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Alternative approach to teach gas turbine based power cycles

Dr. Farshid Zabihian, West Virginia University Inst. of Tech.

Farshid Zabihian, Ph.D. Assistant Professor Department of Mechanical Engineering West Virginia University Institute of Technology

Education: Ph.D., Mechanical Engineering,Ryerson University, 2011 M.S. Mechanical Engineering, Iran University of Science and Technology, 1998 B.S. Mechanical Engineering, Amir Kabir University of Technology, 1996

Authored or coauthored more than 70 papers in Journals and peer-reviewed conferences.

ALTERNATIVE APPROACH TO TEACH GAS TURBINE BASED POWER CYCLES

Farshid Zabihian

West Virginia University Institute of Technology

Montgomery, West Virginia, U.S.A

ABSTRACT

This paper presents the new approach in teaching Applied Thermodynamics in general and gas turbine cycles in particular to undergraduate mechanical engineering students through the integration of a simulation and modeling software to teaching gas turbine based cycles.

Students developed several simple models and conducted sensitivity analysis and interpreted the results through modeling. First, they are asked to find various properties of a stream using the software and compare them with the values they found from the conventional thermodynamic tables. In this step students learn how to retrieve stream properties and how to validate them. Then, they develop a cycle composed of a compressor followed by a gas turbine. In this stage, they learn how to define characteristics and specifications of components in the model. Also, they experience the influences of these specifications on the performance of the equipments. As a next step, they add a combustion chamber to the model to make a complete model of a sample gas turbine cycle. As a part of this step they calculate the net output power, specific work, and efficiency of the cycle. They utilize this model to evaluate effects of the compressor pressure ratio, turbine inlet temperature, ambient temperature and pressure, efficiency of compressor and turbine, and pressure drop in the combustion chamber on the system overall performance parameters including output power, specific work, and efficiency of the cycle. Eventually, some students worked on this model and combined it with other cycles to make a hybrid cycle or other cycles as their projects.

INTRODUCTION

When the author started to teach Thermodynamics, he realized that the teaching methods for thermodynamics have not been changed much since he took the course himself about 20 years ago. So he started to look for other resources and teaching methods. He reviewed and evaluated 25 thermodynamics textbooks covering 1963 - 2013 [1-25]. Great majority of them are using the same teaching approach. Only two of them are taking advantages of computational tools [9, 11].

Three relatively new techniques in teaching are as follows:

CONCEPTUAL-BASED LEARNING VS. CALCULATION-BASED LEARNING

The responsibilities of engineers are usually designing systems. In majority of cases, the design process involves some sort of calculation. That is why traditionally engineering education heavily emphasized the calculation techniques. Until 90s this approach was reasonable and perfectly fitted the requirements of industry. But in the past couple of decades, the applications of computational tools have made a major shift in the industry. Engineers no longer do complicated calculation manually. They just need to design configuration of systems, identify and input data to software, and more importantly analysis and validate the results. This process requires conceptual understanding of topics, skills in using the software, and analysing the results.

For example, when teaching steam cycles, students do not need to be taught how to do the calculation for open and closed feed-water heater, reheater, superheater, economizer, etc. They only need to learn simple steam cycle calculation and how each of these components affects the performance of the cycle. Then, they need to know how to develop the models to simulate these cycles and evaluate the effects of various parameters.

SYSTEM LEVEL VS. PROCESS LEVEL LEARNING

Traditionally teaching thermodynamics starts with definition of terminology followed by how to find thermodynamics properties e.g. property tables, ideal gas calculation, and property relation for fluid and solid. Then, the concept of heat and work are introduced followed by conservation laws, including the conservation of mass and the first and second laws of thermodynamics. These laws are all presented for processes rather than systems.

When the foundation of thermodynamics laid out, these fundamentals are applied in the system level to teach thermodynamics cycles.

In the system level learning, these concepts are presented in the reverse order.

TRADITIONAL TEACHING VS. PROBLEM/PROJECT-BASED TEACHING

In traditional teaching, first a concept is presented and then examples, problems, and projects based on the presented topic are presented. In the problem/project based teaching, first a problem/project is introduced and then the skills needed to solve the problem are developed.

