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Research paper

Feasibility of 25kw parabolic dish - sterling engine based concentrating solar power under Malaysia environment

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Abstract

The feasibility study is to ensure that the implementation of the Parabolic Dish (PD) Concentrating Solar Power (CSP) system is technically feasible and economically justifiable. Therefore, the primarily aim of this study is to carry out the fundamental investigation on the feasibility of solar CSP, focusing on PD type in Malaysia environment. To accomplish the aim, the 25kW PD model has been developed by using Matlab Simulink and by considering the tropical environment in Malaysia. This study has outlines the parameter that's used for 25kW PD system. Solar to electric efficiencies, annual energy, capacity factor, and Levelized Cost of Electricity (LCOE) were analyzed to determine the feasibility of the 25kW PD system under Malaysia environment. This study is covering a few regions in Peninsular Malaysia that are George Town, Kuantan, Subang, Senai and Kuching in East Malaysia. The result from this study shows that operating hours for PD system under Malaysia environment start to operate when solar irradiance 223 W/m2. Therefore, the total days for the PD system to operate in five locations in Malaysia are ranging from 84 to 57 days in a year. Meanwhile, there is a strong relationship between power output, capacity factor, and LCOE. With low power output and capacity power obtained from this study, thus it led to high LCOE. Therefore, this study has revealed the technical and economic analysis of the PD system under Malaysia environment. From the analysis, it shows that the PD system is feasible in term of technical but not economically feasible.

Keywords: *Feasibility; Parabolic Dish; Concentrating Solar Power.*

1. Introduction

Concentrating Solar Power (CSP) is one of the technologies that have ability to harness the solar energy for producing the electricity. There are four types of CSP technologies that are; parabolic troughs, linear Fresnel, power tower and PD system [1] [2].
CSP is also known as concentrating solar thermal power, representing a powerful, clean as well as a reliable source of energy. This technology is using mirrors to concentrate the solar radiation for heating liquid inside receiver and produces steam. The steam then used to drive a turbine generator for generating the electricity in the same way as the conventional power plants
By comparing the available technologies for energy production from solar source; CSP can be considered as one of the technologies that are economically[3]. CSP is the technologies that could give a significant contribution to develop more sustainable energy system. It also has a few attractive features such as the capacity for bulk power generation, viability in a wide range of plant and can be equipped with thermal storage system to generate electricity even during cloudy or after sunset [4].
In the meantime, CSP becomes increasingly important for economies in many countries, especially for the countries that received excellent solar radiation with Direct Normal Irradiation (DNI) higher than 1,900 kWh/m^2/year [5]. In 1997, Trieb et.al., reported that numerous calculations showing CSP systems are more cost effective than PV systems not only in the Sunbelt area [6]. However, V. Quaschning in [7], mentioned that until 2003, the commercial CSP plants are only built in the area with the annual of the global solar irradiation is higher than 2,100 kWh/m^2 such as Mojave Desert. Quaschning, also found that it is not easy to estimate the minimum irradiation for CSP technology to operate more economically than PV system, which may be change in the coming decade and this will depend on the technology development on the CSP system. Whilst, S. Mukhopadhyay in his study has claimed that CSP technologies can be used mostly all around the world [8]. In addition, Rijanto has mentioned that latitude or location in the globe can affect the performance of the CSP system [9]. In which, location between latitudes 15°N and 35°N is the most favourable area, followed by locations that lies between the equator and latitude 15°N. Meanwhile, less favourable area lies between latitudes 35°N and 45°N. Finally, area lies beyond latitude 45°N are consider least favourable. Malaysia lies between the equator and latitude 7°N, which is considered as moderately favourable area for CSP system. Therefore, based on few studies by [8]–[10]; it points out that Malaysia and other countries in the tropic are potentially viable for CSP Plant development.
Meanwhile, among CSP technologies PD system has a few advantages such as modular, suitable for the small CSP plant and has demonstrated a high thermal efficiency. However, PD technology is still an emerging industry in Malaysia with no operation plant installed so far. At the same time, the key successful implementation for any of the new Renewable Energy (RE) technology such as PD system is depending on the cost effective for the conversion of energy. Therefore, before developing PD system in any area, it is essential to study on the system feasibility.

