# The Development of an Innovative Code for the Design and Performance of Stand-alone Parabolic Trough Solar Thermal Power Plant: Code Description and Test (PTPPP)

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# Abstract. An innovative code is presented in this study for the prediction of performances, as well as preliminary plant-sizing, for various parabolic trough solar fields which operate under nominal conditions. The selection and sizing of the system components and the power generation cycle, types of working fluids, and the sizing of the power block are involved in the conceptual design of the Stand- alone Parabolic Trough Solar. In the current solar thermal system, 1.2kW generators are incorporated into a turbine, and flow loop, which is energized by solar parabolic trough concentrators, produces steam. This is in accordance to the in-situ measurements of the direct normal irradiance (DNI). The code enables the separate calculation of heat loss coefficient, based on aperture area (*UL*), aperture effective direct normal irradiance (*I*), heat gain (*Qgain*) and the thermal efficiency of Stand-alone Parabolic Trough Solar Thermal Power Plant in commerce. Besides that, the code is flexible for heat transfer fluid, temperature and pressure range.

# Keywords:

# *direct normal radiation; direct steam generation; parabolic trough; stand-alone solar plant.*

# *Motivation and Significance*

# *Solar energy is one of the renewable energy sources, which is crucial in fulfilling the energy demand in countries with high solar radiation. Specifically, solar thermal power could efficiently fulfill the commercial demand for bulk electrical supply, within ten to hundreds range of MW, with a relatively low land demand and predictable drop of price in the near future. Moreover, through possible decoupling of electricity production from the energy source, this technology enables the adoption of a thermal storage. Generally, there are four CSP technologies that are commercially available: parabolic trough collector (PTC), linear Fresnel reflector (LFR), solar power tower (SPT), and paraboloid dish. PTC, with synthetic or organic oil-based heat transfer fluid (HTF), is the most established and commercially attractive technology [1], compared to other technologies mentioned. In addition, several investigators have proposed that the direct steam generation (DSG) in PTC field is made as an economically feasible option [2, 3]. This paper is involved with the development and testing of an innovative code, namely PTPPP , (Parabolic Trough Power Plant Performance) ) and it is capable of (i) aperture effective direct normal irradiance (I) ,(ii) Calculation of overall heat-loss coefficient, UL, .and (iii) the prediction of solar trough performance, based on CSP plants under nominal conditions. Moreover, the evaluation of the performances of each plant component, which is performed through real equations rather than algebraic correlations, allows an accurate sizing and adequate comprehension of the actual physical phenomena, which takes place in each part of the plant. Aside from this being a useful theoretical approach for the design process and off-design calculations, which will be developed in the upcoming versions of the code, it also allows a complete system layout optimization, due to a flexible description of the plant scheme. For example, speaking of power block, it is configured that the small scale solar parabolic trough power plan has a capacity of 1.2kW. Besides that, the plant is set to depend on primary working fluid water in a direct steam generation (DSG). Figure 1 and Figure 2 display the diagram of DSG-based solar parabolic trough power plant configuration.*

**Figure 1: The proposed solar power plant established**

**Figure 2: Simplified process flow diagram a PTC based solar thermal power plant [4]**

# *Software Description*

# *Software Architecture*

# *PTPPP is based on MATLAB R2015a. Furthermore, MATLAB R2015a initiated the development of the code hourly insulation model, as well as the performance model, which was based on the linked constraints and expressions, and it was implemented in a particular PTC system. An analytical model was firstly developed, in search for direct normal beam hourly insulation on an aperture plane. The parameters, which were made as inputs in the code for the purpose of evaluating the direct normal beam insulation, consisted of: days in a year, the position of the latitude and the longitude. Moreover, air temperature from the environment, wind speed, features of PTC, the temperature of water at the inlet and the direct normal beam hourly insulation were the inputs needed for the evaluation of the model performance. In addition, equations were used to calculate the performance of the collectors. The implementation of a procedure, which is known as trial-and-error, was made, in order to calculate the energy loss; it provided an immediate result, as mentioned in [5]. PTPPP architecture, which was sketched for analytical simulation, is displayed in Figure 3.*

**Fig 3. Algorithm solution flow chart for analytical simulation.**

# *Software Functionalities*

# *PTPPP is an instrument that gathers and displays the measurement of parabolic trough solar power performance .Furthermore, in order to resolve the iterative process for heat losses and evaluation of pressure drops, the code “PTPPP” was designed by MATLAB R2015a. The first step of the processes involving PTPPP is:*

# *1- The parabolic trough technology is applied for the selection of the type of support structure, mirror and absorber tube.*

# *2- The type of cycle, specifically the direct cycle which involves the DSG process.*

# *3- The setting and attributes of power cycle, which organise a net power output*

# *4- The solar field arrangement (“H” or “I” configuration).*

# *5- Sample of surrounding conditions, in terms of temperature, relative humidity, wind velocity, and direct solar radiation.*

