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Analysis and Simulation of CSP and Hybridized Systems

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ACWA Power's CSP Performance Models

An Online Centralized Platform for ACWA Power's CSP Portfolio

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Abstract. ACWA Power develops, owns, and operates several CSP projects, including the largest one in the world. One of the primary objectives for companies in the Concentrated Solar Power (CSP) sector is to lower the electricity costs associated with CSP plants. This goal extends not only to existing operational plants but also to future projects. Enhancing plant performance is a key pathway to achieving this cost reduction. CSP performance models play a pivotal role in this journey by allowing us to analyse different configurations, changes, or modifications without the necessity of their physical implementation. In 2015, ACWA Power made a strategic decision to develop its own CSP performance models. This move aimed to enhance ACWA Power's competitiveness for upcoming projects while also supporting operational plants by identifying avenues for performance improvement. The decision was made to create models for the two prevailing CSP technologies: Parabolic Trough with thermal oil as the heat transfer fluid (HTF) and molten salt storage system, as well as solar tower with molten salts.

Keywords: Performance Model, Online Platform, Concentrating Solar Power (CSP), Renewable, Solar Energy, Performance Analysis, Energy Yield Assessment, ACWA Power

1. Glossary.

Explanation of abbreviations used in this document:

Abbreviation	Explanation
ACWA	The Saudi Arabian company ACWA Power being developer, investor and operator of power generation and desalinated water plants.
NOMAC	Operation & Maintenance company, a fully owned subsidiary of ACWA Power which operates and maintains the ACWA Power assets.
CT	Central Tower concentrated solar plant
PT	Parabolic Trough concentrated solar plant
PV	Photovoltaic solar plant
HTF	Heat Transfer Fluid, used to deliver the energy captured from the receivers of the solar field to the Power Block

TES	Thermal Energy Storage, used to store the thermal energy from the solar field during sunny hours and deliver to the Power Block during the night or cloudy conditions.

2. Purpose of ACWA Power Performance Models

An online centralized platform to integrate all performance models, including the CSP performance models with the following characteristics:

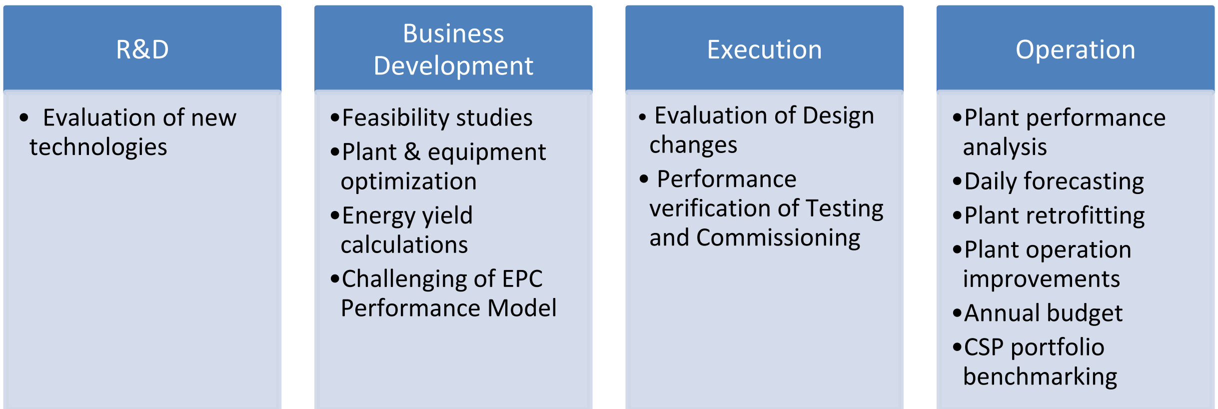
- Programming code is kept in internal secure servers only accessible by the specific key personnel.
- Permission to execute the model is limited to ACWA Power and NOMAC personnel regardless of their location.
- All simulations performed are stored in a database located on ACWA Power's server.
- The functional description has been developed and finished before programming the software and any future modification will first be first realized in the functional description before modifying the software code.

The ACWA Power CSP Performance Models are in an ongoing improvement process. Additionally, they have been widely used in all stages of the projects: innovation, business development, execution, and operation of the ACWA Power's CSP Portfolio.

3. Performance Models Applications

3.1 General

The following figure shows the areas in which the ACWA Power Performance Models have been used since 2016:



3.2 Use for CSP Portfolio

ACWA Power is currently operating one plant in South Africa (Bokpoort), three plants in Morocco, (Noor I, Noor II and Noor III) and four other plants in Dubai (Noor Energy 1 CT, Noor Energy 1 PT 1 to 3). Apart from that, there is another CSP plant under construction (Redstone in South Africa).

