

# Performance and Simulation of a Stand-alone Parabolic Trough Solar Thermal Power Plant

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**Abstract.** In this paper, a Simulink® Thermolib Model has been established for simulation performance evaluation of Stand-alone Parabolic Trough Solar Thermal Power Plant in Universiti Teknologi PETRONAS, Malaysia. This paper proposes a design of 1.2 kW parabolic trough power plant. The model is capable to predict temperatures at any system outlet in the plant, as well as the power output produced. The conditions that are taken into account as input to the model are: local solar radiation and ambient temperatures, which have been measured during the year. Other parameters that have been input to the model are the collector's sizes, location in terms of latitude and altitude. Lastly, the results are presented in graphical manner to describe the analysed variations of various outputs of the solar fields obtained, and help to predict the performance of the plant. The developed model allows an initial evaluation of the viability and technical feasibility of any similar solar thermal power plant.

## 1. Introduction

As observed in the 21st century, there are many problems that raise in perspective of energy and environment; thus, leading to a rising problems in politics and economy. A study stated that for a sustainable supply of energy and a reduction in emissions of the pollutants, there is an intense focus on renewable energy in the world [1]. Another study thoroughly discusses the trough solar thermal power plants in terms of their potentials and developments in Algeria. The authors emphasized that the process of working principles, descriptive parabolic trough power plants, and an assessment of concentrating solar power potential has provide a competitive outcome in terms of viability of CSP plants in Algeria. In addition to that, Algeria needs to consider the pre-requisites such as high-quality insolation, land and water availability, extensive transmission, and the power grid; to provide an economical CSP power generation [2]. However, Boukelia [3] studied carried out in Algeria where the authors tested on Optimization, Selection, and feasibility study of solar parabolic trough power plants. Optimization of the two parabolic trough was integrated and performed with: 1) thermal energy storage TES, and 2) fuel backup system FBS, respectively. The heat fluid used by 1st plant was Therminol VP-1 in field and 2nd plant used molten salt. In relation to that, Garc á et al. [4] developed a simulation model that allows a recalculation of performance of 50 MWe parabolic trough power plant; which is accompanied with thermal energy storage whilst Therminol VP-1 as heat transfer fluid in the solar field. The results obtained from the model are compared with the experimental data which was obtained from operation power plants in Spain. Montes et al. [5] highlighted influences of solar multiple annual performance, natural gas consumption, and levelized cost of electricity of a 50 MWe;



using direct steam generation parabolic trough thermal power plant with thermal storage and auxiliary natural gas-fired boiler.

A study presents a thermodynamic model which allowed an estimation of performance of 100 MW hybrid parabolic trough solar thermal power plant; whilst fossil fuels backup friction required. As it was conducted in four location North Chile); it was based on minimal fossil fuel backup fraction Larra  et al. [6]. Moreover, another author used 50MW solar thermal power plant and requirement of the land area with parabolic trough system integration; and suggests this technology as the best to its industrial advantages Kalogirou [7]. A study analysed an energetic economic assessment of a solar parabolic trough power plant of 100 MW capaciate and discussed amongst the four sites chosen in Algeria Abbas et al. [8]. On the other hand, a study discusses on the technical developments of the parabolic trough solar power plant when combined with molten salt as HTF, and presents the potential of using this technology to reduced LCOE Ruegamer et al. [9]. Typically, this feasibility report was combined with optimization results, where 4E comparison of PTSTPPs with molten salt is primary HTFs was established in solar field. The results obtained were agreed upon by Xu et al. [10]; where presentation of a theoretical framework for energy and exergy analyses of a solar power tower plant whilst incorporating solar molten salt as HTF. Similarly, this analysis was also conducted in another research which accounts for parabolic trough solar thermal power plant using therminol VP-1 as working fluid Reddy et al. [11]. In order to optimize and obtain the maximum plant efficiency, the authors evaluated the energetic and exergetic losses and efficiencies through specified operating conditions.

