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Simulation of a combined cycle gas turbine power plant in Aspen HYSYS

Zuming Liu, I A Karimi*

Department of Chemical & Biomolecular Engineering, National University of Singapore, 4 Engineering Drive 4, Singapore 117585

Abstract

A detailed model is developed in Aspen HYSYS for simulating the operation of a triple-pressure reheat combined cycle gas turbine (CCGT) power plant. To our knowledge, this is the first such model in the literature. A comparison with an equivalent GateCycle model shows that the predictions of the two models (Aspen HYSYS and GateCycle) are comparable. The average relative deviations for the power outputs and thermal efficiencies of the gas turbine, steam cycle, and CCGT plant are less than 2.0%. The minor discrepancies are primarily from the differences in gas enthalpy correlations. On the other hand, Aspen HYSYS may have some advantages over GateCycle. First, its use of the well-proven real-gas Peng-Robinson fluid package may give more accurate predictions. Second, it allows easy integration with various energy systems such as CO_2 capture, organic Rankine cycles, fuel cells, LNG terminals, air separation, absorption chillers, etc. Third, its model can be made dynamic for predicting the real-time behaviour of a CCGT plant.

Keywords: Simulation; Gas turbine; Combined cycle; Power plant; Aspen HYSYS.

1. Introduction

Global warming has become a great concern of our modern society. CO_2 is considered as the main cause of global warming, and more than 40% of the CO_2 emissions stem from the power industry [1]. Owing to the

* Corresponding author. Tel.: +65-65166359.
E-mail address: cheiak@nus.edu.sg

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lower, cleaner emissions and higher thermal efficiencies, combined cycle gas turbine (CCGT) power plants are increasingly preferred over their coal-fired counterparts [2]. Some countries like Singapore produce more than 96% of their electric power from CCGT plants[3].

Since the power demand varies frequently, a CCGT plant often runs in part-load conditions, where its power output is lower than its design capacity. For instance, a gas turbine power plant in Nigeria produced only 64.3% of its nameplate capacity from 2001 to 2010 [4]. The part-load operation arises from several reasons. First, the power demand is hardly steady and rarely equals the design capacity. Second, many countries mandate power plants to maintain spinning reserves (surplus capacity) to guard against unforeseen peaks in demands. Third, a power plant may often be overdesigned to buffer against demand uncertainties. As expected, the thermal efficiency of a power plant decreases as the operation drifts away from the design condition. Therefore, there are strong incentives for improving the plant performance during part-load operations. Clearly, rigorous simulation models that accurately capture the full details of a CCGT plant's part-load operations are valuable and necessary. Such simulation models are the foundation for a variety of routine operational tasks such as benchmarking, process control, process optimization, condition monitoring, fault diagnosis, performance analysis, and performance improvement.

In this work, we present a model in Aspen HYSYS [5] for simulating the operation of a CCGT plant. Aspen HYSYS is a powerful process simulator with a large library of ready-made component models and in-built property packages. It allows the static/dynamic modeling of a wide variety of complex chemical/hydrocarbon fluid-based processes by simply connecting various modules using material and energy streams. This enables the simulation of various energy systems or options other than just power plants. Hence, a simulation model in Aspen HYSYS for CCGT plants allows easy integration with various energy systems such as CO2 capture, ORCs, fuel cells, LNG terminals, air separation, absorption chillers, etc. Moreover, it can be made dynamic for predicting the real-time behaviour.

2. Simulation in Aspen HYSYS

Fig. 1 shows a triple pressure reheat CCGT plant. The equations that describe the off-design operations of various CCGT components are mainly presented in [6]. In this work, we implement those equations in Aspen HYSYS to simulate the operation of the CCGT plant. Detailed simulation description can be found in [7]. We use Peng-Robinson fluid package for air, fuel, and exhaust gas, and ASME steam table for water and steam. Fig. 2 shows the complete block flow diagram (BFD) for the CCGT plant in Aspen HYSYS.

