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AJUSTE Y VALIDACIÓN DE UNA HERRAMIENTA DE SIMULACIÓN PARA CENTRALES TERMOSOLARES DE TECNOLOGÍA CILINDRO-PARABÓLICA

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Abstract

Concentrating Solar Power (CSP) plants play a major role in the newest renewable technologies as they are the only ones with cost-effective possibility of energy store. In this context, it is of major importance to have the convenient tools to predict the behavior of the CSP plants before acting. For this reason, a program which can simulate with accuracy and quickness the behavior of CSP plants was created. The validation process is a must step in any simulation program development, as it provides the reliability and usefulness of such tool and is a fundamental activity to set the input parameters for a successful model performance. The present work presents the validation process carried out for a simulation tool especially designed for the energy yield assessment of concentrating solar plants based on parabolic through (PT) technology.

The validation has been carried out by comparing the model estimations with real data collected from a commercial CSP plant. In order to adjust the model parameters used for the simulation, 12 different days were selected among one-year of operational data measured at the real plant. The 12 days were simulated and the estimations compared with the measured data, focusing on the most important variables from the simulation point of view: temperatures, pressures and mass flow of the solar field, gross power, parasitic power, and net power delivered by the plant. Based on these 12 days, the key parameters for simulating the model were properly fixed and the simulation of a whole year performed. The results obtained for a complete year simulation showed very good agreement for the gross and net electric total production. The estimations for these magnitudes show a 1.47% and 2.02% BIAS respectively. The results proved that the simulation software describes with great accuracy the real operation of the power plant and correctly reproduces its transient behavior.

Keywords: Concentrating solar power; Parabolic trough plant model; Transient modeling and simulation; Model adjustment and validation.

1. Introduction

In a world more and more aware of environmental as well as economic affairs, conventional energies, which may depend on limited resources, are being pushed aside by green and self-sufficient energies. Concentrating Solar Power (CSP) technology is a great example of those, since it takes advantage of solar power and benefits from having the opportunity to store that energy. CSP plants account for a total installed power of 15GW [1] and this sector is expected to increase by 70 times its current capacity in the following 35 years [1]. Most of this capacity is based on Parabolic Trough (PT). Thus, CSP technology and specially PT remains to be a market niche and among all renewable energies, it seems to be the one with the largest opportunity of growth worldwide.

Aiming for a proper performance of the CSP development process, it is of major importance to have the convenient tools to predict the behavior of the CSP plants before acting. For this reason, powerful as well as flexible, dynamic simulation software has been developed for the energy yield assessment of concentrating solar power plants. The objective of the present work is to present the process of adjustment and validation of such tool for the parabolic through technology. This validation process not only provides the opportunity for tuning and perfecting the software but it also becomes a must step to ensure the reliability of any conclusion obtained from analyses based on simulations. The validation process has been carried out by comparing the estimations made by the simulator with measured data from a real CSP plant. The validation has been carried out for a parabolic trough solar power plant with neither storage (TES) nor burner, as those are the real plant's characteristics.

In the following, a brief description of the simulation model, the methodology used for the adjustment and validation process, and the results of this process are presented. Finally, the main conclusions and future work are outlined.

2. Simulation Model

As stated before, the model which is being validated is a simulation tool mainly intended for the electricity yield assessment of CSP plants and related uses like feasibility analyses, optimization of main plant parameters, and more. The software is an object-oriented, differential algebraic equation based model, which allows to conveniently describing complex physical systems as a CSP plant is. Therefore, the model is able to provide the transient behavior of the system, a key aspect to evaluate power plants based on the strongly variable renewable resources, supporting on physical equations and providing non casual answer. In addition, the object-oriented and strongly hierarchical approach offers an incredible flexibility. For instance, it is possible to choose between physical or empirical approaches to model the most relevant components, and countless types of models can be created just by choosing different alternatives for the components. Even if the software was intended to be quick and stable for long-term simulations aiming to electricity yield assessments, it can also provide a highly detailed description for all the components to evaluate the impact of diverse design parameters on the final plant's performance. The structure used for the plant model is presented in Figure 1 and is similar to the one proposed at SolarPACES' guiSmo project [2], in which the authors as well as many other organizations participate.

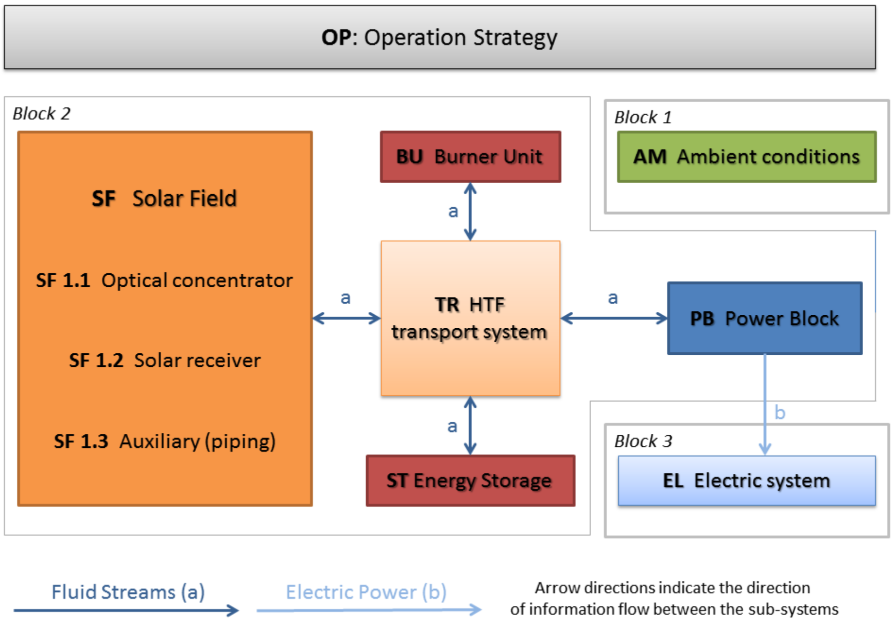

Figure 1. Scheme of the main parts of the CSP plant model according to the document [2].

