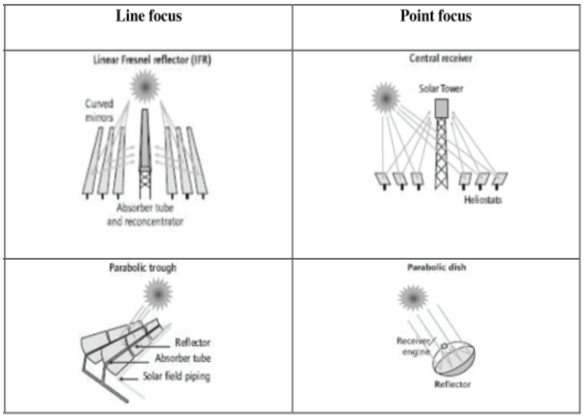

Fig. 1. Four types of the CSP technologies (Pitz-Paal et al., 2012)

Meanwhile, among all of the CSP technologies, PD is one of the technology that shows the highest energy conversion efficiency (Affandi, Gan, Ruddin, 2014; Arvizu et al., 2011). However, PD systems are not extensively studied as other solar technologies such as Parabolic Trough system, Power Tower and photovoltaic system (Fraser, 2008; D. F. Howard, 2010). The development of PD technology compared to the other solar technologies is still at the early stage. Thus, compared to other solar technologies, the data on the performance of the PD system is limited.

Meanwhile, evaluation of PD system performance by using experimental approach is costly and time consuming. Modelling and simulation of the PD systems becomes more and more important, particularly for predicting the system performance under various operating conditions. However, the current literature on the modelling of PD system is limited and scattered (D. Howard & Harley, 2010; Kaddour & Benyoucef, 2012). Therefore, there is a necessary for doing an analysis of the PD system such as in determining the impact of receiver losses resulting from solar irradiation, collector system and receiver system (Fraser, 2008).

This paper brings together the concentrator and the receiver model within the PD system. By using a simulation approach and Matlab Simulink as the simulation tool; a background of the PD system is provided, along with a description of the component model. In addition, a strategy for integrating the system components into a PD model is given, along with typical simulation results.

2. Parabolic Dish System

PD system have not wide operational experience compared to the other CSP technologies such as parabolic trough or power tower system (Mendoza, 2012). However, PD has the potential to become one of the least expensive sources of RE. The advantage of this system is it has the higher of solar to electric efficiencies, modular and suitable for small scale area with each unit typically generating output of 3 to 25 kW.

Generally, the PD system is incorporated in the dual axis tracking system for tracking the sun throughout the day (Mohamed, Jassim, Mahmood, & Ahmed, 2012). The system consists of four main components which are concentrator, receiver, Stirling engine and generator (Refer Fig. 2). In which, the receiver, Stirling engine and generator is contained inside of the Power Conversion Unit (PCU). The concentrator in the PD system needs to focus the solar radiation into the cavity of the receiver and then used the solar energy in the energy conversion process. This system produces the electricity by using concentrated solar energy to drive a Stirling engine.

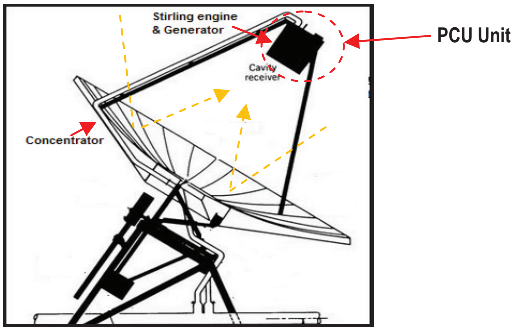

Fig. 2. Parabolic Dish System

3. Parabolic Dish Modelling for Receiver Losses

The model for receiver losses in Parabolic Dish system was developed based on the previous study done by Fraser, Howard and Aker (Fraser, 2008; D. F. Howard, 2010; Aker, 2012). Fraser developed his model specifically to analyse the performance of the PD components in predicting the net power produced. The models were implemented in TRNSYS and have some explanation of the PD components. Meanwhile, Howard developed the dynamic model of the PD system, including models of the Stirling engine working gas and mechanical dynamics using the Custom FORTRAN code. The code is written to model the Stirling engine dynamics within PSCAD/EMTDC. Whilst, based on the work made by Howard; Aker has developed his mathematical model for the concentrator, receiver as well as the Stirling engine. The difference is Aker used the MATLab Simulink and focusing on investigating the feasibility of a variable speed drive in a PD system.