The ACWA Power Performance Models have been widely used for each of the projects as summarized below:

Noor I Ouarzazate

- Automatic daily losses analysis
- Retrofitting analysis and optimization
- Peak generation analysis
- Monthly CSP Benchmarking
- Annual budgeting
- Noor complex restructuring

Noor II Ouarzazate

- Automatic daily losses analysis
- Automatic daily turbine/TES loads optimization and daily generation forecast
- Retrofitting analysis and optimization
- Specific unavailability events analysis and impact forecast
- Monthly CSP Benchmarking
- Annual budgeting

Noor III Ouarzazate

- Retrofitting analysis and optimization
- Automatic daily losses analysis
- Unavailability events impact
- Operation

Bokpoort - South Africa

- Performance guarantee with O&M
- Technical reference for daily reporting
- Automatic daily losses analysis
- Retrofitting analysis and optimization
- Refinancing energy yield
- Facility performance model for Offtaker
- Monthly CSP Benchmarking
- Annual budgeting

Noor Energy 1 - Dubai (UAE)

- Technical reference for daily reporting
- Daily losses analysis
- Annual budgeting
- Performance guarantee with the operator

Redstone - South Africa

- Energy yield
- Retrofitting analysis and optimization
- Evaluation of Technology providers
- EPC Performance Model challenge

4. Performance Model Software Architecture

Centralized database & security is used by all ACWA Power technologies (CSP, Water desalination plants etc.). The Model Platform is built using Microsoft technology:

- .Net Environment
- SQL-Server
- Azure Cloud Platform

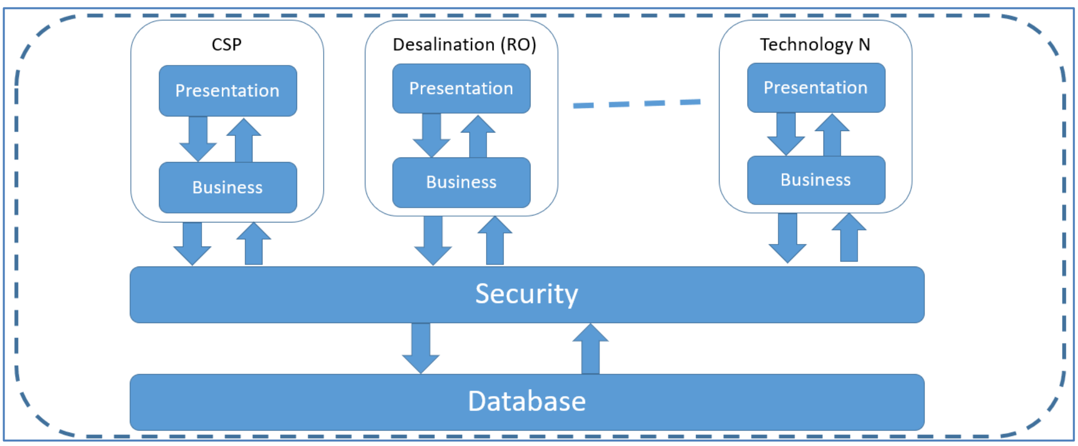


Figure 1. *ACWA Power Performance Model software architecture*

5. User interface

ACWA Power Performance Model has been developed trying to provide as much flexibility as possible for the users, so it can be customized for each specific project and, although different forms of accessing the model have been developed, even some executables models for specific applications, the most common way is through the web.

Figure 2. *Solar Tower Model user interface for the receiver system*

6. Software Structure

One of the main goals kept in mind when developing the software was to provide it with flexibility and modularity. For that purpose, next systems have been modeled in independent modules to facilitate changes within the systems or in the technology itself:

- Solar geometry
- Concentrating system
- Receiver system
- Operational strategies
- Thermal Energy system
- Dumping
- Auxiliary system
- Power Block system
- Transport system
- Electric system