In the developed model, each of the subsystems shown in Figure 1 is replaceable and can be chosen by the user to create different plants configurations. For instance, it is possible to choose between linear focus solar fields (Parabolic Trough or Fresnel technologies), or point focus solar fields (tower) with a wide range of different models eligible for the subparts and components. In addition a variety of direct or indirect molten salts thermal storage models [3] [4], either in two tanks or single tank (thermocline) [5] configurations as well as phase change media storage models are already available, while other approaches are under development. Also a varied range of modeling approaches is available to simulate the power block. The available models include polynomial efficiency correlations in terms of thermal power input, slightly more detailed table based approaches (where the table has been obtained beforehand via multiple simulations of detailed zero-dimensional physical models) or detailed zero-dimensional physical models.

Basic control of the plant establishes an outlet temperature set point for the solar field and a thermal load set point for the power block, which are controlled via the mass flow of the solar field and a defocusing control when necessary. But the model also includes an operational strategy which behaves like a virtual operator of the plant, managing the use of the TES and the burner as well as whatever other relevant operation issue (nightly recirculation, wind protection, etc.). Thus, the user can take advantage from the high flexibility of the software for simulating different operational and control strategies [6].

For the present validation process, one of the most basic CSP plants has been simulated, a PT plant with neither storage nor burner, as those are the characteristics of the real plant from which the measured data was collected. In addition, relatively simple models were selected as a first step in the validation process, considering that higher levels of detail often add more uncertainty rather than larger accuracy to the simulations. The validation of more complex modeling approaches (and the evaluation of their convenience from the accuracy point of view) is left for future works.

Specifically, the parabolic trough plant has been simulated with the following main modeling approaches:

- A number of equal solar fields in which only one is simulated, according to the symmetry and extremely similarity of the subfields in the real plant.
- For the subfield, only one representative loop is simulated with lumped hot and cold headers. To account for appropriate losses, this loop is the last one in the solar field.
- The model used for the loops considers all collectors connected in line, with no additional pipes, elbows, etc.
- Parabolic through concentrator optical and geometrical characteristics are fixed to fulfill the concentrator design in terms of dimensions (width and length), effective mirror area, reflectivity and peak optical efficiency and orientation (cosine effect), etc. The incidence angle modifier is taken from the literature [7].
- For the absorbers tubes the model is similar to the one proposed by Zaversky [8], except for the heat losses calculation in which, instead of Forristall's approach, an empirical correlation based on experimental data carried out by Burkholder F. and Kutscher [9] is used.
- The selected power block model is a simple quasi-steady power model that fits three characteristic polynomials depending on the thermal load: one for the thermal to electricity efficiency, one for the heat transfer fluid temperature drop at the steam generator and a last one for the auxiliary power consumption.
- The plant operation strategy turns out to be quite simple, since the plant produces whenever there is enough solar resource and is turned off during night periods. There is also a start up strategy in the early hours where a recirculation mass flow is established before the concentrators start tracking the sun to prevent HTF from burning. This recirculation mass flow is also maintained throughout the day as a minimum operating solar field mass flow. Finally, the maximum mass flow is controlled to avoid over loading the power block, and defocusing occurs whenever a maximum solar field outlet temperature is reached.

As a summary, Figure 2 shows the simple schematic representation of the modeled PT plant.

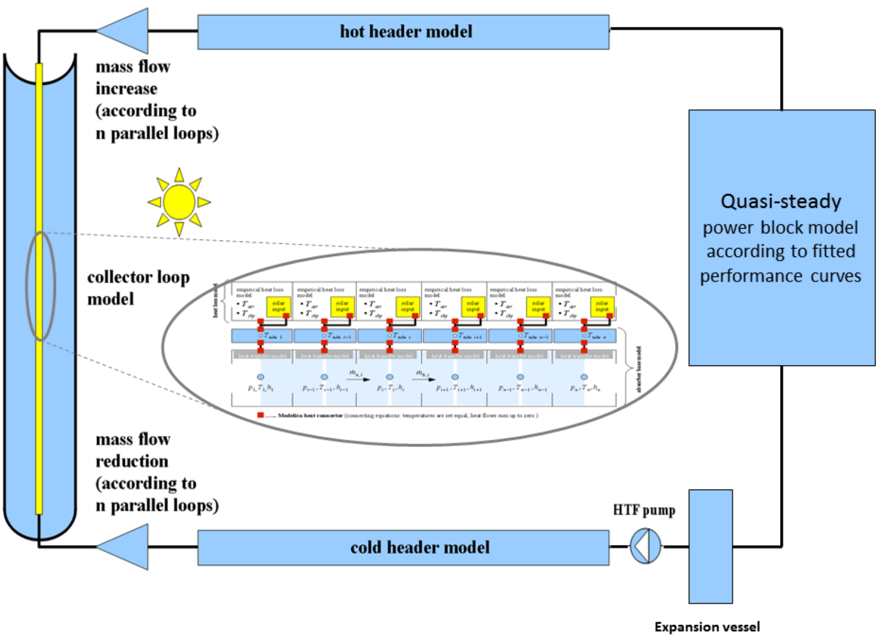

Figure 2. Scheme of the main parts of the parabolic trough plant model.