Therefore, by referring to the model developed by Fraser, Howard and Aker; this paper explained on the development of a 25kW PD model by focusing on the receiver losses. The PD system modelling for receiver losses is shown as in Fig. 3.

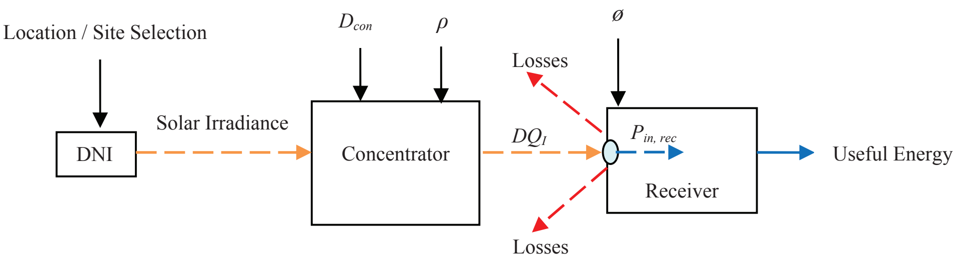

Fig. 3. PD system modelling to study on the Receiver losses

4. Parabolic Dish Components

4.1. Concentrator

PD concentrator is consisting of a mirror that is arranged in the paraboloid shape. The aim of the PD concentrator is to collect and concentrate the solar radiation from low density to the small area. When solar radiation is concentrated in the small area, this will increase the solar radiation density to a few hundred times. The parameters that help to increase the quantity and density of solar energy are the opening area of the concentrator and the reflector material (D. Howard & Harley, 2010; Sembiring, Napitupulu, Albar, & Husein, 2007).

The opening area of the concentrator is based on the size of the concentrator. Basically, size of PD concentrator is determined by the engine and depends on the input power. Therefore, the concentrator needs to size to assure it can deliver enough of thermal energy to the receiver (Aker, 2012; D. F. Howard, 2010; William B. Stine, 1994). Meanwhile, the quality of a concentrator is measured by its reflectance. In which, reflectance can be determined as the percentage of incident sunlight that reflected from the concentrator mirror surface. However, it is critical to identify the suitable and economical reflective material for PD concentrator (Rafeeu & Kadir, 2012). Concentrators that have a high quality of the reflector are made from highly reflective materials and in present designs; mirror reflectivity is in the range of 91 – 95%. In which, silver is preferred to use as the reflector material with aluminum second (Fraser, 2008; D. Howard & Harley, 2010; Noor & Muneer, 2009; William B. Stine, 1994).

4.2. Receiver

In PD system, the most important factor in matching a concentrator and the receiver is the intercept factor. Intercept factor is the fraction of solar radiation from the PD concentrator that enters the aperture of the receiver (Bakos & Antoniades, 2013). Meanwhile, receiver in the PD system acts as a thermal interface between the concentrated sunlight and the PCU. It needs to absorb as much solar energy reflected from the concentrator and transfer the heat to the cavity of receiver with minimum losses (D. F. Howard, 2010; Sembiring et al., 2007). Therefore, to minimize the receiver losses, receiver area must be large enough to ensure most of reflected solar energy intercepted by the receiver (William B. Stine, 1994).

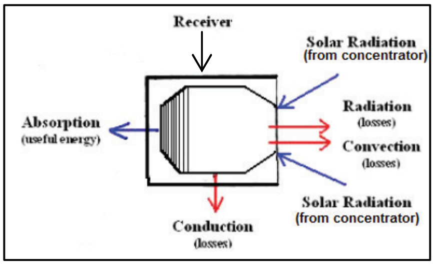

Fig. 4. Losses of solar radiation from the concentrator to receiver (Fraser, 2008)

However, if the receiver area is large, the losses will increase. On the other hand, if the receiver area is small, the value of heat loss will decrease. Apart from that, it will cause some of the reflected solar energy blocked from entering the cavity of the receiver. As shown in Fig. 4, the receiver losses occur in PD system are due to the convection, conduction as well as the radiation (Fraser, 2008; D. F. Howard, 2010). Convection and radiation decrease the useful energy absorbed in the receiver. Meanwhile, James Baker and Todd Meyer in (James Baker & Todd Meyer, 2009) have revealed that the receiver losses are present in a small amount. In which, the losses can reach 10% from the total of the reflected solar energy to the receiver. Therefore, despite of missing or losses, typically the receiver is about 90 % are efficient in transferring the solar energy from the concentrator to the Stirling engine (Bakos & Antoniades, 2013; Fraser, 2008).