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Basically, the feasibility study is to ensure that the implementation of the PD system is technically feasible and economically justifiable. However, at present, the information on the costs of PD system in Malaysian currency is not available in the public domain. The economic analysis for PD system is limited compared to the other CSP technologies such as parabolic trough and power tower. This is due to parabolic trough and power tower is mature technology, therefore many analyses have been done with these two technologies compared to PD system which is still under R&D phase. In this study, to evaluate whether the 25kW PD system is economically feasible, the annual energy and capacity factor are used to calculate the LCOE. Meanwhile, the solar to electric efficiencies are used to analyse the technical feasibility.

Therefore, the aims of this study are to investigate feasibility of the 25kW Parabolic Dish (PD) Concentrating Solar Power under Malaysia Environment by analyzes critically the outcome from solar to electric efficiencies, annual energy, capacity factor and LCOE value using simulation approach. Then, the results and information gathered is used to answer the question of whether it is feasible to implement the PD system under Malaysia environment.

2. Methodology

2.1. Site selection

To analyse the feasibility of PD system, it is interesting to evaluate the difference of the PD output from more than one case, such as solar input from different geographical sites. Thus, it is interesting to see how the results from the comparison are affected when considering geographical sites where the insolation varies in a year. Meanwhile, selecting a suitable site is one of the most crucial parts for developing a viable solar CSP plant such as the PD technology.

Fundamental to the siting of CSP technologies is, PD facilities requires an abundant of DNI in order to generate electricity. Even so, this apparently depends on average meteorological conditions of the location over a year. For example, the DNI in Malaysia is heavily influenced by the meteorological factors such as the cloud cover, humidity and local environmental factors such as debris and air contamination. Therefore, in selecting a site or the location for the PD system, the aim should be for maximizing the output and minimizing cost.

For the site selection in this study, five sites or locations in Malaysia are selected. Five sites or location selected in this study are based on the [11] and it is covering a few regions in Peninsular Malaysia that are George Town, Kuantan, Subang, Senai and Kuching in East in Malaysia. All of the selected regions are site that has the meteorological and radiation station. All of the stations are well distributed over the entire country for meteorological data monitors and solar radiation monitors.

2.2. Direct Normal Irradiation (DNI) data

The output from a CSP plant is highly dependent on the DNI since this is the input to the system. Only strong DNI can be focused to generate high temperatures and required for generate the electricity. To analyse the performance and feasibility of the PD system, the irradiance data for the selected location is needed [12]. Meanwhile, the yearly DNI data for five locations in this study is downloaded by using the Meteonorm 7 Software with radiation period from year 1986 - 2005. Table 1, show the yearly DNI Data for five locations in Malaysia.

Table 1: Yearly DNI Data for Five Locations in Malaysia

Cities	DNI [kWh/m²/year]
George Town	1,246
Senai	1,045
Kuantan	1,013
Subang	932
Kuching	834

From Table 1, it shows that the DNI in Malaysia is highest at the northern region compares to the east and central region in Peninsular Malaysia, except for Senai that has high DNI and located in southern region. George Town, Penang receives the highest of yearly DNI data with value of 1,246 kWh/m^2/year, followed by Senai 1,045 kWh/m^2/year, Kuantan 1,013 kWh/m^2/year, Subang with 932 kWh/m^2/year and Kuching with 834 kWh/m^2/year.

2.3. Development of 25kW PD system modelling

The evaluation of the PD system by using experimental method is still expensive and time consuming. Yet, at the same time, the modelling and simulation for the PD system is getting more significant.

This study is using a simulation approach. Two software's that are Matlab Simulink version 7.14 (R2012a) and Meteonorm 7 is used to develop, simulate and analyse the 25kW PD system. Matlab Simulink is software that is proven and successfully used to simulate the PD system.

2.4. 25kW PD system modelling

The operational framework for PD performance simulation is shown in Figure 1.