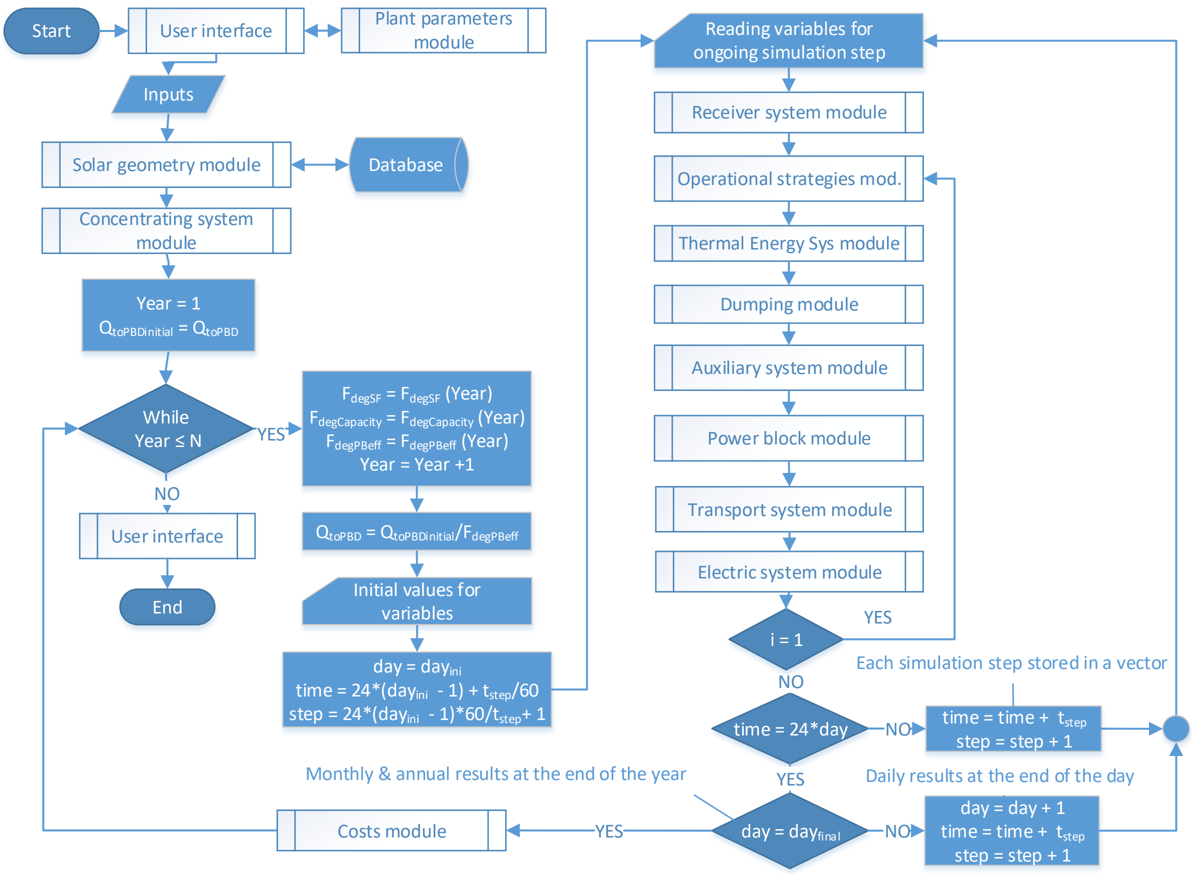


Figure 3. *Solar Tower performance model general structure*

All modules except for the solar geometry and the concentrating system model must be run one after the other for every time step since the variables are interrelated.

The following sections summarize the most relevant systems.

6.1 Receiver system

The main goal of the receiver system is to obtain for each step the outlet temperature and mass flow from the solar field. For that, an iteration process is required as none of them are known at the beginning of the thermal balance calculation. Four different modes of operation have been implemented in the model, night, warm-up, off design and design as shown in the below figure.