5. Direct Normal Irradiance (DNI)

CSP is depending on the intensity of the sun’s radiation referred as the DNI. DNI is solar irradiance that comes in a direct line from the sun. On clear sky conditions, the DNI represents more than 80% of the solar energy reaching the earth’s surface. Meanwhile, some of the solar radiation reaching the earth's surface is absorbed and scattered (Fig. 5). The solar radiation is absorbed by ozone, oxygen and water vapor. Weather conditions such as storms and clouds become the primary factor that changed solar radiation to the surface. In which, on a cloudy day the direct beam radiation is almost zero.

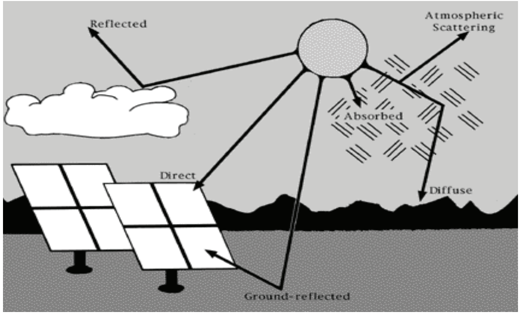

Fig. 5. Radiation from sun.
[Source: http://rredc.nrel.gov/solar/pubs/shining/page12_fig.html].

Therefore, to get an accurate analysis, especially on the performance of CSP system; it is essential to know about the quality and the future reliability of the sunlight (Stoffel, Renné, Myers, & Wilcox, 2010). Meanwhile, to increase the amount of rate of heat transfer to the receiver, it is important to have as high and as long time possible for the input irradiance. Hence, a good solar resource is a top priority for CSP technology and only strong solar irradiance can be concentrated for produce high temperatures for producing steam and then generate the electricity.

6. Methodology

In this study, a 25kW PD system is used and Matlab simulink was used as the simulation tool. The irradiation data were downloaded from Meteonorm 7 Software. Furthermore, to develop the PD model and to study on the receiver losses in PD system, it is essential to know the rate of heat transferred from concentrator (DQ_I) and solar power intercepted by the receiver ($P_{in, rec}$). Therefore the concentrator and receiver model need to develop by using mathematical equations to represent the models in Matlab Simulink. Besides, a few of external inputs data or parameters are required in developing the model such as; the location irradiance/DNI data, the concentrator parameters such as the diameter concentrator, aperture area, reflectivity and receiver parameter such as the reflectance material and the intercept factor. The parameters used to develop the model are explained in the following section.

6.1. Site Selection and Collecting Direct Normal Irradiance (DNI) Data

In Malaysia, solar radiation is highest at the Northern states and decrease at the Southern states. Northern states such as Perlis, a part of Kedah, Penang, Kelantan, a part of Melaka and a few places in East Malaysia (especially Sabah) received the most amount of solar radiation, while Johor at the southern Peninsular Malaysia and most parts in Sarawak receives the lowest solar radiation (Azhari, Sopian, & Zaharim, 2008; Nair & Ford, 2012).

In this study only one location/site with higher DNI data is used. Therefore, George Town, Penang is selected because it receives the highest DNI compared to the other cities in Malaysia (Refer Table 1). Fig. 6 shows the annual DNI data in George Town, Penang. Overall, for the monthly DNI in George Town, Penang, the highest DNI is in January and followed by March, February, December, April, May, November, July, Jun, August, September and the lowest is in October.

Meanwhile, to show the effect of solar irradiance to the rate of heat transfer to a receiver, solar power intercepted by the receiver and the receiver loses; three days data were used in this study. Three day data is the lowest solar irradiance, medium solar irradiance and highest solar irradiance in a year for George Town. Therefore, by referring

Fig.7 it shows the highest solar irradiance data for George Town is on 15 January with a value of 1004 W/m^2, medium DNI is on 1 November and lowest DNI is on 9 January.

Table 1. Yearly irradiation data for selected locations in Malaysia.