3. Methodology and adjustment

For the adjustment and validation process, a complete year of operational measured data from a real CSP plant based on parabolic trough technology has been used. That is the period for which the validation has been carried out by comparing the model estimations with the real performance of the plant. Several measured data' variables have been analyzed and compared with the estimations, including the mass flow, inlet and outlet temperature and pressure drop in the solar filed –describing the thermo-hydrodynamic behavior of the solar field-. Also, the gross power produced by the plant, the auxiliary power consumed (both by the solar field due to the pumping and by the power block) and the net power were compared.

Before carrying out the simulation, several input parameters and conditions are needed for the model. Firstly, direct normal irradiation (DNI) and other meteorological variables were measured in the plant and used as inputs in the model. Secondly, almost all the data necessary for accurately describing the plant were collected. However, some of these, especially data related with the operational behavior, were not known. Moreover, the real plant seemed to follow slightly changing operation criteria from one day to another, which the simulator is not able to follow. Thus, it was necessary to deeply analyze the measured data to get the appropriate input parameters (mainly related to operation criteria) before carrying out the simulations and comparing the estimates with the measured data.

However, doing that process for every single day of the year would have been a very tedious and senseless task. For this reason, only a reference set of days representative of all the casuistry found on the complete year were deeply analyzed in order to obtain appropriate input parameters for describing the plant operation. Specifically, a reference set of 12 days belonging to the measured data was selected and the model estimations were compared in terms of the variables mentioned above. This helped not only to validate in great detail the model for this specific set of days, but also to find out some input parameters and criteria common to all the days that could be used for the complete year simulation. Then, there was enough information to run the complete year and make the long term simulation validation. Measured data were collected every 5 minutes, so the model estimations were given as well every 5 minutes, not only for the reference days, but also for the complete year simulation.

The specific methodology used for the adjustment and validation is explained in more depth in the sections below.

3.1 Reference set

The main criteria for the selection of the 12 reference days of measured data was to focus on days with different meteorological conditions, as the simulation tool should properly reproduce distinct conditions (e.g.: strong DNI variations, partial load operation, etc.) and thus being able to check how the model adapts to transient periods. The selected group is composed of: 3 summer sunny days for which the rated nominal power of the plant is exceeded, 3 autumn sunny days operating below the rated power of the plant, 3 sunny days with punctual clouds and 3 overcast days.

Once the physical characteristics of the plant are set into the model, the most important input parameters to properly simulate each of the reference days were guessed by processing the measures as follows:

- Date and meteorological characteristics: measured at the real plant and read directly by the software. Meteorological data includes DNI, global horizontal irradiation (GHI), direct horizontal irradiation (DHI), ambient air temperature, wind speed, wind direction, relative humidity and atmospheric pressure, although not all of them are used in the model.
- Controlled recirculation solar field mass flow: set as the 50th percentile of the solar field mass flow measurements during the periods when the DNI was over 10W/m2 but the power block was offline (gross power < 1MW).
- Design solar field outlet temperature: set as the 75th percentile of the solar field outlet temperature measurements during the periods when the plant is in regular operation, i.e. the mass flow in the solar field is over the minimum recirculation mass flow and the power block is online (gross power > 1MW).

- Maximum power: set as the 75th percentile of the gross power measurements during the periods when the nominal gross power of the plant was exceeded.
- Parasitic power consumed during offline periods: set as the 75th percentile of the auxiliary consumption measurements during the periods when both the solar field and the power block were offline (solar field mass flow < 10 kg/s and gross power < 1MW).

With these input parameters, obtained from the measured data, each of the reference days was simulated and a detailed comparison was made. Several variables were studied: gross power, parasitic power and net power; related with the electric production of the plant, and others such as the solar field pressure drop, solar field temperature inlet and outlet and solar field mass flow; related with the hydro-thermodynamic state of the plant.

3.2 Complete year

Once the initial parameters for the reference set were fixed, there was enough information to perform the year's simulation supporting on those parameters. The input parameters for the year's simulation were obtained as follows:

- Date and meteorological characteristics: As mentioned in the previous section, the measured data were directly read by the software.
- Controlled recirculation solar field mass flow: The mean of the 12 values of controlled recirculation solar field mass flow obtained for the reference set.
- Design solar field outlet temperature: The 75th percentile of the 12 design outlet temperatures obtained for the reference set.
- Maximum power: The mean of the (3) maximum gross power values corresponding to the days of the reference set in which nominal power was exceeded.
- Parasitic power consumed during offline periods: The mean of the 12 values of the parasitic power consumed during offline periods obtained for the reference set.

In an analogous process to the reference set's an analysis was made to shed light on the accuracy, adaption and ultimately usefulness of the simulation tool for the complete year simulation. This time greater importance was given to the 3 power variables (gross, net and parasitic) and to the total energy produced during the year, taking into account that the main objective of this simulation tool is providing accurate energy yield assessments.

4. Validation Results

In this section, the results will be exposed and analyzed. For the reference set, all the variables before mentioned will be studied in detail, whereas for the complete year the main focus was on the electric variables, in particular the gross, auxiliary and net energy. The analysis supports on graphics and some simple statistics figures, as the percentage deviation. Numeric data of the comparison has been concealed because of confidentially matters.

4.1 Reference set

The 12 days were simulated and compared with the measured data. In Figure 3, gross power, auxiliary electrical power consumption and net power are represented for one day belonging to each of the different groups of days (summer sunny days, autumn sunny days, punctual passing clouds days and overcast days).