To conclude the above discussions from literature, it is discovered that the technical disability of PTSTPP is yet to be established for a location that has a high DNI availability. In addition, there is also a need to identify on the CSP technology for Malaysia climatic condition. In this article, a proposed design of Stand-alone Parabolic Trough Power Plant with an average capacity of 1.2kW is discussed. Unversiti Teknologi PETRONAS, Perak, Malaysia has been selected as the location of operation. Theoretical Calculations have been carried out for the stated power output at MATLAB software. The results of the calculations are employed in this software as inputs/parameters in order to model & simulate the performance of the stand-alone parabolic trough solar power plant in Simulink® Thermolib software, effectively.

## 2. PTSTPP Analysis

This section presents the mathematical modeling Figure 1. Firstly, PTSTPP energy analysis is carried out using the equations proposed by authors in [12], [13]; hence, the solar system model is presented. Secondly, the performance assessment equations for the overall systems are shown; with assumptions that there is a steadiness in the system state.

In addition, it is negligible if there is a change in the pressure in pumps and turbines. However, the useful energy rate from the collector is defined as:

$$Q_{gain} = m_{CL} \cdot (h_7 - h_6) = \eta \cdot I \cdot A_p \quad (1)$$

$$\eta = \eta_o - U_L \cdot \left( \frac{\Delta T}{I} \right) \quad (2)$$

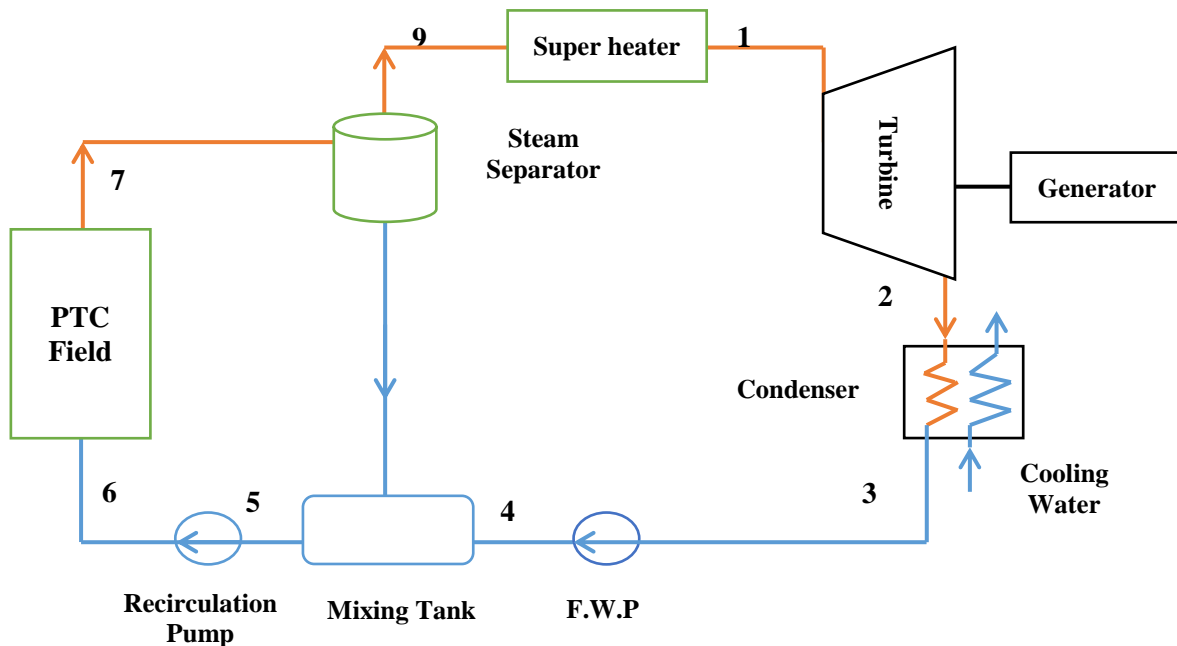
$$\Delta T = T_m - T_a \quad (3)$$

Where  $m_{CL}$  is the mass flow rate of steam passing through Collector (kg/s),  $I$  is direct normal incidence radiation ( $W/m^2$ ),  $A_p$  is aperture area of the collector ( $m^2$ ),  $T_m = (T_6 + T_7)/2$ , denotes mean temperature ( $^\circ C$ ),  $T_a$  is ambient temperature ( $^\circ C$ ), and  $U_L$  is loss co-efficient based on aperture area ( $W/m^2 \cdot K$ ). If the work input Feed Water Pump (F.W.P) and Recirculation Water Pump (RC.W.P) as well as heat losses through piping are neglected then:

$$Q_{gain} = m_{CL} \cdot (h_7 - h_6) = m \cdot (h_1 - h_3) \quad (4)$$

From Eqs. (1) and (4):

$$m \cdot (h_1 - h_3) = \eta \cdot I \cdot A_p \quad (5)$$

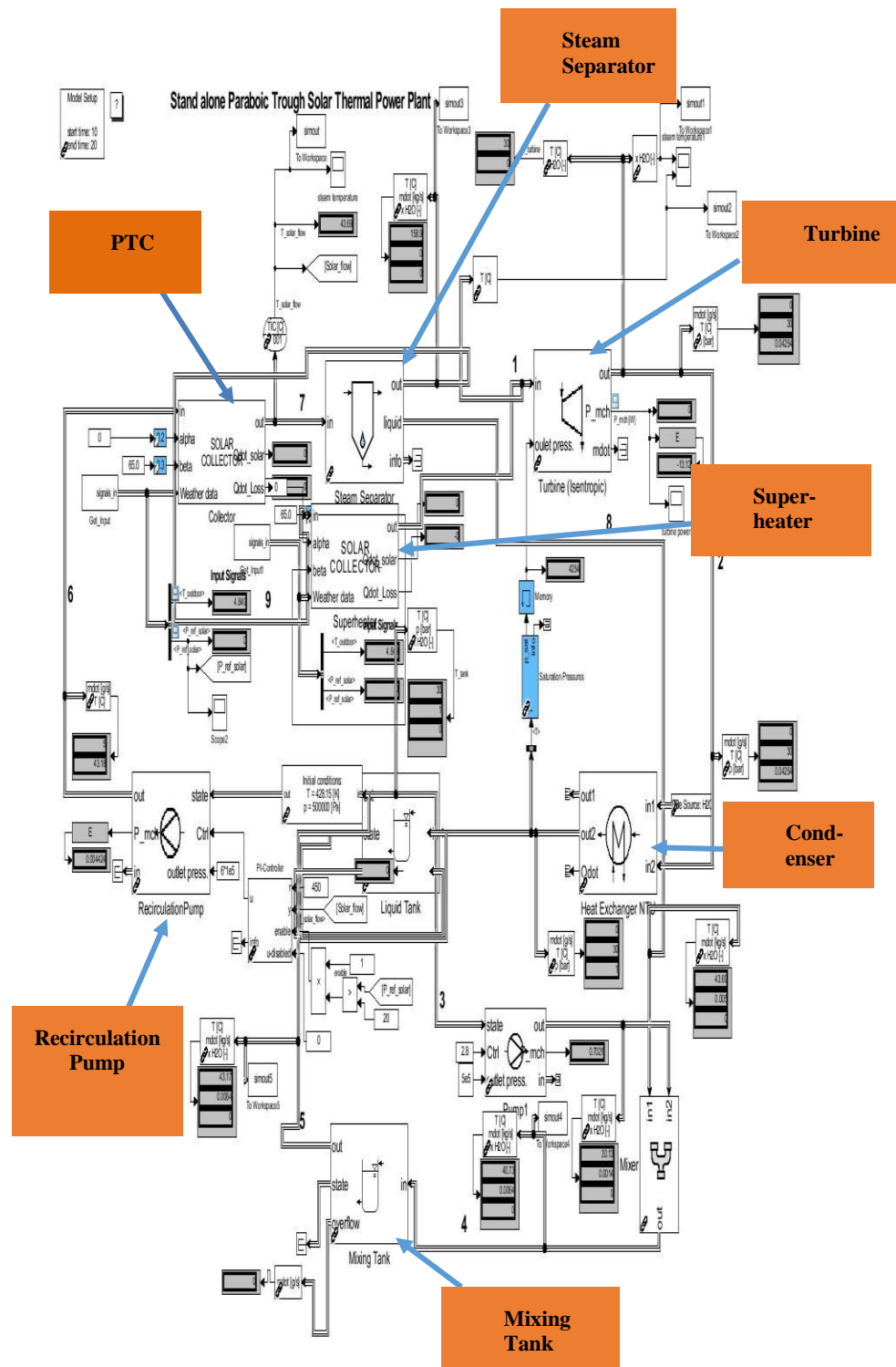


**Figure 1.** Simplified process flow diagram of PTC based solar thermal power plant.

In the modeling part, each component of the power plant is analyzed, defining and evaluating its efficiency by properly identifying the inputs and outputs. The stand-alone parabolic trough solar thermal power plant to be investigated is assumed to operate using the Rankine power cycle. Steam leaving the turbine and cascaded wet-vapor from the feed water heaters is condensed in the condenser. The condensate is pumped to the mixing tank pressure. The recirculating pump pressure water to the PTC solar field. Steam separator tank is separates water from steam, steam passing through superheater and water return into mixing tank. The complete schematic diagram of the power plant is shown in Figure 2.

**Table 1:** Characteristics of PTC used for simulation

Parameters	Value
Length of the receiver (L)	6.4m
Width of the collector (Wa)	2.6m
Focal length (F)	0.87m
Receiver external diameter (Dao)	40mm
Receiver internal diameter (Dai)	38mm
Concentration ratio (C)	20
Rim angle (°)	72.5
Absorptance of the receiver ( $\alpha$ )	0.95
Emittance of the receiver ( $\epsilon_{ab}$ )	0.10
Glass envelope transmittance ( $\tau$ )	0.91
Glass envelope emittance ( $\epsilon_c$ )	0.91