# *The thermal power demand and parasitic consumptions are firstly determined through the calculation of thermodynamic conditions, at each stage of the Rankine power cycle. Then, the size of solar field is determined by acquiring the number of loops, length of the rows, thermal losses, amount of pressure drop, and HTF circulating pump consumption. During this stage, the gross power output and the auxiliary power consumption could be distinguished through the evaluation of the net power output. In addition, it is necessary to apply the iterative procedure, in order to match the target value, which is defined by the user, with the results. Next, the whole plant investment cost calculation will be based on the results of solar thermal power plant sizing at nominal conditions. Besides, various ranges of efficiency are utilized for the description of solar thermal power plant performances [6,7].*

# *Illustrative Examples*

*This code’s objective is to conduct investigation on parabolic trough power plant. In this part of this study, the default parameter for power plant is displayed in Figure 4 which is documented in a video that is available online at* [*http://dx.doi.org/10.1016/*](http://dx.doi.org/10.1016/) *j.softx.2016.04.001 together with this article. . After that, the tested PTPPP’s capabilities are displayed through the evaluation of a real-world example. As for the validation of the existing model, a comparison was done on the outlet Design turbine output of the simulation results, which was obtained by (Nishith et al., 2015) [8]. The performance analysis of SPTC was rated, based on the outcomes obtained from the model, which was presented for Design DNI and mass flow. The specifications of SPTC are included in Table 1, which are utilized for validation. Additionally, 30℃ is set as the ambient temperature, for the assessment of the performance of the existing model, which is conducted by the authors.*

**Fig 4. Generator model (e.g. modeling a power plant with similar units and controls, but with their own respective parameters).**

**Table 1. Characteristics of PTC used for validation of the model [8].**

Results of simulation were compared with the present estimations of the model for the SPTC performance where the incidence angle is at zero as displayed in Table 2. In Table 2, a well agreement for every data point that was used is mentioned. The design turbine output (MW) contained errors that were 0.61% with the average variation of 0.18%.

**Table 2: Validation of present developed model with simulation Nishith data [8].**

1. ***Impact***

# *PTPPP is a code for the performance of parabolic trough power plant and thermodynamic simulations, like other domain-specific instruments. Traditional studies can be conducted on the thermodynamic simulations efficiency, however, it could not perform the calculation of aperture effective direct normal irradiance (IND) every hour, and the finding of performance parabolic trough power plant according value (IND). Furthermore, this flexibility mainly originates from the use of MATLAB. The obvious exchange of thermodynamic models and their parameters is essential for the coordination between PTPPP. The demonstration is made on how the PTPPP can be coupled to existing standards for obtaining information, so that the details on models thermodynamics could be provided, therefore, the extensibility provided by some MATLAB environment is utilized. The open-source nature of PTPPP promotes more demonstration and implementation projects, and this becomes an advantage of the open, flexible, and extensible MATLAB language. In addition, full awareness of the models’ limitations to system analyst is raised, due to the full-access given to the models’ description. This will enable the extension of the library, in order to fulfill the users’ particular needs, which eventually results to the expansion of the PTPPP. Finally, this implies that, in spite of the type of simulation tool being utilized, it is assumed that with the similar integration solver implementation and parameters, MATLAB of various countries are able to obtain equivalent simulation results.*

# *Conclusions*

# *The prediction of the required hydrothermal parameters of the system was enabled by the conversion of the model into a programme within MATLAB environment. In order to account for the consistent generation of power from turbine generator unit in the hours of sunshine, the control ideology of plant contains the joint effect of the solar field under ambient conditions, as well as the mentioned solar radiation. It is found that the current model is suitable for the estimation of heat loss coefficient, based on aperture area, aperture effective direct normal irradiance (I), heat gain, and the thermal efficiency of Stand-alone Parabolic Trough Solar Thermal Power Plant under different operating conditions.*

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# Required Metadata

# Current code version

# *Ancillary data table required for subversion of the codebase. Kindly replace examples in right column with the correct information about your current code, and leave the left column as it is.*

# *Table 1 – Code metadata (mandatory)*

|  |  |  |
| --- | --- | --- |
| **Nr** | **Code metadata description** | ***Please fill in this column*** |
| C1 | Current code version | *For example v42* |
| C2 | Permanent link to code/repository used of this code version | *For example: https://github.com/mozart/mozart2* |
| C3 | Legal Code License | *List one of the approved licenses* |
| C4 | Code versioning system used | *For example svn, git, mercurial, etc. put none if none* |
| C5 | Software code languages, tools, and services used | *For example C++, python, r, MPI, OpenCL, etc.* |
| C6 | Compilation requirements, operating environments & dependencies |  |
| C7 | If available Link to developer documentation/manual | *For example: http://mozart.github.io/documentation/* |
| C8 | Support email for questions |  |

# Current executable software version

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# *Table 2 – Software metadata (optional)*

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| --- | --- | --- |
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| S5 | Installation requirements & dependencies |  |
| S6 | If available, link to user manual - if formally published include a reference to the publication in the reference list | *For example: http://mozart.github.io/documentation/* |
| S7 | Support email for questions |  |