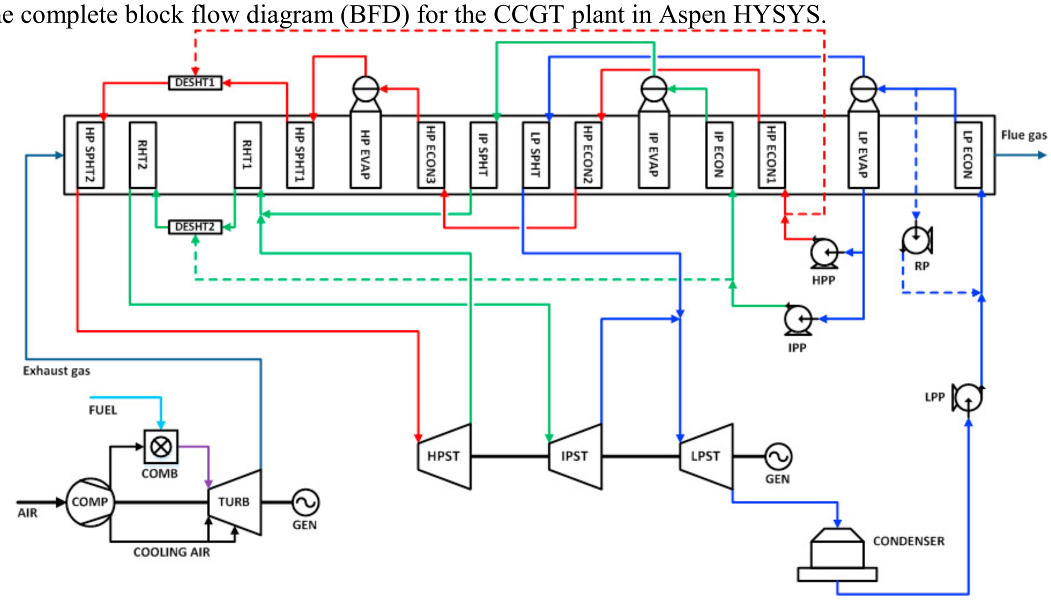

Fig. 1. Schematic of a triple-pressure reheat CCGT power plant.

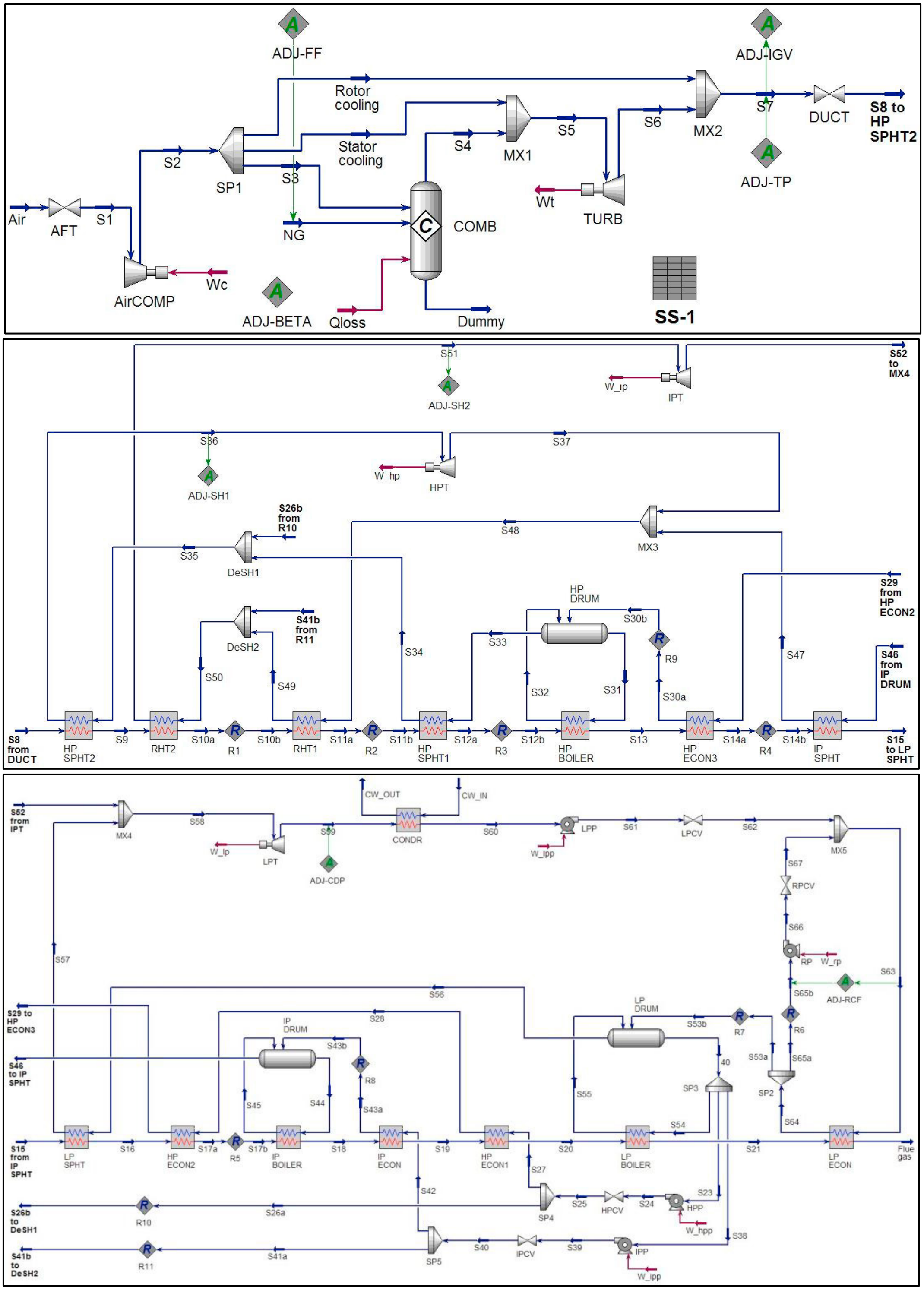

Fig. 2. Block flow diagram (BFD) for the CCGT plant in Aspen HYSYS: (a) Gas turbine (GT), (b-c) Steam cycle (SC).