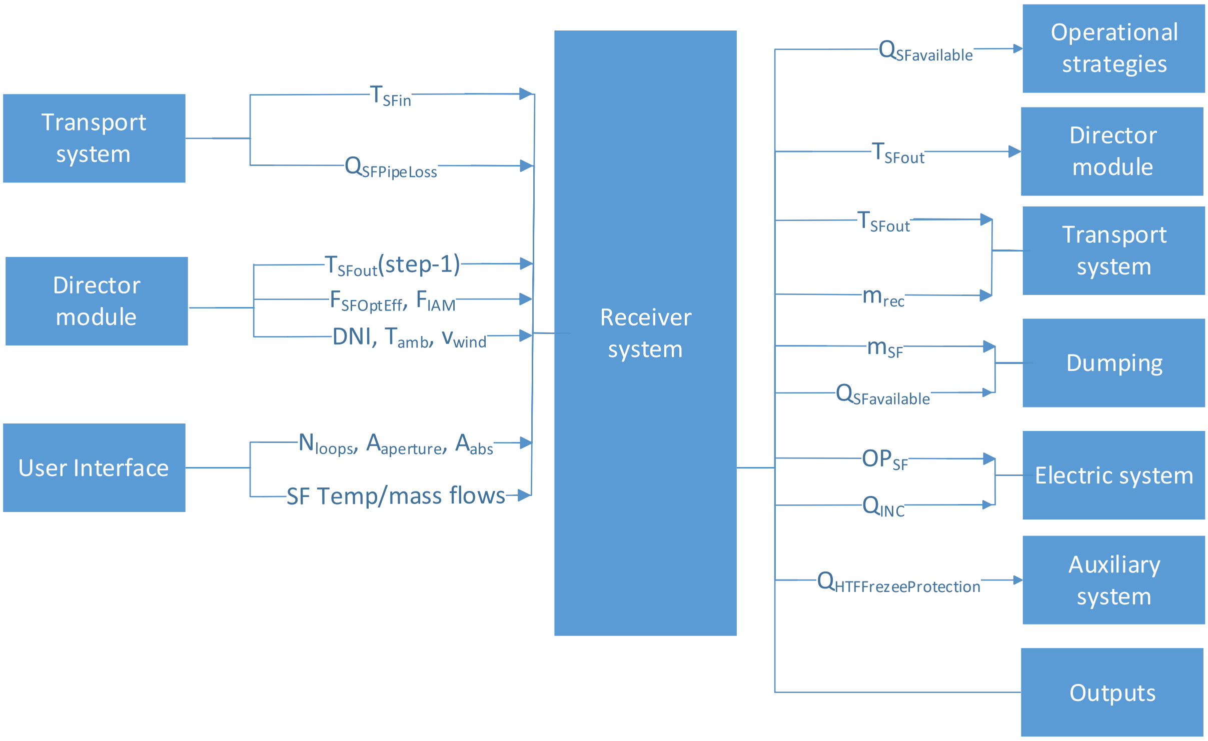


Figure 4. *Receiver system flowchart diagram*

6.2 Concentrating System

The main goal of the concentrating system module is to determine the optical solar field efficiency for each time step. Inputs come from solar geometry (solar altitude and azimuth), from general interface (solar field configuration and solar field components properties). The outputs obtained in this module are the solar incident angle, collector tracking angle, solar collector optical efficiency, heat collection element optical efficiency and solar field optical efficiency and end loss factor for each time step. In the following figure, main inputs and outputs and interactions between modules have been represented.

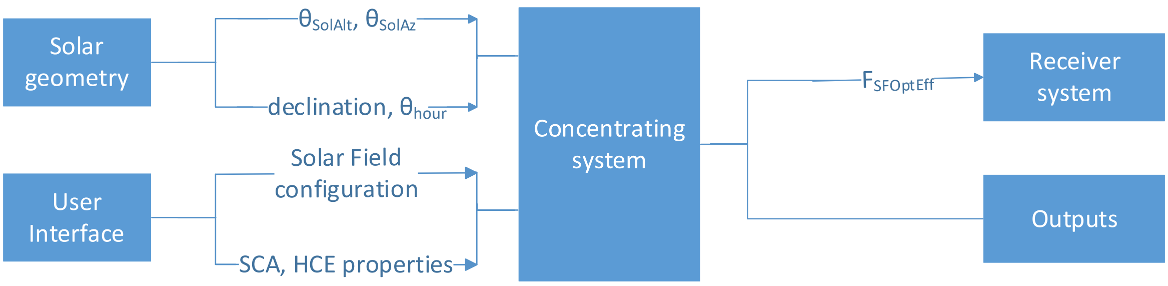


Figure 5. *Concentrating system flowchart diagram*

6.3 Operational Strategies

This module is where the decisions about what to do with the available thermal power are taken at each time step. It receives information from the rest of the system about the available thermal power or the status at the previous time step. Apart from that information this module uses the user restrictions to define what to do with the available energy.