Reflector surface reflectivity( $\rho$ )	0.7
Intercept factor ( $\gamma$ )	0.93
Aperture Area (m)	80



**Figure 2.** Block diagram of PTC based solar thermal power plant in Simulink® Thermolib.

### 3. Case study

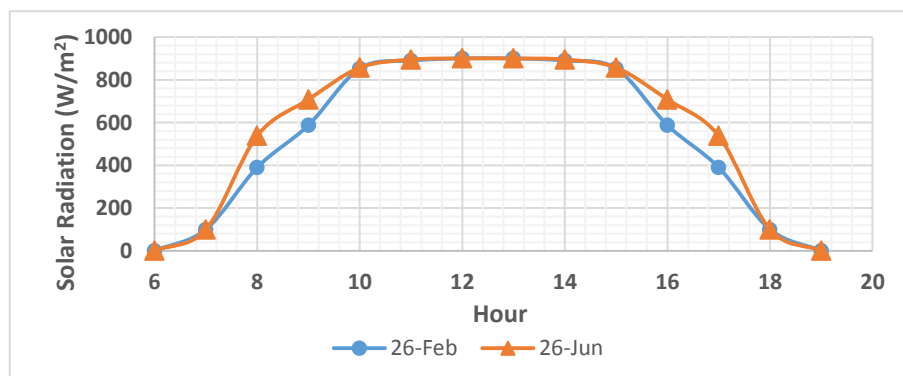
In the case study, the study gathered a one whole year data to analyse system performance. However, only several days are presented in this article. The days include: February 26, June 26, September 9 and December 28, 2016. The days are chosen due to two reasons: clear and cloudy weather. Each

figure below presents the solar radiation for each day, respectively. With the data collected, the performance of the system is observed through the evaluation of the results that are provided by the simulation model constructed in the study. With the assistance of the model, it is able to provide valuable data which is capable of plotting graphs, such as: 1) Solar radiation, 2) steam temperature leaving the collector field, and 3) the power output of the system. With that, there were a few system parameters which were kept constant: (1) water mass flow rate and steam's mass flows, (2) number of collectors, (3) water inlet temperature, (4) condensate water temperature and pressure and (5) the turbines' operating pressure. The SEGs was used to monitor these parameters carefully. Thus, providing a means of system control. PTC specifications and their characteristics that are considered throughout the system monitoring are shown in Table 1.