3. Comparison of Aspen HYSYS and GateCycle simulation models

Since GateCycle [8] is a widely used commercial software in the power industry, it is useful to see how the results from Aspen HYSYS and GateCycle compare with each other. For this, we construct an equivalent model in GateCycle and evaluate the relative deviations (RD) between the two models (Aspen HYSYS and GateCycle) defined as follows:

$$RD(\%) = \frac{\text{HYSYS Result-GateCycle Result}}{\text{GateCycle Result}} \times 100 \tag{1}$$

3.1. Gas turbine (GT) performance

Fig. 3 shows the relative deviations for the key operating parameters of the compressor and turbine. Nearly all are within 1.0%. Moreover, the average deviation is 0.5% for the parameters in Fig. 3. After a thorough analysis of how Aspen HYSYS and GateCycle work, we conclude that the minor discrepancies are due to the differences in the gas property calculations. For gas properties, GateCycle uses NASA method [9], in which ideal gases are assumed. In contrast, Aspen HYSYS uses the Peng-Robinson equation-of-state [10], which is based on the experimental data. The NASA method uses two separate fourth-order (5-parameter) polynomials to compute the enthalpies below and above 1000 K (726.85 °C). Aspen HYSYS computes the enthalpies directly from the Peng-Robinson equation-of-state. Aspen HYSYS predicts a higher (lower) enthalpy below (above) 1000 K than GateCycle. The differences in the enthalpy predictions affect the complex interactions between the compressor and turbine, represented by the matching between the compressor map and turbine characteristics. This leads to the minor discrepancies shown in Fig. 3. Hence, Aspen HYSYS predicts a lower GT power output and efficiency than GateCycle, as shown in Fig. 4. Moreover, as the plant load decreases, the differences in enthalpy predictions drive the GT power output and efficiency of Aspen HYSYS farther way from GateCycle. While the maximum deviations are within 3.2%, and the average deviation is within 2.0%, Aspen HYSYS may be more accurate, as it uses the Peng-Robinson equation-of-state specifically meant for real gases.

3.2. Steam cycle (SC) performance

Fig. 5 shows the relative deviations for the operating parameters of HPST, IPST, and LPST. Since both Aspen HYSYS and GateCycle use the ASME steam table for water and steam, their differences are primarily from their gas models. Aspen HYSYS predicts higher steam flows, and higher ST power outputs than GateCycle due to two reasons. The first is the higher gas enthalpy from Aspen HYSYS, as the SC operates below 1000 K, and the second is the higher turbine exhaust flow (see Fig. 3(b)). However, the steam pressures and temperatures for HPST, IPST, and LPST are all less than 0.6% from the two models, and steam flows and power outputs are within 2.4%. Moreover, the deviations in SC power output and efficiency range between 1.2% and 2.0% as shown in Fig. 4, and the average deviation is less than 1.5%.

3.3. CCGT performance

Fig. 4 shows the relative deviations for the plant power output and efficiency. Aspen HYSYS predicts a relatively lower power output and efficiency than GateCycle, as the GT power output dominates the total output. The relative deviations are the largest (smallest) at 40% (100%) plant load. However, they are at most 1.0%, and their average is less than 0.6%. The reason is that Aspen HYSYS predicts a higher SC power output, which compensates its lower GT output. By comparing the predictions from Aspen HYSYS with those from GateCycle, we conclude that the predictions from the two simulation models are comparable.

Overall, Aspen HYSYS may have an edge over GateCycle, as its model can be easily integrated with various energy systems (e.g. CO2 capture, ORCs, fuel cells, LNG terminals, air separation, absorption chillers, etc.), which is not possible with GateCycle.

4. Conclusions

We presented a comprehensive model for simulating the part-load operation of a triple-pressure reheat CCGT plant in Aspen HYSYS. To our knowledge, this is the first such model in the open literature. A comparison with an equivalent GateCycle model for 40-100% part-loads showed that the predictions from the two models (Aspen HYSYS and GateCycle) are comparable. The relative deviations for the most key operating parameters of the GT and SC are within 1.0%, and 0.6%. Moreover, the average deviations for the power outputs and thermal efficiencies of the GT, SC, and CCGT plant are less than 2.0%, 1.5%, and 0.6%, respectively. We believe that these minor deviations primarily originate from the differences in gas enthalpy correlations.