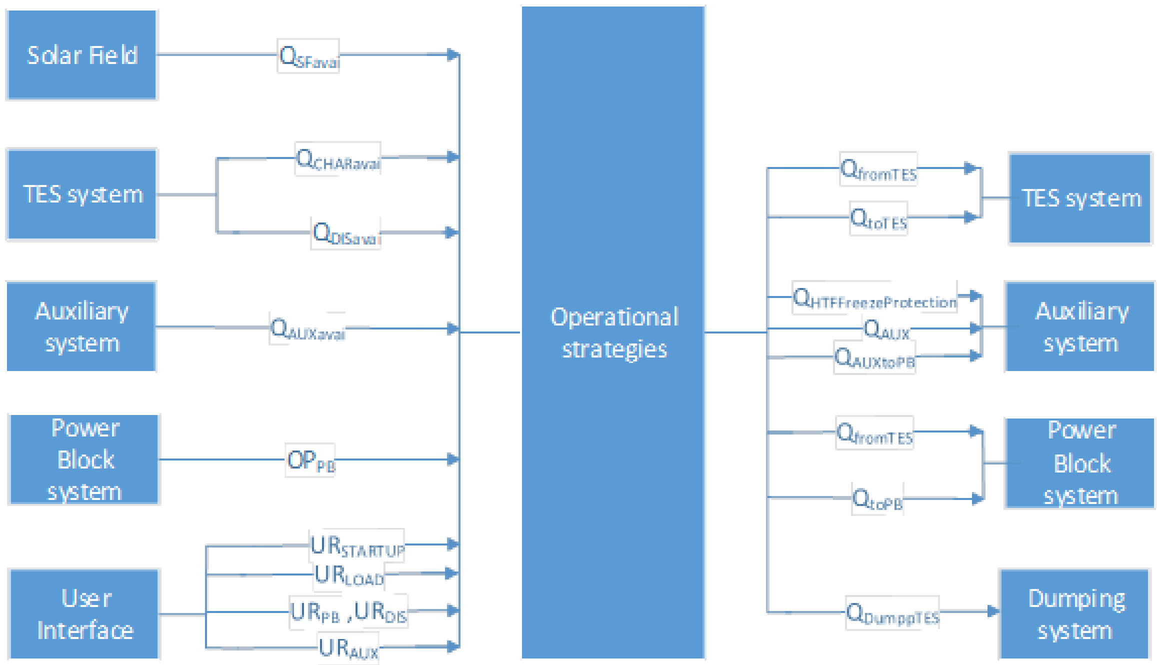


Figure 6. *Operational strategies flowchart diagram*

6.4 Thermal Energy Module

The purpose of this module is to determine stored thermal energy, available thermal power for charging and discharging and salt mass flow for auxiliary consumption for each time step.

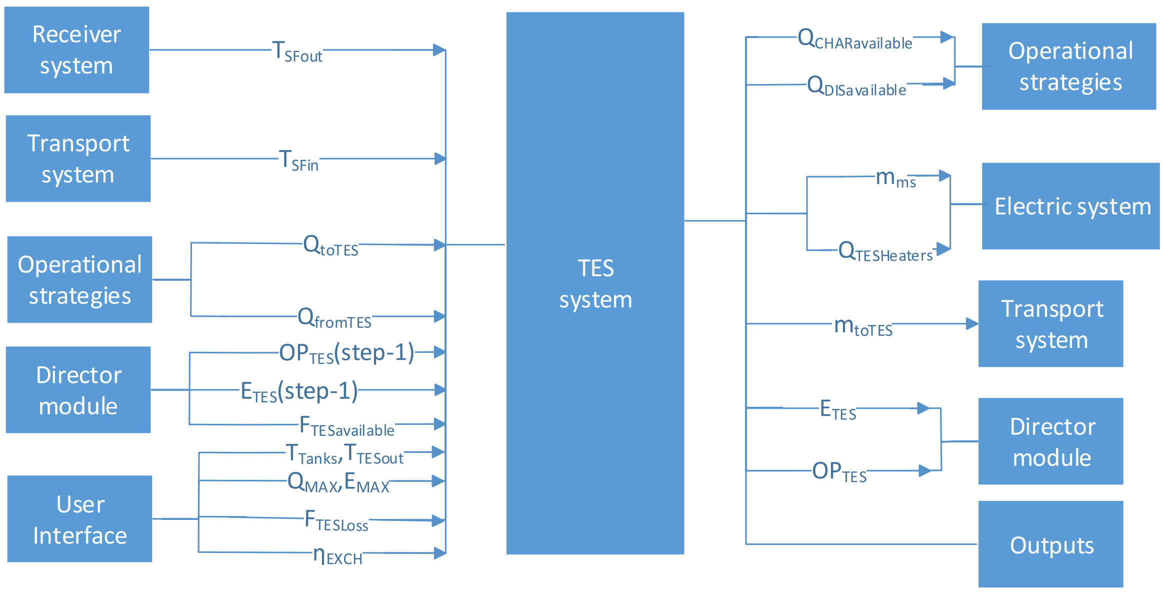


Figure 7. *Thermal Energy Module flowchart diagram*

6.5 Power Block System

This module determines the gross electric power generated in each time step. The outputs calculated are generated gross power, power block efficiency, HTF mass flow and outlet temperature in power block and water consumption.