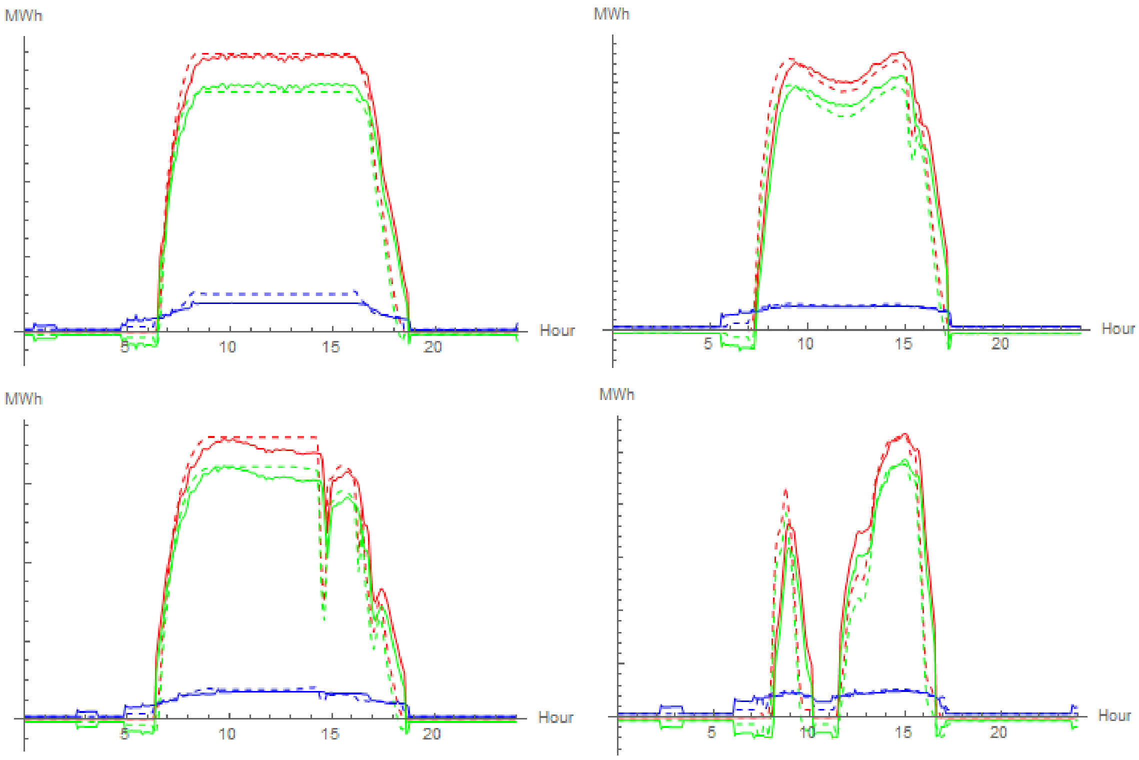

Figure 3. Comparison of the estimated (dashed) and measured (solid) for the gross power (red), net power (green) and auxiliary power (blue,) for a summer sunny day (top, left), an autumn sunny day (top, right), a summer sunny day with punctual clouds (bottom, left) and an overcast day (bottom, right).

Figure 3 shows that the simulation tool gives extremely accurate estimations for both steady state and transient periods, therefore properly simulating most of the real plant's behavior. It can also be appreciated that the maximum power is reached simultaneously in sunny days and that on days working at partial loads (autumn days) the estimations and measured data show almost perfect agreement during all the day. It can be observed that during central hours the simulation tool is able to reproduce the cosine effect, rightly following measured data. For days with punctual clouds and overcast days, very good response to sudden DNI changes is obtained from the simulation, reproducing the real plant's stops and startups. Only slightly differences between the simulator's results and measured data are observed; like a sharper fall in the electricity production in the late hours, probably because of a minor underestimate of the thermal inertia of the power block. Also peaks and valleys are sharper in the model estimations, for which control system seems to be slightly over reacting to variations in the solar resource, in contrast with the real plant, which presents a staggered control and thus, not tracking the DNI changes as quick as the model does.

Table 1 shows the totals for the gross, auxiliary and net energies as well as other statistics figures calculated for the gross, auxiliary and net powers.

Table 1. Statistics figures for the gross energy (top), auxiliary energy (middle) and net energy (bottom).

Days	**TOTAL Model** (MWh)	**TOTAL Measured** (MWh)	**BIAS (%)**	**MAE (%)**	**RMSE (%)**
	GROSS ENERGY		**GROSS POWER**		
SUMMER SUNNY	2422.85	2449.9	-1.24	5.39	12.59
AUTUMN SUNNY	1369.82	1414.98	-3.19	7.79	79.87
PUNCTUAL CLOUDS	1841.81	1906.19	-3.37	11.36	21.24
OVERCAST	802.711	888.65	-9.67	16.96	41.1
ALL DAYS	**6437.18**	**6659.72**	**-3.39**	**9.15**	**20.62**
	AUXILIARY ENERGY		**AUXILIARY POWER**		
SUMMER SUNNY	332.57	304.45	1.5	11.04	16.95
AUTUMN SUNNY	182.84	184.9	-1.78	13.97	24.19
PUNCTUAL CLOUDS	242.51	256.59	-4.73	13.06	20.5
OVERCAST	153.92	170.69	-7.25	20.34	33.81
ALL DAYS	**911.85**	**916.63**	**-1.81**	**13.93**	**22.63**
	NET ENERGY		**NET POWER**		
SUMMER SUNNY	2090.28	2145.45	-1.63	6.21	14.22
AUTUMN SUNNY	1187	1230.1	-3.94	10.27	23.07
PUNCTUAL CLOUDS	1599.3	1649.6	-3.17	13.02	23.41
OVERCAST	648.79	717.96	-10.24	23.55	50.89
ALL DAYS	**5525.34**	**5743.08**	**-3.65**	**11.2**	**23.53**

As expected from Figure 3, statistics of the 3 energies turn out to be excellent. Gross, auxiliary and net power present a less than 4% BIAS for the reference set as a group and around 1.5% deviation for sunny days reaching full load, which are the ones with major contribution to the total annual energy production. These results mean that the software achieves to provide very accurate estimations of the power and energy production for a 24 hours period, which requires a very demanding modeling of the transient periods. It is worth to mention that measured DNI is based on one unique value and thus partial shadowing of the field is not reflected, what could explain part of the slightly larger deviation showed for the overcast days.