INTEGRATION OF PROCESS MODELING SOFTWARE TO APPLIED THERMODYNAMICS

The combination of three aforementioned methods, namely conceptual learning, system level learning, and problem/project-based teaching has led the teaching approach presented in this paper. A commercial process modeling software is utilized to deepen student understanding of the gas turbine-based cycles and evaluation of effects of various parameters on the cycle performance. In this course, Aspen Plus is used for this purpose.

FIRST ASSIGNMENT

Students are first introduced to the software and learn how to work with it through several step by step tutorials.

SECOND ASSIGNMENT

The objective of this assignment is to teach students how to extract thermodynamics parameters from the software. Also, students are asked to find same properties from their textbook and compare them with what they found from the software. They realize that the values of some parameters, such as density, are the same regardless of the source of information i.e. their textbook or the software. But for some properties, such as enthalpy and entropy, they find totally different values. At this point, I ask them to compare the values of the enthalpy and entropy difference between two states found from the tables and the software. The students can see firsthand that the differences are the same because the two methods are just using different reference points to report the properties.

THIRD ASSIGNMENT

The objective of this assignment is to investigate the effects of pressure and temperature of various thermodynamics parameters of the streams. They develop two simple models. One model includes a simple pressure change device e.g. half-closed valve. The temperature of the flow is constant and only the pressure changes. Students are supposed to find the effects of pressure on the specific volume, enthalpy, and entropy at constant pressure and draw the diagrams of these properties as a function of pressure. The different student teams will be assigned with various substances e.g. water, ammonia, carbon dioxide, etc.

The other model will include a simple heat exchanger with no pressure drop. The students will perform the same analysis but for independent variable of temperature at constant pressure. They also validate their results using the tables from the textbook.

FOURTH ASSIGNMENT

At this point, the students are ready to integrate various components in their modeling. In this assignment, I ask students to develop an Aspen Plus® model for a compressor followed by a turbine with the following specifications. They are supposed to run their model and report the results for the following three cases with different inlet flows to the compressor and two sets of efficiencies for the turbine and the compressor.
The objective of this assignment is to investigate the effects of equipment characteristics on the performance of the system. They also recognize the significant impact of the efficiencies of the turbine and the compressor on the overall performance system.

In order to improve their communication skills, I ask them to prepare a technical report for each assignment. The report should be prepared based on the technical report preparation guideline that I give them and should include:

- A table showing all main information of all streams for each case,
- A table showing all main information of turbine and compressor,
- The net work and efficiency of each system,
- A comparison of the results for cases 1 and 2,
- Discussion on the results.

Compressor:
Type: Isentropic
Pressure ratio (P_2/P_1): 10
Isentropic efficiency: 80% and 90%
Mechanical efficiency: 75% and 85%

Turbine:
Type: Isentropic
Pressure ratio (P_1/P_2): 10
Isentropic efficiency: 80% and 90%
Mechanical efficiency: 75% and 85%
Three cases for compressor inlet:

Case 1:
Stream composition (mass fraction): air 100%
Temperature: 40°C
Pressure: 1 atm (absolute)
Mass flow rate: 100 kg/s

Case 2:
Stream composition (mass fraction): N_2 79%, O_2 21%
Temperature: 40°C
Pressure: 1 atm (absolute)
Mass flow rate: 100 kg/s

Case 3:
Stream composition (mass fraction): water 100%
Temperature: 400°C
Pressure: 10 atm (absolute)
Mass flow rate: 100 kg/s

For Properties/Property methods and models the students use following information:
Process type: POWER
Base method: PR-BM

FIFTH ASSIGNMENT

This assignment is similar to the previous one but in this one a chemical reaction i.e. combustion is added to the cycle. This is the first time that the students develop the model of an actual system.

In this assignment, the students are asked to develop an Aspen Plus® model for a simple gas turbine cycle consists of a compressor followed by a combustion chamber and a gas turbine with the following specifications. They are supposed to run their model and report the results for the following two cases with different inlet fuels. The report should be a professional one and should include:

- A table showing all main information of all streams for each case,
- A table showing all main information of the equipment,
- LHV and HHV of the fuel for each case,
- Efficiency (based on LHV and HHV) and net work production of the cycle,
- A comparison of the results for cases 1 and 2,
- A comparison of the results for case 2 with the operational values from the Whitby cogeneration power plant at the same conditions: Output power 58 MW, GT exhaust temperature 431°C (find the errors and explain any possible sources for the errors),
- Discussion on the results.