Cities in Malaysia	DNI [kWh/m^2]
George Town	1246
Kota Kinabalu	1192
Kota Bahru	1107
Senai	1045
Kuantan	1013
Durian Tunggal	973
Tawau	969
Sitiawan	949
Subang	932
Kuching	834

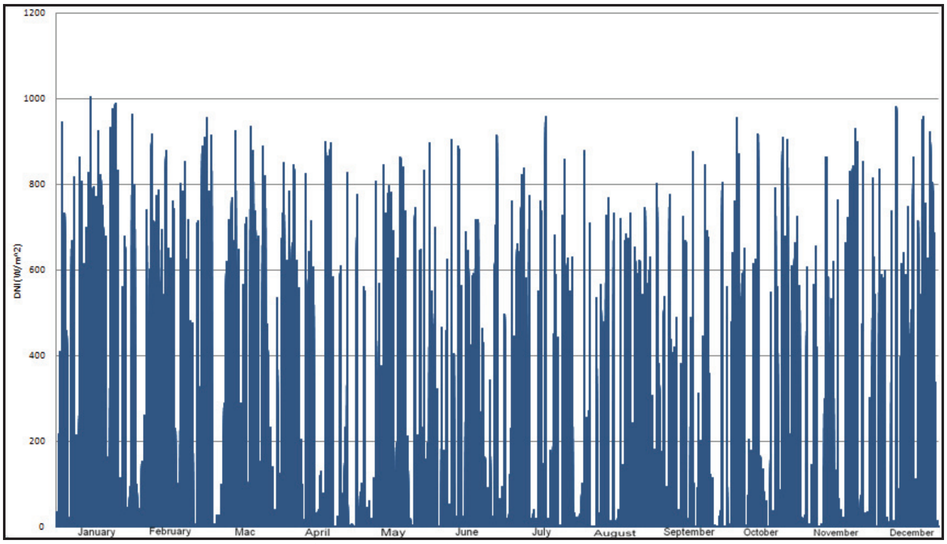

Fig. 6. The annual DNI data for George Town, Penang.

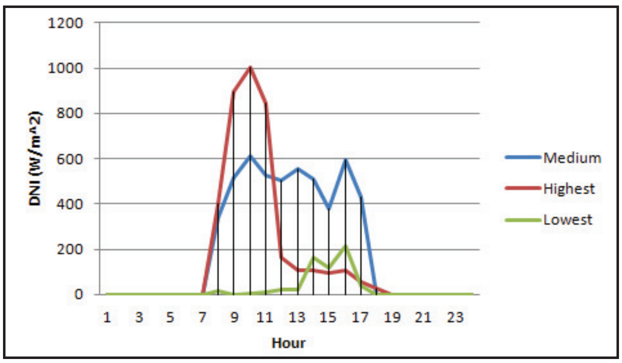

Fig. 7. The Highest, medium and lowest Irradiance for George Town, Penang.

6.2. Aperture Area of Concentrator.

Eq. 1 used for calculating the aperture area of the PD concentrator;

$$A_{aperture} = \frac{\pi}{4} D_{con}^{2} \tag{1}$$

From eq. 1, D_{con} is the diameter of the concentrator. This study is using 25kW PD system and diameter/size of the concentrator is 10.1815 meters. Therefore, with a size of 10.1815 meters, the $A_{aperture}$ is equal to 10.75 m^2.

6.3. Reflective Material.

Aluminium and Silver is two reflective material used for this study. Aluminium has 92% of reflective material, while Silver has 96% of its reflective material (James Baker & Todd Meyer, 2009; Kruger, Pitz-paal, & Rietbrock, 2003; Peiyao, Laishun, Yuhua, Qiuya, & Jianzhong, 2007).

6.4. The Parameters for Heat Transfer from the Concentrator

The rate of heat transfer from the concentrator to the receiver can be approximated by using an equation:

$$DQ_1 = \pi \left(\frac{D_{con}}{2}^{2}\right) I\rho \tag{2}$$

By referring to eq. 2, D_{con} is the diameter of the concentrator, ρ is reflective material for the concentrator and I, is the solar irradiance or DNI.

6.5. The Parameters for Solar Power Intercept by the Receiver.

The value of solar power intercepted by the receiver (Kribus, 2002; Mendoza, 2012) can be calculated by using mathematical equation;

$$P_{in,rec} = I\, A_{\text{aperture}}\, \rho\phi \tag{3}$$

From eq. 3, it shows that the value of solar power intercepted by the receiver depends on the amount of solar radiation I, the opening area of the concentrator $A_{aperture}$, reflective material ρ and the intercept factor $ø$.