In Figure 4, the estimations against the measured data for the gross energy produced by the plant, the auxiliary energy consumed and the net energy for each of reference set days are shown. The points shown in these graphics represent the ratio between the estimations and the measured data accumulated along all the day. Thus, points coincident to the central line mean that both estimations and measured data have the same value, while larger distances from the central line represent larger discrepancies.

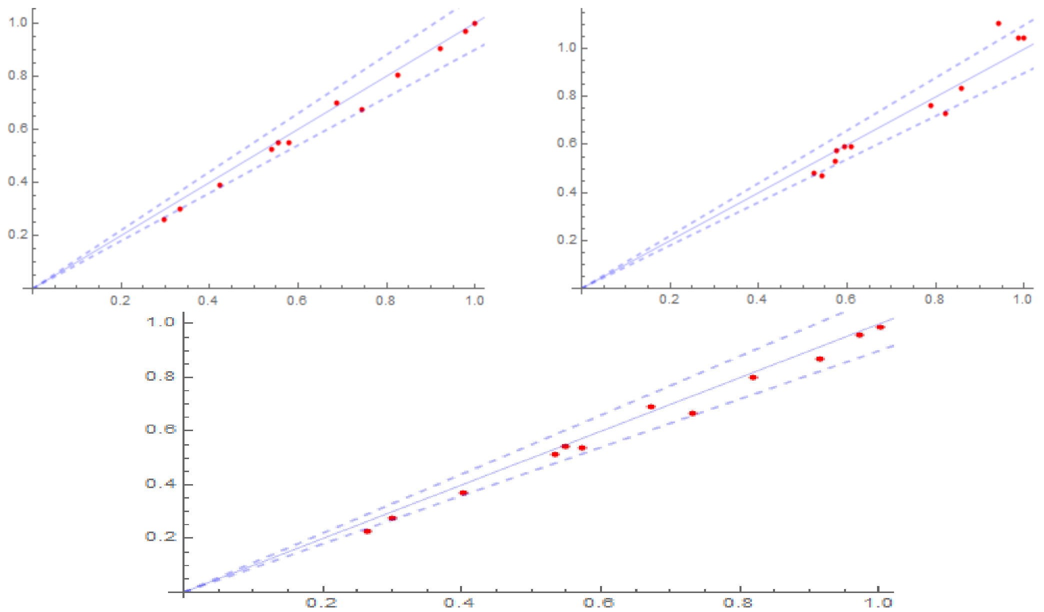

Figure 4. Comparison between the estimation and the measured data for all the days of the gross energy (top left), the auxiliary energy (top right) and the net energy (bottom).

Figure 4 shows how most of the points are contained in between the 10% deviation dashed lines (only one point for the auxiliary energy is out of bounds). Points remain extremely close to the central line for sunny days (corresponding to the 3 higher points in the graphics) at the gross energy graphic and this is almost the same for the net energy except for a negligible distancing caused by the little overestimation of the auxiliary energy for these days. Again, the accuracy of the model in terms of gross, parasitic and net energies is shown for the selected reference set when using appropriate input parameters for the plant operation.

Mass flow, inlet and outlet temperatures of the solar field for the same days are shown in Figure 5.