Compressor:
Type: Isentropic
Pressure ratio (P_2/P_1): 33.7
Isentropic efficiency: 80% and 90%
Mechanical efficiency: 75% and 85%

Turbine:
Type: Isentropic
Pressure ratio (P_1/P_2): 32.1
Isentropic efficiency: 80% and 90%
Mechanical efficiency: 75% and 85%

Two cases for the inlet fuel:

Case 1:
Fuel pure methane

Case 2:
Fuel with following composition:

Air inlet stream:
Temperature: 10°C

Pressure: 100.232 kPa (absolute)
Mass flow rate: 158.2 kg/s
Stream composition (mass fraction): N_2 79%, O_2 21%

Fuel inlet stream:
Temperature: 68°C
Pressure: 55.5atm (absolute)
Mass flow rate: 10,793 kg/h
Stream composition (mass fraction): case 1 and case 2.

As stated, the students should compare the results of their model with the performance data of an actual cycle from the Whitby cogeneration power plant. They also report on the sources of the discrepancy between modeling results and actual data. As a part of this step they calculate the net output power, specific work, and efficiency of the cycle. They utilize this model to evaluate effects of the compressor pressure ratio, turbine inlet temperature, ambient temperature and pressure, efficiency of compressor and turbine, and pressure drop in the combustion chamber on the system overall performance parameters including output power, specific work, and efficiency of the cycle.

PROJECTS

The assignment five is the last uniform assignment for whole class. Beyond this point the students should form a team and choose a project from the following list. They may also suggest their own topic for the project.

- Modeling of a gas turbine-based cogeneration cycle: exergy analysis.
- Modeling of a combine cycle power plant (CCPP): exergy analysis.
- Modeling of a gas turbine-based cogeneration cycle: effect of the compressor inlet air cooling system.
- Modeling of a combine cycle power plant (CCPP): effect of the compressor inlet air cooling system.
- Experimental and numerical analyses of the micro gas turbine.
- Modeling of ocean thermal energy convertors (OTEC).
- Modeling of geothermal systems.
- Modeling of an Organic Rankine Cycle (ORC).
- Modeling of a gas turbine cycle: exergy analysis.
- Modeling of hybrid tubular solid oxide fuel cell (SOFC) and gas turbine cycle
- Modeling of an Integrated Gasification Combined Cycle (IGCC).
- Modeling of air separation units.
- Modeling of CO_2 capture units.
- Modeling of Oxyfuel power plants.

SAMPLE PROJECT

In one of these projects, the students studied the combined cycle power plant (CCPP) modeling when the ambient temperature is varying. The model of the CCPP was developed using a gas turbine and a heat recovery steam generator (HRSG) models that had been already developed and validated. The model of the components was developed based on an actual existing power plant and then the operational data of the power plant was used to validate the model. The results of running the model for various ambient temperatures demonstrated that the performance of the gas turbine part of the cycle was heavily affected by the changes in the ambient temperature, particularly the output power of the gas turbines. However, the performance of the steam cycle was almost untouched by the changes of ambient temperature. This suggested that operation of the CCPP is more stable than stand-alone gas turbine in hot summer days especially if the cycle is not equipped with an inlet air cooling system [26].

In order to develop the model of the combined cycle power plant (CCPP), first a model of a gas turbine was developed (Figure 1).