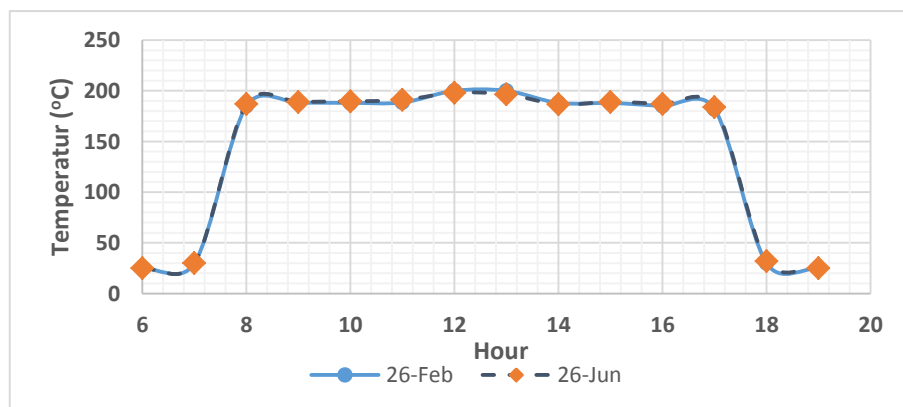
#### 4. Results and discussion

The result of the simulation for four days of operation, two clear days (February 26, June 26) and two cloudy days (September 9, December 28) are given below. For the clear day simulation, all the mass flow rates and inlet and exit temperatures as well as the power generated are established to be equal to the design value. The cloudy day simulation, however, shows that all the results are highly dependent on DNI values for improved output from this kind of power plants.

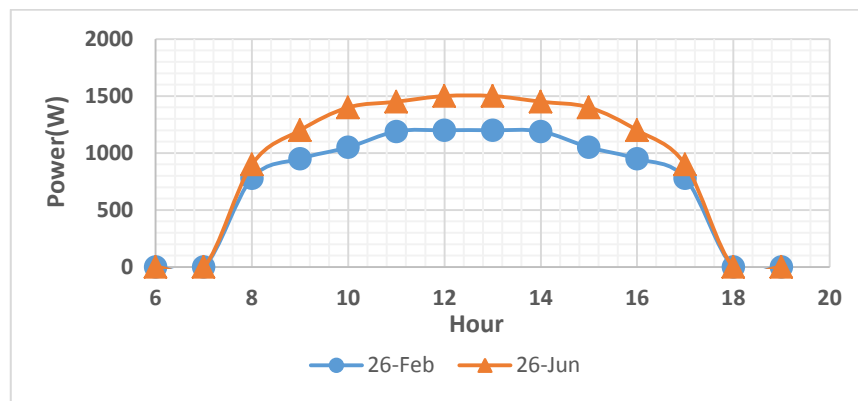
Figure 3 shows results obtained on a clear sunny day, thus, more radiation and an optimal system performance is observed, respectively. On a clear days such as June 26, 2016, the capacity of the power plant is achieved for a period of about 9 hours (9:00 – 17:00 hours) with maximum power 1500 W. However, when solar transients due to clouds occur, it shows an overall drop in system temperature. Hence, the power output drops. If the occurrence of these transient is for a period of 5 to 10 minutes intervals, then the system is able to return to its steady power production state as the solar radiation is maintained. However, if the solar transients are prolonged (an hour or more); then the system performance is gradually reduced in a great amount and a possibility of system recovery is merely present.



(a)



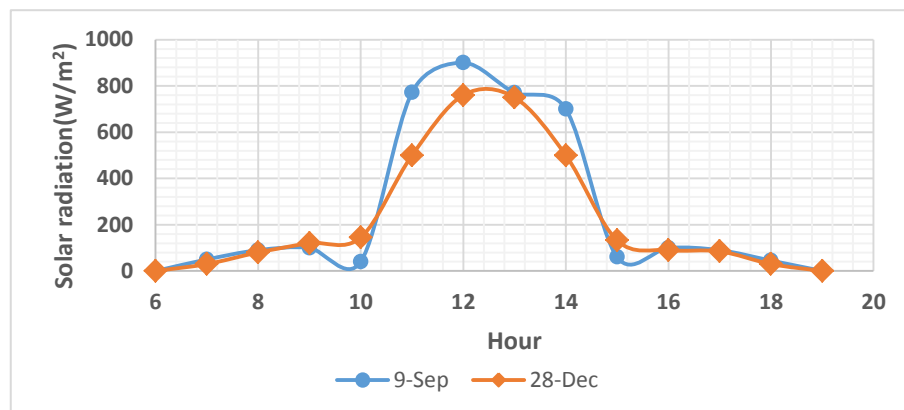
(b)