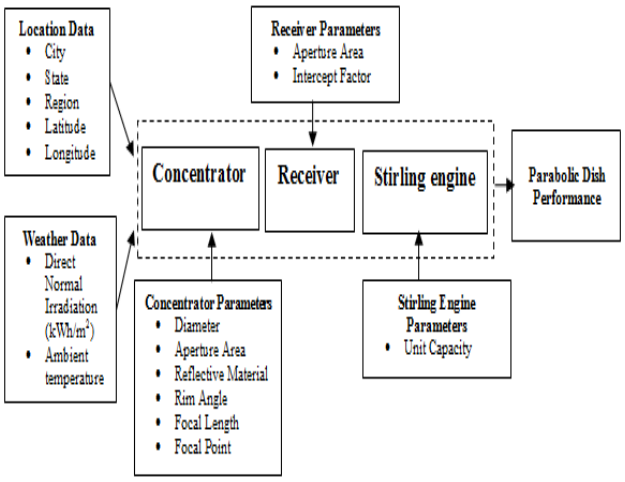


Fig. 1: Operational Framework for PD Performance Simulation.

The simulation for the PD model generates the output power and net power data. The output power and net power value is used to calculate the annual energy, solar to electric efficiencies, capacity factor as well as the LCOE to analyse the feasibility of implementing PD system under Malaysia environment. By referring to Fig 1, modelling and simulation of PD system performance requires few external inputs such as the location data that is site or location, solar irradiance data, the concentrator, receiver and Stirling engine parameters. Meanwhile, all of the input data for every subsystem in the PD components were summarised as in Table 2.

Table 2: Concentrator, Receiver and Stirling Engine Parameter for 25kw PD System Modelling

No	Parameter	Parameter value
1.	PD concentrator diameter D_{con} (m)	10.1815
2.	Concentrator aperture area (m^2)	81.4
3.	Reflective material (Aluminium)	0.92%
4.	Rim angle ϕ_{rim} (degree)	45
5.	Focal length (m)	6.15
6.	Focal Point Diameter (m)	0.05
7.	Receiver aperture area (m^2)	0.184
8.	Intercept factor	0.1
9.	Stirling engine type	SES

3. Simulation result

3.1 Annual energy

The annual energy for five locations in Malaysia (George Town, Senai, Kuantan, Subang and Kuching) is shown in Fig 2. It shows that the annual energy for George Town, Senai, Kuantan, Subang and Kuching are ranging from 8,385 kWh to 4,897 kWh for solar radiation ranging from 1,246 kW/m2/year to 834 kW/m2/year respectively. The highest annual energy is in George Town then, it is followed by Senai, Kuantan, Subang and finally Kuching. Therefore, the result in this section shows that the location with high DNI will achieve high annual energy compared to the location with low DNI. Meanwhile, it shows that the annual energy is significantly increase with the increase of the DNI.

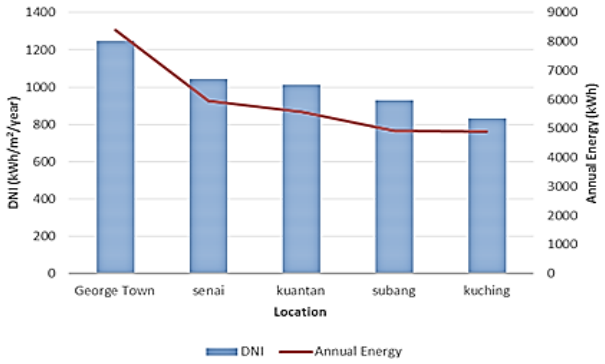


Fig. 2: Annual Energy for Five Locations in Malaysia.

3.2 Capacity Factor

Capacity factor for a power plant can be defined as the ratio of its actual output of annual energy over a period of time, to its potential output if it were possible for it to operate at full capacity continuously over the same period of time. The capacity factor for PD system is calculated by using the following equation:

$$CF = \left| \frac{Energy}{24hours * 365days * 25kW} \right| * 100 \quad (1)$$

The capacity factor for five locations in Malaysia are calculated by using equation 1, and the results is shown in Table 3. From the table, the capacity factor for George Town, Senai, Kuantan, Subang and Kuching are ranging from 3.83% to 2.23% for solar radiation ranging from 1,246 kW/m2/year to 834 kW/m2/year respectively. The result shows that the capacity factors are vary between different locations. Location with high DNI has high capacity factor compared location with low DNI. Therefore, the result in this section shows that the capacity factor is linear with DNI.