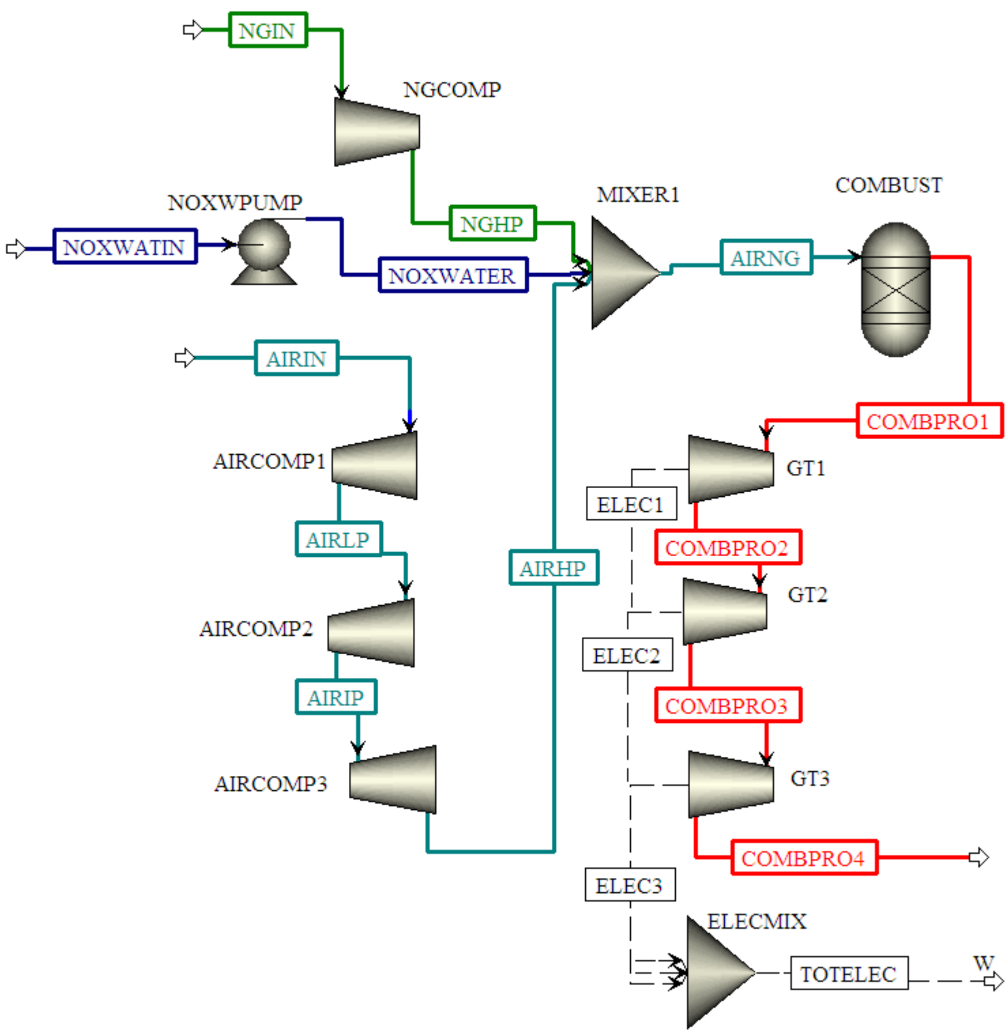

Figure 1: Schematic of a simple gas turbine cycle model

This model then was validated against the data collected from operation of the actual gas turbine system. This model and its validation along with the important thermodynamic properties and operational parameters have been presented elsewhere [27, 28].

The next step was to add a heat recovery steam generator (HRSG) to the bottom of the cycle and again validate the model. The results of this step were presented elsewhere [27].

The final step was to develop the complete model of the CCPP. Figure 2 illustrates the model of the CCPP cycle developed for this project. The model was run with the ambient temperature range from 5 degrees Celsius to 45 degrees Celsius, with 5 degree increments. Table 1 shows the power produced by the gas turbines and steam turbines along with the power consumed by air and natural gas compressors.

