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Concentrated solar power components toolbox in an object oriented environment

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ABSTRACT

A toolbox for modeling solar components for gas and steam turbine Solar Thermal Power Plants (STPPs) is presented. It has been created in order to supplement the PROOSIS modeling environment that covers the power production parts. Solar and power production parts are both represented at a similar level of fidelity. The toolbox contains components for simulating all the individual solar elements used in STPPs in order to materialize Brayton, Rankine and Combined Cycles. Functionalities for computing solar irradiation properties as well as working fluid thermodynamic properties are included. The use of the toolbox is demonstrated through simulation cases at component and plant level, while its features, capabilities and merits are discussed. The developed capabilities offer the possibility to perform plant design optimization, operational support through performance prediction at various operating modes as well as assessment of the effect of components malfunctions.

1. Introduction

The use of fossil fuels for power production is one of the main contributors to climate change at local and global level, while their finite nature highly affects their selling price and availability. In order to limit their effects, renewable energy sources, such as wind and sun power, are used for their substitution. Solar energy, already extensively exploited through photovoltaics, can be used in Solar Thermal Power Plants. Solar thermal power addition to Brayton and Rankine cycles can partially or totally substitute the fuel thermal power.

Solar Thermal Power Plants have already been built, mainly using troughs for solar heat collection and oil as Heat Transfer Fluid in Rankine cycle [1]. The Direct Steam Generation from troughs is under investigation as well as the use of other materials as HTF [2–4]. In the Brayton cycle, solar thermal power has been used to preheat the air before it enters the combustion chamber. EU funded projects [5–7] and other research studies examine this option [8–11].

The prediction of the behavior of such plants and the accurate simulation of their performance is a necessary task in order to estimate economic aspects of an investment and evaluate new concepts. There are many in-house and commercial

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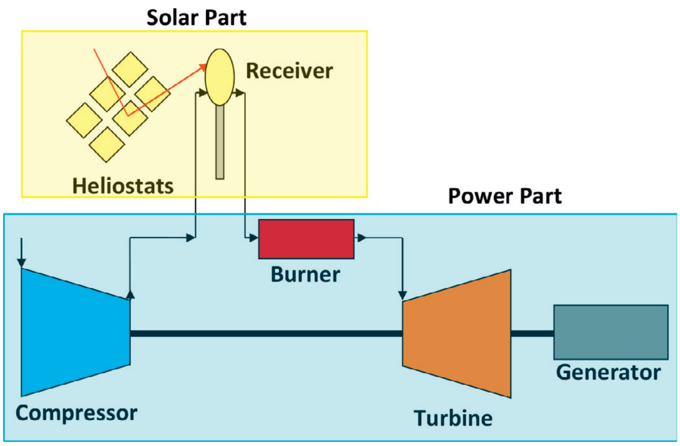

Fig. 1. Solar thermal power and Brayton cycle.

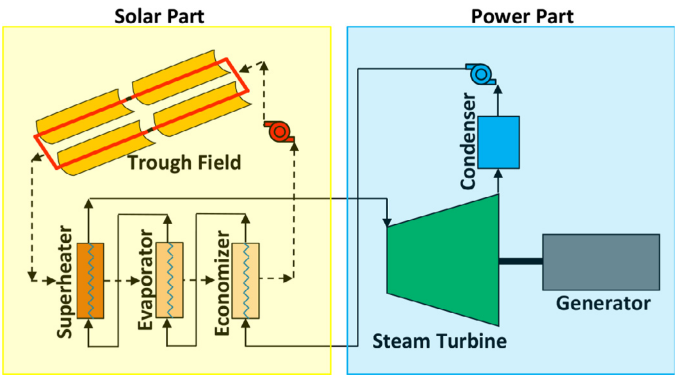

Fig. 2. Solar thermal power and Rankine cycle.

simulations tools available based on or linked with two widely used simulation programs, namely SAM [12] and TRNSYS [13]. SAM is a powerful package limited to simulating only Rankine cycles [12], thus it cannot be used for the evaluation of Combined Cycle and Gas Turbine type of STPPs. TRNSYS [13] utilizes semi-empirical relations for simulating gas and steam turbine operation. This approach does not offer flexibility for performing various types of performance and optimization studies, such as the optimization of a gas turbine IGVs schedule for hybrid operation. Additionally, it does not allow efficient component faults modeling and engine health monitoring.

PROOSIS is a powerful tool used for simulating the performance of thermal turbomachines in an object oriented environment and is currently used throughout the aeronautical community [14]. It contains the TURBO library [15] which allows the accurate simulation of gas turbines [16]. For modeling Rankine cycles and Combined cycles, in conjunction with the TURBO library, the authors developed the WAST library [17]. For modeling STPPs a suitable library has been developed, named SOLAR. It contains components for simulating all the individual solar elements used in STPPs (e.g. Figs. 1 and 2). The libraries have been used by the authors for investigating the effect of gas turbine configuration on the performance of a hybrid Brayton cycle and to evaluate approaches for exploiting the rejected Sun power [18,19].

In the present work, the development of SOLAR library is discussed. The components mathematical modeling along with validation examples are presented. For demonstrating the cooperation of the different libraries the model of a hybrid gas turbine based STPP is built, its operation is simulated for various scenarios and relevant results are discussed.

2. Component modeling

The library has been developed in PROOSIS [14], an object-oriented environment. It uses libraries (e.g. TURBO, ELECTRICAL, CONTROL) which contain components. A library component is the mathematical model of real world component exhibiting the following features:

- providing reliable modeling of physical reality, using appropriate mathematical formulations
- structured with variables allowing easy adaptation to practical cases (eg handling different working media)
- ability to communicate with other components, so that entire installation models can be produced
- be user friendly and flexible to accommodate alternative configurations