6.6. Intercept Factor.

Generally, the intercept factor is between 90 and 99% (Bakos & Antoniades, 2013). Meanwhile, PD from the type of Wilkinson, Goldberg, and Associates, Inc or (WGA) have a high degree of accuracy with an intercept factor that over than 99%. In this study, the intercepted factor used to calculate the receiver losses is in the range of 0.9 to 1.0.

6.7. Analysis of the Simulation Result

From Table 2 and Table 3; it shows that the rate of heat transfer to the receiver, solar power intercepted by the receiver and the receiver loses. The result shows the receiver loses achieve the highest value which is 10% for low, medium and high level of DNI and using silver and aluminum as the reflective material when intercept factor is 0.9.

Meanwhile, the receiver loses is decreased to 0% for low, medium and high level of DNI and using silver and aluminium as the reflective material when intercept factor is 1.0.

Table 2. Result for rate of heat transfer to receiver, solar power intercepted by the receiver and losses for 25kW PD by using silver as the reflective material.

Intercept factor ϕ	For lowest DNI			For medium DNI			For highest DNI		
	DQ_I (watt)	Pin_Rec (watt)	Losses (%)	DQ_I (watt)	Pin_Rec (watt)	Losses (%)	DQ_I (watt)	Pin_Rec (watt)	Losses (%)
0.9	16650	14985	10	47684	42915	10	78480	70635	10
0.91	16650	15152	9	47684	43392	9	78480	71419	9
0.92	16650	15318	8	47684	43869	8	78480	72204	8
0.93	16650	15485	7	47684	44346	7	78480	72989	7
0.94	16650	15651	6	47684	44823	6	78480	73774	6
0.95	16650	15818	5	47684	45300	5	78480	74559	5
0.96	16650	15984	4	47684	45776	4	78480	75344	4
0.97	16650	16151	3	47684	46253	3	78480	76128	3
0.98	16650	16317	2	47684	46730	2	78480	76913	2
0.99	16650	16484	1	47684	47207	1	78480	77698	1
1	16650	16650	0	47684	47684	0	78480	78480	0

Table 3. Result for rate of heat transfer to receiver, solar power intercepted by the receiver and losses for 25kW PD by using aluminum as the reflective material.

Intercept factor ϕ	For lowest DNI			For medium DNI			For highest DNI		
	DQ_I (watt)	Pin_Rec (watt)	Losses (%)	DQ_I (watt)	Pin_Rec (watt)	Losses (%)	DQ_I (watt)	Pin_Rec (watt)	Losses (%)
0.9	15957	14361	10	45690	41127	10	75210	67691	10
0.91	15957	14520	9	45690	41584	9	75210	68444	9
0.92	15957	14680	8	45690	42041	8	75210	69196	8
0.93	15957	14840	7	45690	42498	7	75210	69948	7
0.94	15957	14999	6	45690	42955	6	75210	70700	6
0.95	15957	15159	5	45690	43412	5	75210	71452	5
0.96	15957	15318	4	45690	43869	4	75210	72204	4
0.97	15957	15478	3	45690	44326	3	75210	72956	3
0.98	15957	15637	2	45690	44783	2	75210	73708	2
0.99	15957	15797	1	45690	45240	1	75210	74461	1
1	15957	15957	0	45690	45690	0	75210	75210	0

7. Conclusion

From the simulation result, it can be concluded that, by minimizing the intercept factor, the fraction of solar power entering the receiver will be decreased. Thus, the losses of solar radiation that transferred from the concentrator to the receiver will increase. Therefore, to increase the fraction of solar power entering the receiver, the intercept factor must be increased. Thus, the losses of solar radiation that transferred from the concentrator to the receiver will be decreased.

Acknowledgement

The authors would like to gratefully acknowledge the funding support provided by the Ministry of Education Malaysia under the research grant No: FRGS/2/2013/TK02/FKE/01/F00167.

References

Affandi, R., Gan, C. K., Ruddin, M., & Ghani, A. (2014). Performance Comparison for Parabolic Dish Concentrating Solar Power In High Level Dni Locations With George Town, Malaysia. Applied Mechanics and Materials, 699, 570–576. Doi:10.4028/Www.Scientific.Net/AMM.699.570

Aker, R. (2012). Investigation of Feasibility For An Inverter-Controlled Variable Speed Drive In A Stirling CSP Application.