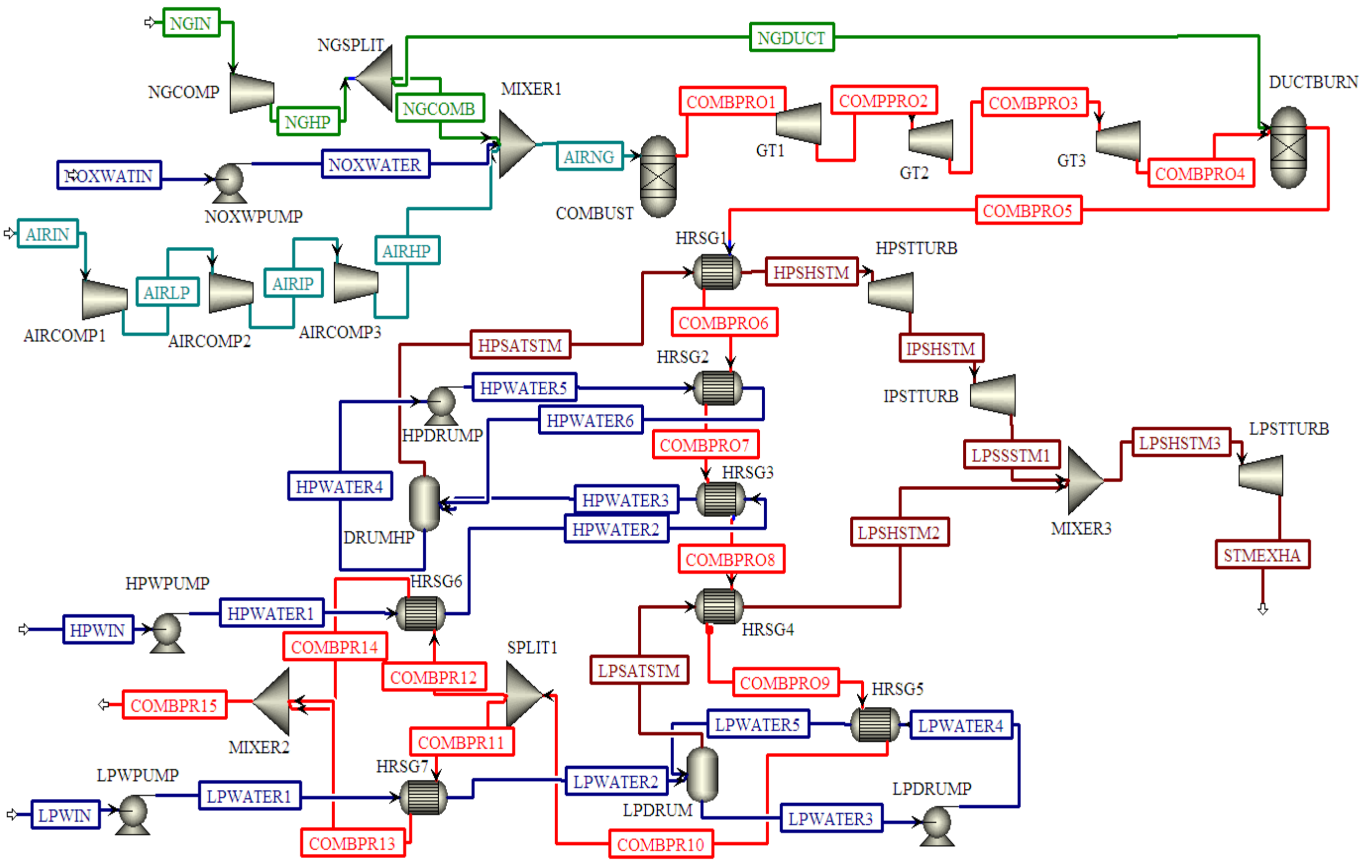

Figure 2: Schematic of an Aspen Plus® model of a two-pressure CCPP

Table 1: Power produced by the gas turbines, steam turbines, and entire system along with power consumed by air and natural gas compressors at each temperature

Ambient Temp. (◦C)	Power Output of Gas Turbines (MW)	Power Output of Steam Turbines (MW)	Power Consumption of Compressors (MW)	Net Total Power Production (MW)
5	163.38	20.77	100.62	83.53
10	160.23	20.77	100.52	80.48
15	157.19	20.77	100.41	77.55
20	154.26	20.77	100.31	74.72
25	151.42	20.77	100.20	71.99
30	148.69	20.77	100.10	69.35
35	146.04	20.77	99.99	66.81
40	143.48	20.77	99.89	64.36
45	141.00	20.77	99.78	61.99

DISCUSSION

This alternative approach to teaching gas turbine based power engines to undergraduate students seem to be effective and engaging.

In this course, I also use active learning method. In this teaching methodology, unlike traditional methods, students are not just passive listeners. Before each session, students are assigned a section of the textbook. They must read the assigned section and come to class prepared. In the beginning of each class, there is a quiz related to the assigned reading. Then, there is discussion on the questions in the quiz. During this discussion, the concept related to the topic(s) of the day is reviewed. Depending on the topic, there may be a numerical problem(s) that is attempted by the students and instructor. Finally, the class is concluded by a quiz related to the material covered in the class.

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