Table 3: The Capacity Factor for Five Locations in Malaysia

Locations	DNI [kWh/m²]	Capacity factor (%)
George Town	1,246	3.83
Senai	1,045	2.68
Kuantan	1,013	2.54
Subang	932	2.24
Kuching	834	2.23

3.3 Capital Cost

The accurate costing's for the complete PD system are not publicly available. Therefore, notes from National Renewable Laboratory (NREL) for System Advisor Model (SAM), version June 2015 are used as a reference to estimate the capital cost of the project as well as the costs of various PD components. The calculated capital costs for 25kW PD system is about USD 60,574.00 which is equal to RM 256,227.00. It is assumed that PD system components are directly imported from the US. The cost includes cost for the collector, receiver and the Stirling engine for the total solar field area of 200 m2. Meanwhile, operation and maintenance (O&M) cost is the annual expenditures on equipment and services that occur after the system is installed. It is assumed that the O&M cost is RM550/kW. The lifespan of PD system is assumed to be 10 – 25 years life time [13].

3.4 The Levelized Cost of Electricity (LCOE)

The PD system LCOE is defined as the cost of electricity generation for the PD system, which is associated with the PD system over its lifespan. The LCOE calculation is done with some main assumptions of relevant collector cost, receiver cost, Stirling engine cost and prices of the conventional electricity. Basically, LCOE for the PD system varies by its design, location, solar energy resource, operating costs and the efficiency or performance of the system. Meanwhile, there are various ways for calculating the LCOE. Therefore, the inclusion or exclusion of various factors as well as the differences in calculation methods will influence the value of LCOE.

The LCOE for PD system can be calculated using equation 2. It is based on the division of capital and operating costs by the electricity produced over the useful life of a plant.

$$LCOE = \frac{O\&M + CC\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]}{Energy} \quad (2)$$

From equation 2, CC is the total capital cost of the PD system, O&M is the yearly operating and maintenance cost, Energy is the net amount of energy produced over a year, i is the interest rate on capital and n is the life of the system.

3.5 Solar to electric efficiencies

PD system can reach the solar to electric efficiency from 12% to as higher 31%. In order to check the performance of the 25kW PD system, solar to electric efficiency was calculated by using equation;

$$\text{Solar to electric efficiency} = \left(\frac{\text{Generated Power}}{\text{DNI x Projected Mirror Area}} \right) \text{x } 100 \quad (3)$$

From equation 3, the generated power is a net power output, DNI values are simultaneously measured once during the power generation. Meanwhile, the projected reflection area is projected mirror area of PD which is facing the sun and receives the solar radiation. Table 4 shows the highest solar to electric efficiencies value for five locations in Malaysia.

Table 4: Solar to Electric Efficiencies for Five Locations in Malaysia

Location	Highest Solar to electric efficiencies (%)	Highest daily solar Irradiance in a year (W/m²)
Senai	22	1,033
Kuching	21	1,019
George Town	20	1,004
Kuantan	18	958
Subang	18	952

Table 4, shows that Senai is location that achieve the highest solar to electric efficiencies compared to the other locations. Then, it is followed by Kuching, George Town, Kuantan and finally Subang. From the result, it shows that the solar to electric efficiencies is linearly increase with the daily solar irradiance. The higher the solar irradiance, it will help to achieve the highest solar to electric efficiencies. Therefore, the location with high solar irradiance can achieve higher solar to electric efficiencies compared to the location that receive low solar irradiance.

4. Feasibility of the PD system under Malaysia environment

The feasibility analysis in this study covers the technical and economic feasibility based on five locations in Malaysia. PD system is considered to be feasible if the systems are able to operate continuously and generate power with minimum loss until the end of its life time. The technical feasibility of the PD system are analysed based on the solar to electric efficiencies result of the PD system. Meanwhile, the annual energy, capacity factor, and LCOE are used to analyse the economic feasibility.