Aspen HYSYS may have an edge over GateCycle due to several reasons. First, its use of the well-proven real-gas Peng-Robinson fluid package may give more accurate predictions. Second, Aspen HYSYS allows easy integration with a variety of energy systems or options such as CO_2 capture, ORCs, fuel cells, LNG terminals, air separation, absorption chillers, etc. Third, its model can be made dynamic for predicting the real-time behavior of a CCGT plant.

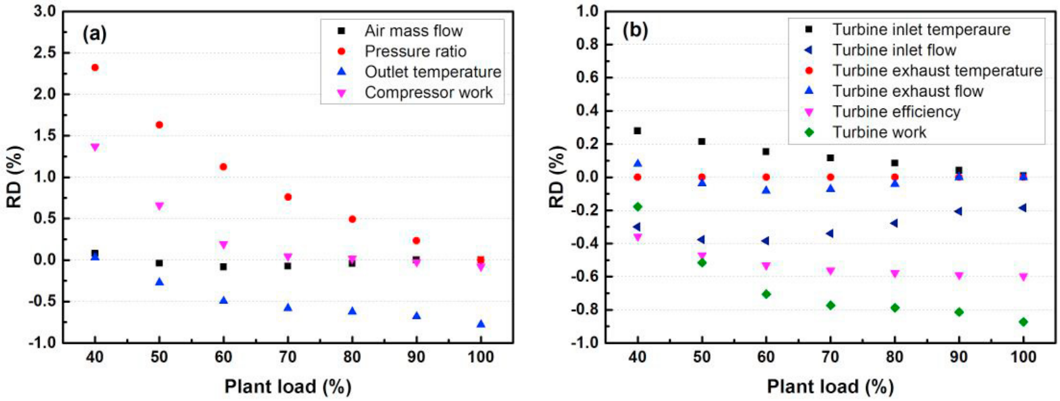

Fig. 3. Relative deviations for the operating parameters of the compressor (a) and turbine (b).

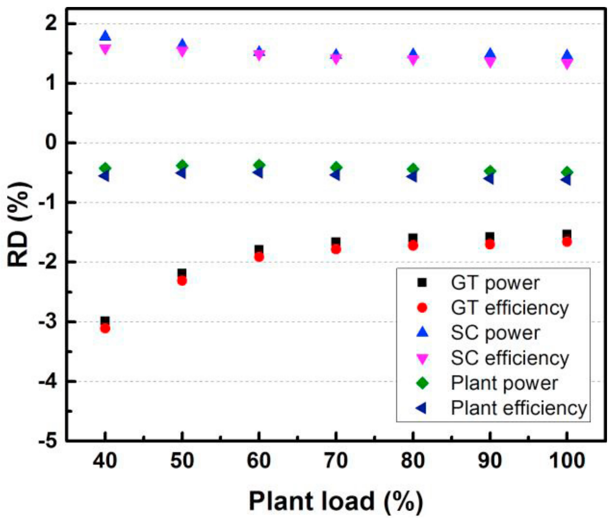

Fig. 4. Relative deviations for the power outputs and efficiencies of the GT, SC, and CCGT plant.

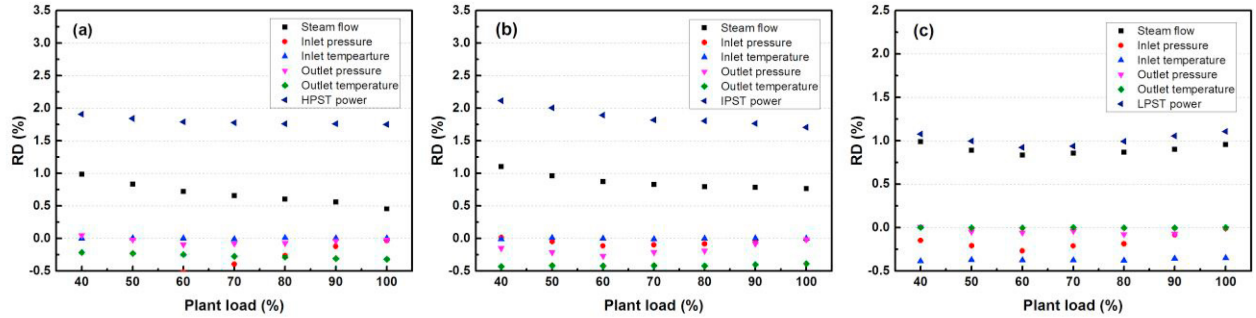

Fig. 5. Relative deviations for the operating parameters of HPST (a), IPST (b), and LPST (c).

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