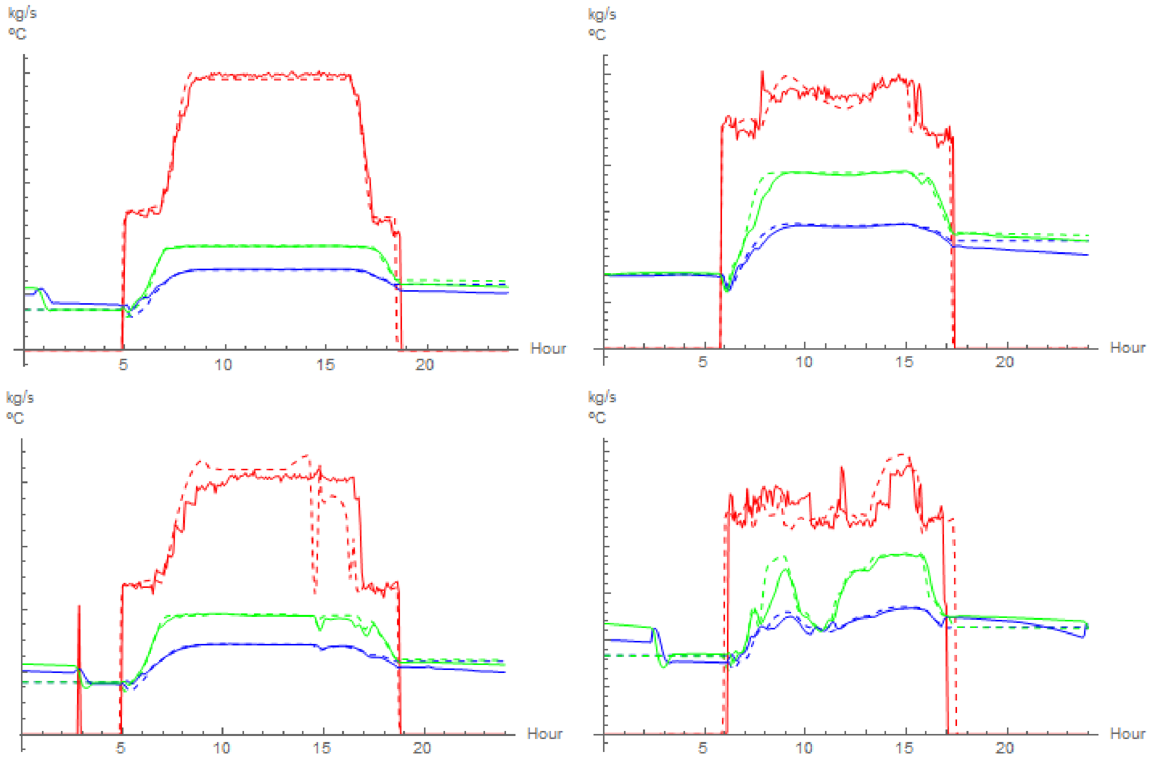

Figure 5. Comparison of the estimated (dashed) and measured (solid) solar field mass flow (red), outlet temperature (green) and solar field inlet temperature (blue), for a summer sunny day (top, left), an autumn sunny day (top, right), a summer sunny day with punctual clouds (bottom, left) and an overcast day (bottom, right).

From Figure 5, both inlet and outlet solar field temperatures accurately follow the real measured temperatures not only during the steady state periods, but also during the transient periods at the beginning and the end of the day as well as during sudden DNI changes. It is also found that the start-up strategy implemented in the model behaves very closely to the real plant. Considering the solar field mass flow, a very good agreement is found most of the time. Main differences in the mass flow are due to a quicker and sharper response to DNI variations. These differences are minor and can be explained due to a better control of the solar field by the software in order to keep the solar field outlet temperature set point, which is not so fast and precise in the real plant.

As well as for the energy variables, some statistics regarding solar field mass flow, solar field inlet and outlet temperatures as well as its pressure drop, are shown in Table 2.

Table 2. Statistics figures for solar field mass flow,
solar field inlet temperature, solar field outlet temperature and solar field pressure drop.

Days	**BIAS (%)**	**MAE (%)**	**RMSE (%)**
SOLAR FIELD MASS FLOW			
SUMMER SUNNY	-1.18	4.11	11.17
AUTUMN SUNNY	-3.92	7.07	25.51
PUNCTUAL CLOUDS	0.22	9.82	18.98
OVERCAST	-0.76	10.86	30.33
ALL DAYS	**-1.26**	**7.47**	**19.7**
SOLAR FIELD INLET TEMPERATURE			
SUMMER SUNNY	-0.39	4.21	6.44
AUTUMN SUNNY	3.44	4.66	6.44
PUNCTUAL CLOUDS	-3.46	10.03	12.57
OVERCAST	0.21	4.09	6.7
ALL DAYS	**0.27**	**5.84**	**8.31**
SOLAR FIELD OUTLET TEMPERATURE			
SUMMER SUNNY	0.33	2.81	5.24
AUTUMN SUNNY	1.37	3.33	5.48
PUNCTUAL CLOUDS	0.25	3.65	6.31
OVERCAST	-1.23	6.91	9.64
ALL DAYS	**0.21**	**4.08**	**6.7**
SOLAR FIELD PRESSURE DROP			
SUMMER SUNNY	3.95	9.66	15.65
AUTUMN SUNNY	-9.71	12.63	22.28
PUNCTUAL CLOUDS	2.62	19.82	33.08
OVERCAST	-4.01	17.04	34.26
ALL DAYS	**0.33**	**14.02**	**25.51**

Regarding the study of the solar field mass flow, BIAS is less than 4% for all types of days and only 1.26 % considering the reference set as a group showing that the model accurately reproduces the solar field mass flow over time for any kind of day. Major differences are found in autumn days, for which the model slightly underestimates the mass flow, caused by the better control of the solar field (outlet temperature drops due to staggered control in the real plant not appearing in the model). Drawing the attention now to both inlet and outlet solar field temperatures, it can be checked that the software gives more than accurate estimations, taking into account the less than 0.4% deviation of the reference set as a group.

Finally, the solar field pressure drop is represented in the Figure 6, again for the same days presented above.