Arvizu, Balaya, P., Cabeza, L., Hollands, T., Kondo, M., Konseibo, C., … Hansen, G. (2011). Direct Solar Energy. (R. Z. Arvizu, D., P. Balaya, L. Cabeza, T. Hollands, A. Jäger-Waldau, M. Kondo, C. Konseibo, V. Meleshko, W. Stein, Y. Tamaura, H. Xu, Ed.)Direct Solar Energy (Pp. 333–400). United Kingdom and New York, NY, USA.

Azhari, A. Y. U. W., Sopian, K., & Zaharim, A. (2008). A New Approach For Predicting Solar Radiation In Tropical Environment Using Satellite Images – Case Study Of Malaysia, 4(4), 373–378.

Bakos, G. C., & Antoniades, C. (2013). Techno-Economic Appraisal Of A Dish/Stirling Solar Power Plant In Greece Based On An Innovative Solar Concentrator Formed By Elastic Film. Renewable Energy, 60, 446–453. Doi:10.1016/J.Renene.2013.05.031

Fraser, P. R. (2008). Stirling Dish System Performance Prediction Model.

G T Machinda, S Chowdhury, S P Chowdhury, S. K. And R. A. (2011). Concentrating Solar Thermal Power Technologies : A Review. In IEEE CONFERENCE PUBLICATIONS (Pp. 1–6). India.

Howard, D. F. (2010). Modeling , Simulation , And Analysis Of Grid Connected Dish-Stirling Solar Power Plants. Georgia Institute of Technology.

Howard, D., & Harley, R. G. (2010). Modeling Of Dish-Stirling Solar Thermal Power Generation. In Proc. 2010 IEEE PES General Meeting, Minneapolis, Minnesota (Pp. 1–7).

James Baker, T. S., & Todd Meyer, C. T. (2009). Stirling Solar Engine Design Report.

Kaddour, A., & Benyoucef, B. (2012). Simulation and Modelization of Parabolic Solar Concentrator. Earth Science & Climate Change, 3(2), 3–5. Doi:10.4172/2157-7617.1000113

Kribus, A. (2002). Thermal Integral Micro-Generation Systems for Solar and Conventional Use. Journal of Solar Energy Engineering, 124(2), 189. Doi:10.1115/1.1464879

Kruger, D., Pitz-Paal, R., & Rietbrock, P. (2003). Comparative Assessment Of Solar Concentrator Materials. Solar Energy, 74(2), 149–155.

Mendoza, S. (2012). WREF 2012 : Modeling Generation Systems From Using Solar Stirling Engines Parabolic Dishes (Solar / Dish), 1–8.

Mohamed, F. M., Jassim, A. S., Mahmood, Y. H., & Ahmed, M. A. K. (2012). Design and Study Of Portable Solar Dish Concentrator. International Journal Of Recent Research And Review, III(September), 52–59.

Nair, N. L., & Ford, J. L. (2012). Evaluation Of Solar And Meteorological Data Relevant To Solar Energy Technology Performance In Malaysia. Sustainable Energy & Environment, 3, 115–124.

Noor, N., & Muneer, S. (2009). Concentrating Solar Power (CSP) And Its Prospect In Bangladesh. In IEEE Conference Publications (Pp. 1–5).

Peiyao, Y., Laishun, Y., Yuhua, L., Qiuya, N., & Jianzhong, T. (2007). Development Of The Experimental Bench For A Research On Solar-Dish. In ISES Solar World Congress 2007: Solar Energy And Human Settlement (Pp. 1785–1790).

Rafeeu, Y., & Kadir, M. Z. A. A. (2012). Thermal Performance of Parabolic Concentrators Under Malaysian Environment : A Case Study. Renewable And Sustainable Energy Reviews, 16(6), 3826–3835. Doi:10.1016/J.Rser.2012.03.041

Sembiring, M., Napitupulu, F., Albar, A. F., & Husein, M. N. El. (2007). A Stainless Steel Parabolic. In ICEE (Pp. 45–49).

Silvano Vergura, V. D. F. (2012). Matlab Based Model Of 40-MW Concentrating Solar Power Plant. In International Conference On Renewable Energies And Power Quality (ICREPQ'12).

Stoffel, T., Renné, D., Myers, D., & Wilcox, S. (2010). Concentrating Solar Power Best Practices Handbook For The Collection And Use Of Solar Resource Data. Colorado 80401. Retrieved From Www.Nrel.Gov

William B. Stine, R. B. D. (1994). A Compedium of Solar/ Dish Stirling Technology.