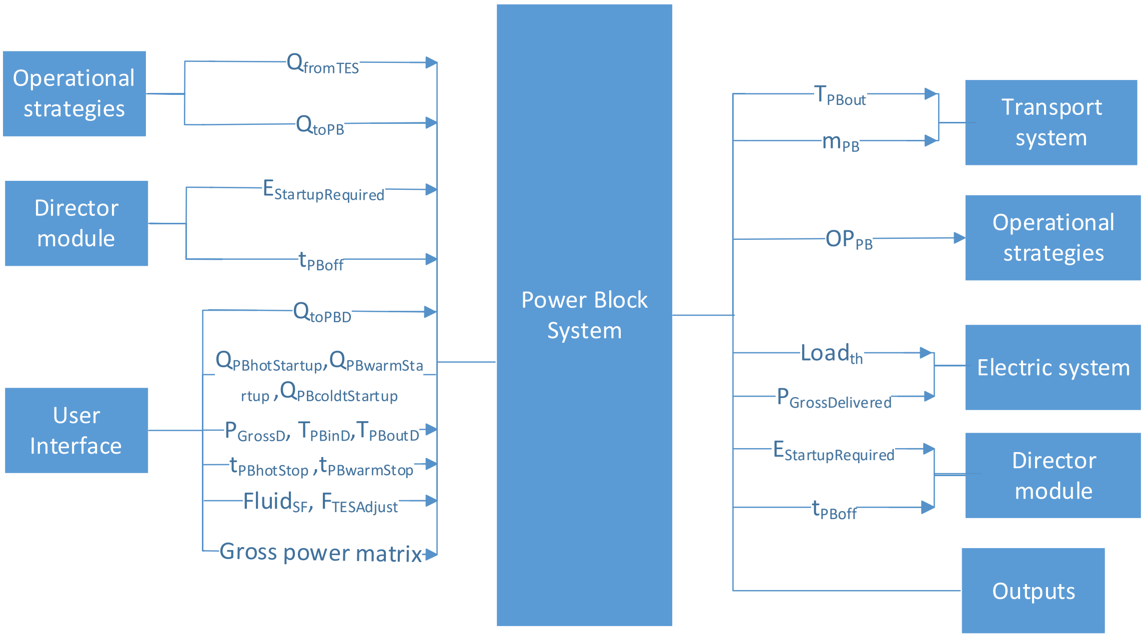


Figure 8. *Power Block Module flowchart diagram*

6.6 Electric Module

The electric module obtains the net electric power and auxiliary consumption in each time step. Among the outputs of the electric module are net power at connection point, net power delivered by PV plant (in case there is a PV plant considered for auxiliary consumption or other purposes), rejected gross and net power due to grid restrictions.