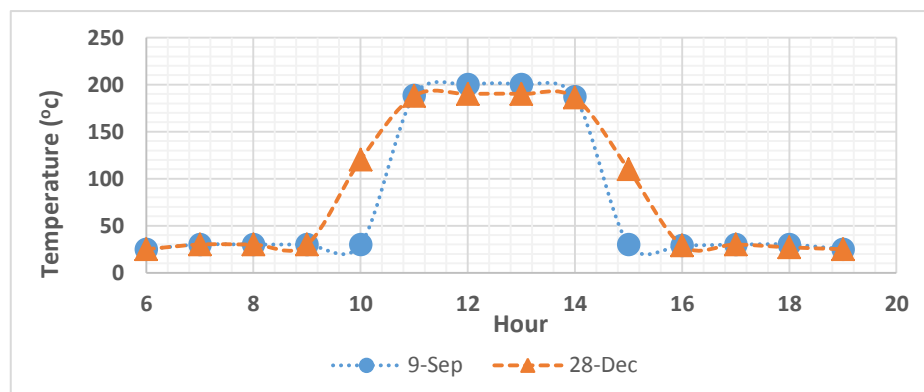
(c)

**Figure 3.** (a) Daily measured Solar Radiation, (b) Steam Temperature and (c) the respective Power Output for clear days: 26-Feb and 26-Jun, 2016.

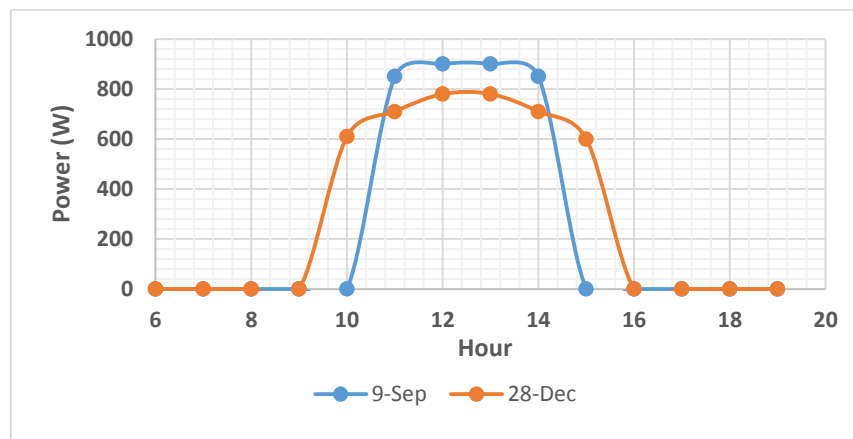
Figure 4 illustrates the presence of solar transients due to long periods of rainy weather. The capacity of the power plant is achieved for a period of about 4 hours (10:00 – 15:00 hours) on a cloudy day such as September 9, 2016 with maximum power 900 W. It shows that the system has produce zero power output as the rain begins. There were various aspects taken into consideration in this study, however, they were not involved in simulation model due to maintaining the simplicity, as most cases could be negligible. This includes: (1) system's piping losses, (2) collectors' optical losses, and (3) no customization of power block.



(a)



(b)



(c)

**Figure 4.** (a) Daily measured solar radiation, (b) steam temperature and (c) the respective power output for cloudy days: 9-Sep and 28-Dec, 2016.

## 5. Conclusion

To conclude this article, a 1.2 kW stand-alone parabolic trough solar power plant is designed and proposed to carry out analysis on Simulink® Thermolib. Simulink® Thermolib is used by creating a solar field model which allows prediction in the performance under various weather conditions at Perak (Malaysia) throughout a year duration period. The model is able to adapt distinctive designs by varying the parameters values that are associated with the parabolic trough; which can be easily achieved through Simulink® Thermolib. In addition to that benefits, the Thermolib model can be implemented for simulating the performance of parabolic trough field which may be located at an entirely different site with entirely distinctive weather conditions by only integrating weather data of that site. Although the data is readily provided by measurements, the comparison of theoretical and simulation is highly required to allow a justification of the results that are validate by the Thermolib Model. Lastly, Thermolib model assures to be an effective and reliable tool for confirming and analysing the average and transient performance of the solar parabolic trough efficiently.

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