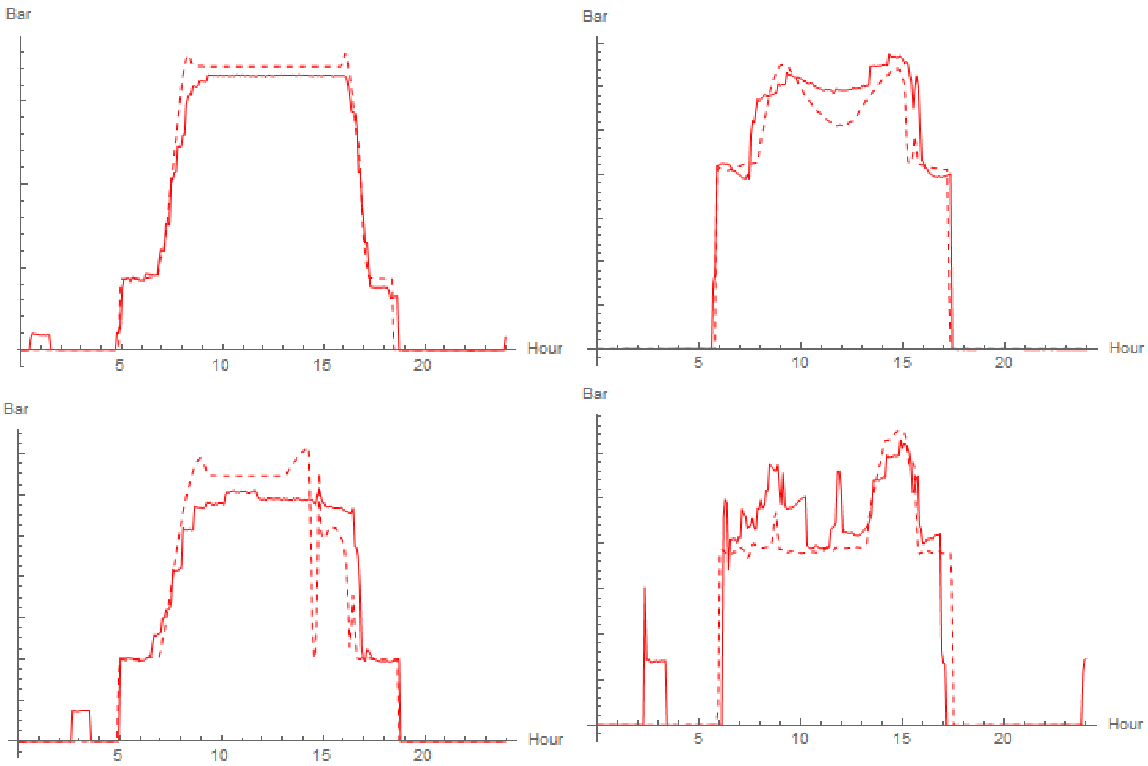

Figure 6. Comparison of the estimated (dashed) and measured (solid) solar field outlet pressure drop, for a summer sunny day (top, left), an autumn sunny day (top, right), a summer sunny day with punctual clouds (bottom, left) and an overcast day (bottom, right).

Again, the pressure drop estimations and measured data agree well from an overall stand point. The ups and downs are reached in a similar way, driven by the accurate estimation of the mass flow. However, the little deviations in the mass flow are reproduced here showing larger discrepancies due to the exponential dependence of the pressure drop on the mass flow. Despite this, the statistics in Table 2 demonstrate a very good agreement of the estimations and the measured data, leading to a very little BIAS (0.33% of the reference set as a group) and a reasonable RMSE. This very little overestimation of the solar filed pressure drop becomes even more insignificant due to its very little impact on the auxiliary consumption deviation, showing a -1.81% BIAS as previously presented in Table 1.

4.2 Complete year

A similar comparison was performed for a simulation of the whole year, as explained in the methodology. The statistics for the gross, net and auxiliary energy for the whole year are presented in Table 3. These statistics have been calculated in terms of daily totals, i.e. for 365 points, instead of using the 105120 simulation and measured points. In this way, simpler and more representative information is presented. Errors within each day, which might be large in some instants, are not shown, but still, the model should be accurate day by day. Note that final figures (annual total energies) are not affected at all by this.

Table 3. Statistics figures for gross, auxiliary and net energies.

	TOTAL Model (MWh)	**TOTAL Measured** (MWh)	**BIAS (%)**	**MAE (%)**	**RMSE (%)**
GROSS ENERGY	146506	144372	1.47	7.47	13.64
AUXILARY ENERGY	22798	23114.9	-1.37	7.2	10.94
NET ENERGY	123708	121257	2.02	8.59	15.11

As shown in Table 3, excellent results are found for the complete year estimations in terms of daily and total energies with BIAS just over 2% in the worst case. Note that deviations for the gross, auxiliary and net total energies are even lower than those found for the reference set (Table 1). This means that some error canceling exists but also the rather low MAE and RMSE show that the estimations are good also in a day by day basis, and thus this error canceling effect is limited.

In Figure 7, the graphical comparison of the gross, auxiliary and net energies both in a daily and in an accumulated basis are presented. The figures in the left show the daily energy estimations against the corresponding measured data, while the figures in the right show the accumulative energy plots for the complete year.