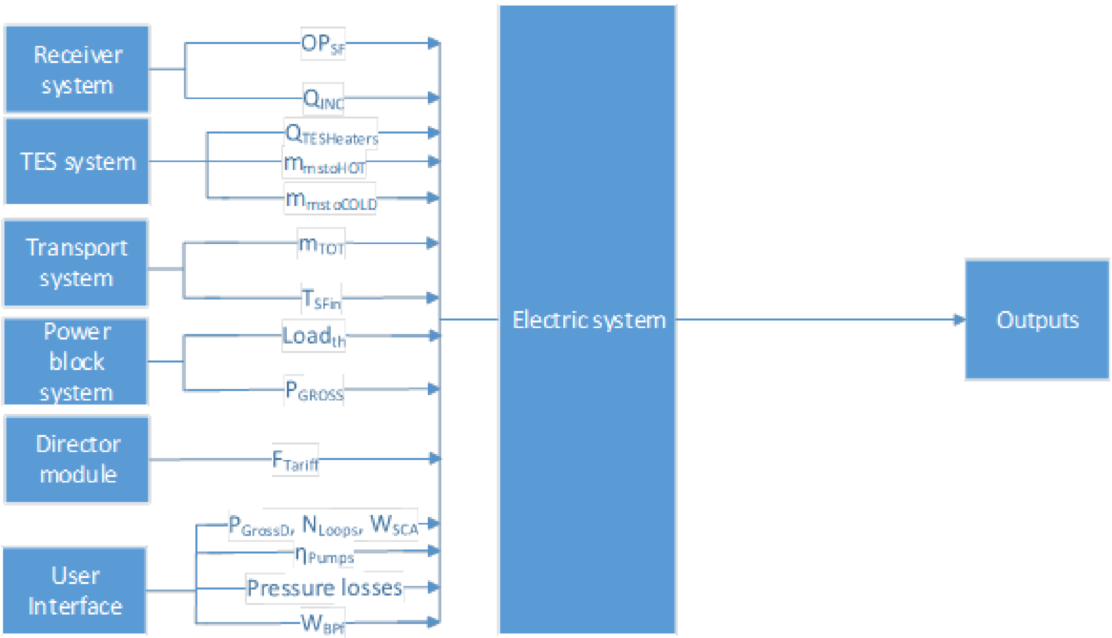


Figure 9. *Electric Module flowchart diagram*

7. User Inputs

The ACWA Power Performance Models have different input configurations depending on the final use of the software. For example, the design team has a complete set of parameters and inputs to be modified during the design stage until a plant is completely designed. In case the project is already in operation, the performance engineer on site has a limited number of inputs to be modified. These inputs are depending on the variability of the conditions that you may have and potential component unavailability which affect the plant operation and performance. Typical inputs of a plant in operation are:

- Inputs in 10- minute time resolution:
  weather data, plant initial status, grid availability, turbine availability, steam generation system availability, power block availability, HTF pump availability, thermal storage availability, solar field availability, operation strategy (load)

- Inputs for each day:
  heat collection element status, photovoltaic plant availability, solar field cleanliness, power block degradation, solar field degradation, thermal energy capacity limitation.

8. Software Development Process

The models have been developed through detailed functional specifications which were finalized before starting the programming. There are three different functional descriptions for parabolic trough, solar tower and hybrid models.

Standard structure has been used for an easier understanding; each specification considers the following:

- Flowchart diagram
- Inputs
- Variables from /to other systems
- Outputs
- Mathematical and empirical description

After developing all functional specifications, an IT engineer develops the coding of the software. As the model is well documented, it facilitates improvement, error finding, result comprehension or responsibility take-over. Every time there is an improvement of the model or modification, it is identified in the relevant functional specification with track error and clean version.

9. Model Validation

For the Bokpoort project in South Africa a performance model had to be provided to the electricity off taker and the lenders. For that purpose, the ACWA model was compared with the contractual EPC performance model, which has an hourly resolution of the inputs. Compared to the contractual performance model the ACWA Model calculates lower production at lower radiation and higher production in sunny weather conditions, which corresponds much better to the actual power productions. That was the reason why the ACWA Model was chosen by the Lenders Technical Advisor and the off taker as the performance model to compare with the actual production.

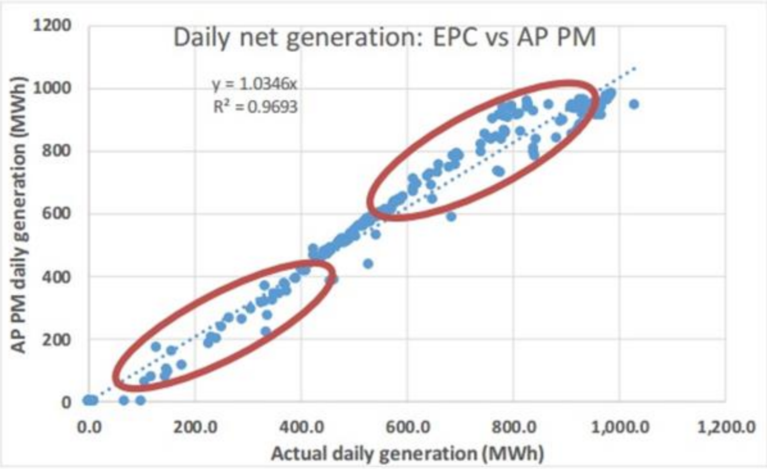


Figure 10. *Comparison of daily generation ACWA vs contractual model*

10. ACWA Power's CSP Simulation Platform

ACWA Power Simulation Platform is connected to ACWA Power Performance Models. This Simulation Platform launches automatically simulations following actual data coming for any of the projects. Then, this platform is performing all simulations. The platform is also incorporating other functionalities such as EPC Performance Models connection that are used for Guaranteed Generation from EPC (Engineering, Procurement and Construction) company. This platform enables users to save a lot of time in the daily performance analysis. And it is a centralized way to manage all relevant data from the projects as data based and performance analysis tool.