From the study, the solar to electric efficiencies for five locations in Malaysia obtained from the simulation result are varies between 18 to 22%. The value is in the range of the normal PD system that is between 12 to 31%. Therefore, based on solar to electric efficiencies for five locations in Malaysia, it shows that the PD systems under Malaysia environment are technically feasible. In which, the result has shown that PD system are operate and performed as well as the actual PD system located at the real plant. Meanwhile, George Town has the highest DNI and the highest output power followed by Senai, Kuantan, Subang and Kuching. The result proved that the annual DNI affect the output power of the PD system. In which, the higher the annual DNI, the higher the annual energy is achieved. However, the PD system for all five locations in this study does not achieve the power rated needed for the PD system to become feasible. Table 5 shows the minimum of yearly output power needed for the 25 kW PD system.

Table 5: DNI, Yearly Output Power for Five Locations in Malaysia and the Minimum of Yearly Output Power for PD System to Become Feasible

Location	DNI [kWh/m²]	Yearly output Power (kW)	Minimum yearly output power for PD system become feasible (kW)
George Town	1,246	8,735	
Senai	1,045	6,123	
Kuantan	1,013	5,797	54,750
Subang	932	5,114	
Kuching	834	5,101	

From the table, 54,750 kW of yearly output power is the least needed value for the 25 kW PD system to generate, to assure the system is feasible under Malaysia environment. If PD system can generate 54,750 kW yearly output power, this value is equal to 25% capacity factor; therefore the PD system can be considered as feasible. However, the main factor that cause PD system did not achieve its power rated and feasible under Malaysia environment is the meteorological factor. The cloudiness, rain and humidity that associated with the tropical settings in Malaysia make the solar irradiation are less than adequate, except for certain times of the year. Besides, it needs some improvements to the PD system design to assure that it can achieve 25 % of capacity factor. The design are including on the size, reflectivity material of the concentrator as well as the thermal storage and temperature control system for the PD system.

The PD system in this study operates at solar irradiance 223 w/m^2 and above. It can be indicated that on many days, the output power, solar to electric efficiencies and annual energy would be very low and achieve zero if the solar irradiance is below than 223 W/m^2. Table 6 shows total hours for solar irradiance 223 W/m^2 to 1000 W/m^2 in a year for five locations in Malaysia. From Table 6, it shows that George Town has the largest number of hours for solar irradiance 223 W/m^2 to 1,000 W/m^2 in a year, followed by Kuantan, Senai, Subang and finally Kuching.

Table 6: Total Hours for Solar Irradiance 223 W/M^2 to 1000 W/M^2 in A Year for Five Locations in Malaysia

Location	Solar irradiance 223 – 1,000 W/m^2 in a year (hour)
George Town	2,020
Senai	1,756
Kuantan	1,771
Subang	1,577
Kuching	1,365

Table 7 shows the data for the total hours, days and month for PD system to operate in a year for five locations in Malaysia. Therefore, from the data, the total hours, days and month for PD system to operate can be predicted. The result shows that the total hours, days and month for PD system to operate in a year for five locations in Malaysia is ranging from 2,020 hours to 1,365 hours, 84 days to 57 days and 2.8 months to 1.89 months respectively. George Town has the most numbers of hours, days and months for the PD system to operate in a year. It is followed by Kuantan, Senai, Subang and finally Kuching. However, from the table, although Senai has DNI highest than Kuantan, Kuantan has most numbers of hours, days and months for the PD system to operate in a year compared to Senai. The reason is, Kuantan has most number of hours for solar irradiance 223 W/m^2 to 1000 W/m^2 in a year compared to Senai.