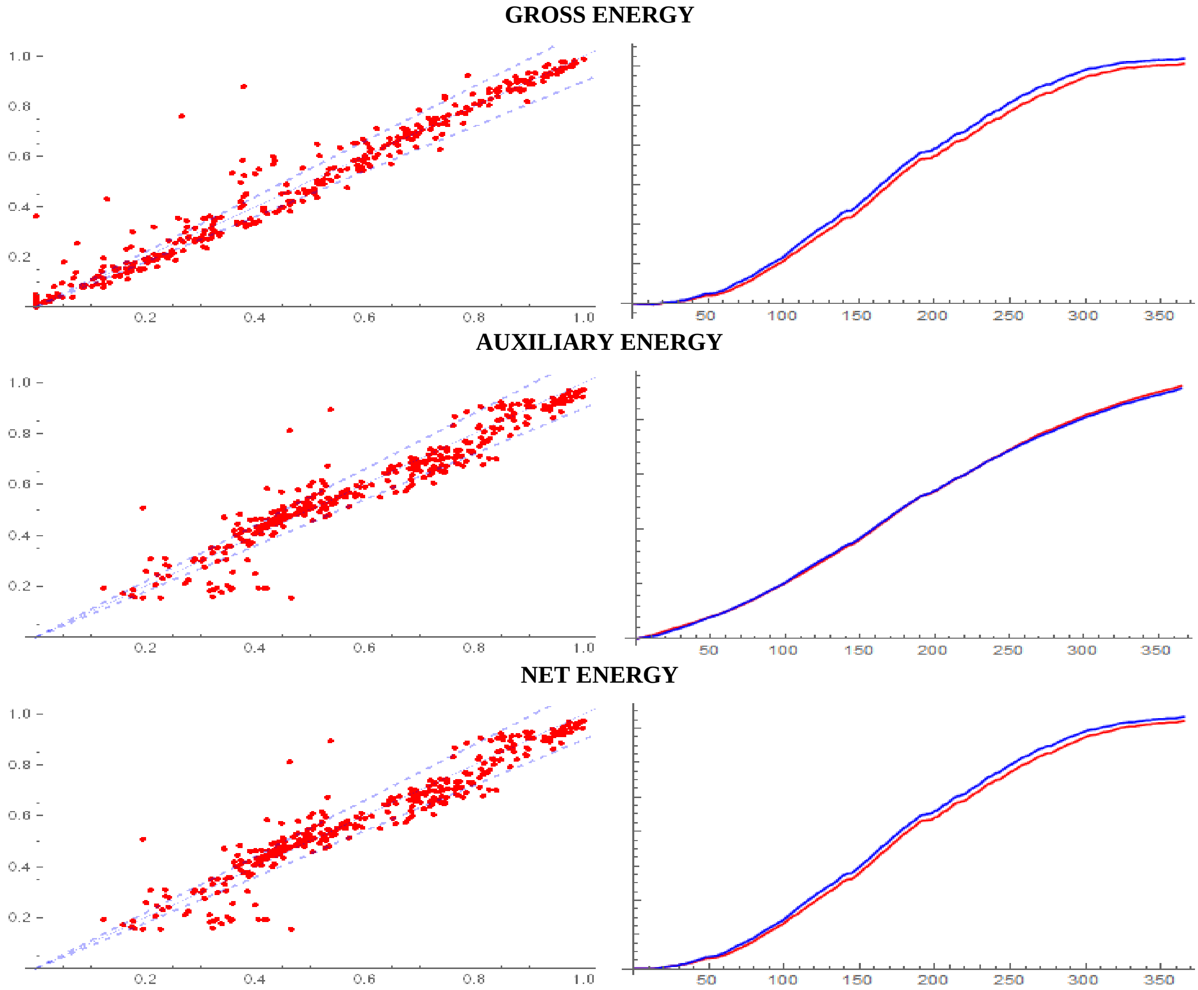

Figure 7. Comparison between the estimation and the measured data for all the year's days of the gross energy (top left), auxiliary energy (middle left), net energy (bottom left) and accumulative plot along one year, according to the software (blue line) and to measured data (red line) of the gross energy (top right), auxiliary energy (middle right) and net energy (bottom right).

As expected from the statistics analysis, gross, auxiliary and net energy estimations agree very well with measured data. The very little total energy deviations can be found in the rightmost values of the cumulative plots, while the good agreement in a day by day basis is shown in the point plots, in where most of them are very close to the central line. Only a slightly trend to underestimate the gross energy in low production days can be found in the plots, as well as larger deviations in specific days which are not worth analyzing (partially sunny days with no real plant operation, etc.). In general terms, very little dispersion is found for the three energies.

Looking into the accumulated gross energy plot, it can be noticed that approximately around day 100 a little overestimation is produced and dragged for the rest of the year (both curves separate a fixed distance from this day on). This means that estimations are really accurate for the periods in which the majority of the annual energy is produced (curves are almost perfectly parallel from Spring to Autumn)

To sum up, extremely accurate estimations for the daily and accumulated energies of a complete year have been provided by the model. The whole year deviation is under the 3% for all the gross, auxiliary and net energies, and thus most probably within the solar resource and other measurements uncertainty. With this results, and having in mind this validation process limitations (only one year of measurements was available, some parameters needed to be inferred from the data, etc.) it is found that the developed model satisfactorily fulfills its objectives.

5. Conclusions

This work presents the validation process carried out for a simulation tool for CSP plants based on parabolic trough technology. With a straightforward methodology, the simulation software's accuracy has been evaluated by comparing one complete year of measured operational data from a real plant with the model estimations.

As a first step in the validation process, little parameter adjustment was needed to properly represent the real plant operation. 12 days were selected among the 365 days of the complete year, and were analyzed to provide the model with accurate input parameters regarding operating temperatures, recirculation mass flows, power block maximum overloading, and others. Once the plant operation parameters were set, a detailed comparison of the model estimations with the measured data was performed, showing great agreement for both the steady state and transient periods and therefore properly simulating most of the plant's behavior. Comparing the gross, auxiliary and net powers as well as solar field mass flow, inlet and outlet temperatures, the deviations are within a 4% if considering all the 12 days and down to 1.7% for the summer sunny days. In this detailed comparison, main differences showed to be due to a quicker and sharper response of the model control system to DNI variations. The modeled control system seems to adapt almost perfectly to the variations of the solar resource to keep the desired outlet temperature, in contrast with the real plant, which presents a slightly staggered control and thus, not tracking sudden DNI changes as precisely as the model does.

Finally, the complete year simulation was compared in terms of gross, auxiliary and net daily and total energies, finding even more accurate results. The deviation of the total energies for the complete year resulted under the 3% for all cases (gross, auxiliary and net energies) and also very good RMSE (15% in net energy) was obtained, showing that the model has good accuracy also in a day by day basis.

The validated model used pretty simple approaches for modeling each of the plant's sub–systems and components. Further work will include studying whether or not providing the model with more detailed approaches for simulating each of its sub parts will result in more accurate estimations. In addition, the validation process needs to be carried out for a plant including TES and burner systems, to check the software on its complete extension. However, measured data from a plant with those characteristics would be needed for such validation, and unfortunately that is not the case and it is not likely to be.

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