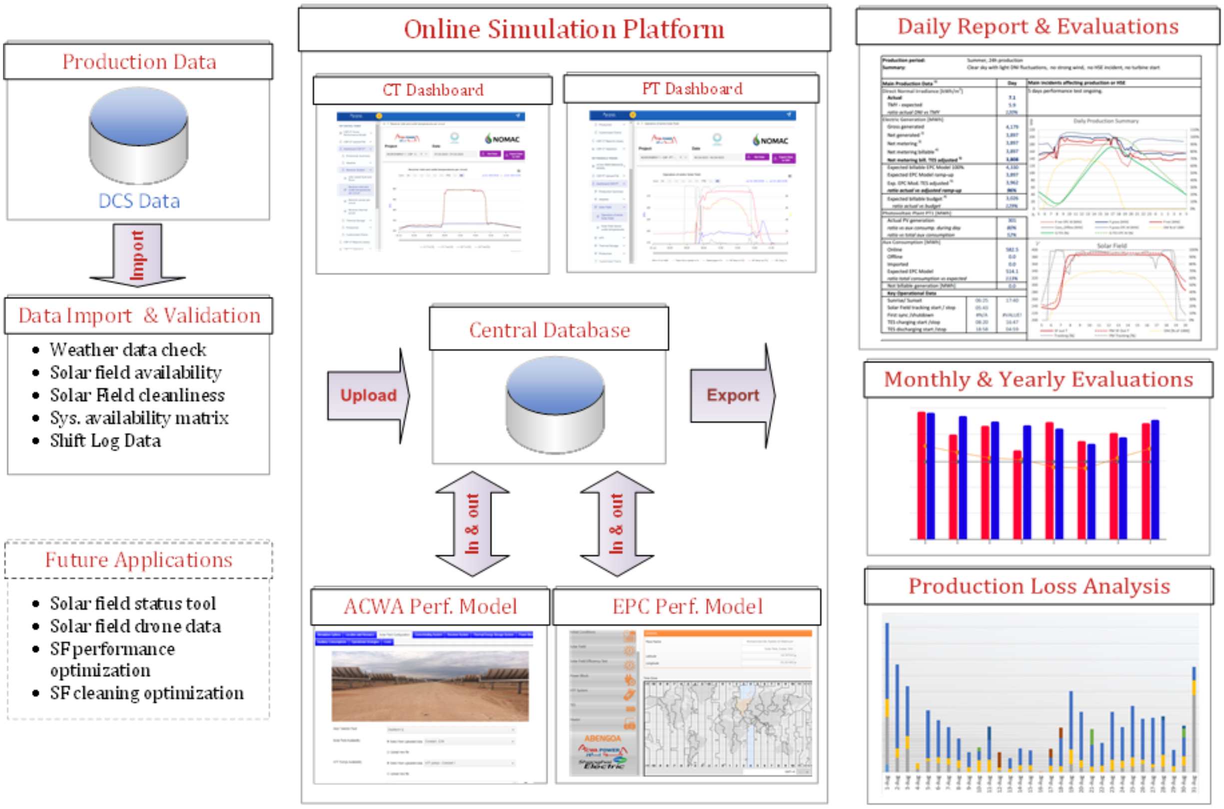


Figure 11. *ACWA Power CSP Simulation Platform*

11. Final remarks

Online centralized platform to integrate all performance models, including the CSP performance models with the following characteristics:

- Programming code is kept in internal secure servers only accessible by the minimum key personnel.
- Permission to execute any the model is only got by the ACWA Power and NOMAC relevant personnel regardless of their location.
- All simulations performed are stored in a database located on ACWA Power's server.
- Functional specifications are developed and finished before the beginning of the software programming and any future modifications are first captured in such specifications.
- Data basis for the design of future CSP plants.
- Automation and analysis standardization.

Data availability statement

The Performance Model has been developed and is property of ACWA Power. The program code and its simulation results are not publicly accessible as indicated in the section above.

Author contributions

Jose Maria Barea: Concept, Methodology, Writing, Jose Barragan: Concept, Methodology, Khaled Azab: Software development, Oliver Vorbrugg: Writing and Reviewing, Thomas Altmann: Supervision

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] M. Mehos, et.al., 2020, Concentrating Solar Power Best Practices Study. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-75763

[2] Kesseli, Devon, Mike Wagner, Rafael Guédez and Craig S. Turchi. 2018. CSP-Plant Modelling Guidelines and Compliance of the System Advisor Model (SAM): Preprint. Golden, CO: National Renewable Energy Laboratory. NREL/CP-5500-72183.