Table 7: Total Hours, Days and Month in a Year of PD System to Operate for Five Locations in Malaysia

Location	Total hours for PD system operate in a year (Hour)	Total days for PD system to operate in a year (Day)	Total month for PD system to operate in a year (Month)
George Town	2020	84.17	2.8
Senai	1756	73.17	2.44
Kuantan	1771	73.79	2.46
Subang	1577	65.71	2.19
Kuching	1365	56.88	1.89

As mentioned earlier, the solar irradiance is influenced by the meteorological factor. Therefore, the tropical settings such as heavy rainfall, high value of cloud cover, wind blow as well as high value of humidity become the main cause for the less days with solar irradiance 223 w/m^2 and above in a year in Malaysia. All of the meteorological factor fluctuate and decrease the value of solar irradiance in Malaysia and indirectly affect the output power, as well as the annual energy. Therefore, the output power and the annual energy in this study is low compared to the other PD system located at location with high solar resources. Even though the PD system is technically feasible; the tropical environment in Malaysia has become one of the main factors that the PD systems are less viable in Malaysia.

Meanwhile, in terms of economically feasible; as the solar resource become one of the factors that makes PD system economically feasible; therefore, with less sunny days with solar irradiance 223 W/m^2 and above, this will indirectly cause low annual energy and low capacity factor in Malaysia. Annual energy and capacity factor are part of parameters that used to define the LCOE. Thus, when the annual energy and capacity factors are low, this indirectly will lead to increased value of LCOE. PD system is considered economic feasible if the LCOE is less than the levelised tariff. The levelised tariff for solar thermal and photovoltaic power generation is RM 1.72/kWh and RM 0.7522/kWh respectively. The tariff for PV is under the FiT scheme SEDA. Meanwhile, the tariff for solar thermal are referred to studies done by Reddy and Veershetty [14]. From the study, the current LCOE for the CSP plants are falls in a range of USD 0.19 – USD 0.43/kWh or RM 0.76/kWh – RM 1.72/kWh. Therefore, PD system is economically feasible if LCOE lies between RM1.72/kWh and RM 0.7522/kWh. The PD system is considered not economic feasible when the LCOE is greater than RM 1.72/kWh. Based on the analysis, annual energy, capacity factor and LCOE for five location in Malaysia ranging from 8,385 kWh to 4,897 kWh, 3.83% to 2.23% and RM 3.432/kWh to RM 5.877/kWh respectively.

From the result, the PD system are considered not economic feasible. This is because, the LCOE for all five locations in Malaysia are high and more than the levelised tariff. Due to the high value in LCOE, the payback period is expected to be longer and cause higher risk of investment. Thus, with less day operation, low value in annual energy and capacity factor and high value of LCOE, it can be concluded that the PD system under Malaysia environment does not really achieve the economic feasibility at the moment

compared to the other plant such as PV and fossil fuels based electricity. Meanwhile, Table 8 shows the annual energy, capacity factor and LCOE for five locations in Malaysia.

Table 8: Annual Energy, Capacity Factor and LCOE for Five Locations in Malaysia

Location	Annual Energy (kWh)	Capacity Factor (%)	LCOE (RM XXX /kWh)
George Town	8,385	3.83	3.432
Senai	5,887	2.68	4.888
Kuantan	5,565	2.54	5.171
Subang	4,906	2.24	5.866
Kuching	4,897	2.23	5.877

5. Conclusions

This study has explained on the feasibility of the 25 kW PD system under Malaysia environment. Based on the result, the 25kW PD system under Malaysia environment is technically feasible; however, not economically feasible. From the result analysis, it is found that the constraints for PD system under Malaysia environment is mainly came from the meteorological factor that affect the power output and the annual energy, except only for certain times of the year. With the limited of operation time in a year and with high initial cost for PD system, this will indirectly affect the economic viability of the PD system under Malaysia environment. However, changes in global RE markets, investments, industries and policies have been so rapid in recent years. This occurred as other RE technologies such as wind and PV technology, where the initial cost was high but Cumulative Capacity (MW) will be decreased when installed capacity increased. The same trend will be occurred for PD system, where it will be cost competitive when the technology evolves toward maturity and the technologies attain the commercial viability. Besides, these limitations can be overcome through innovation as well as ongoing research on PD system, especially in Malaysia tropical environment.

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