MAE110A Design Project

Due March 7, 2014

You are asked to design a solar thermal power tower plant located in Imperial Valley, California. Turbines have isentropic efficiencies of 85%, and compressors have isentropic efficiency of 81%. The average solar irradiance over the day (06-22-2000) is 388 W m^{-2} (Fig. A1).

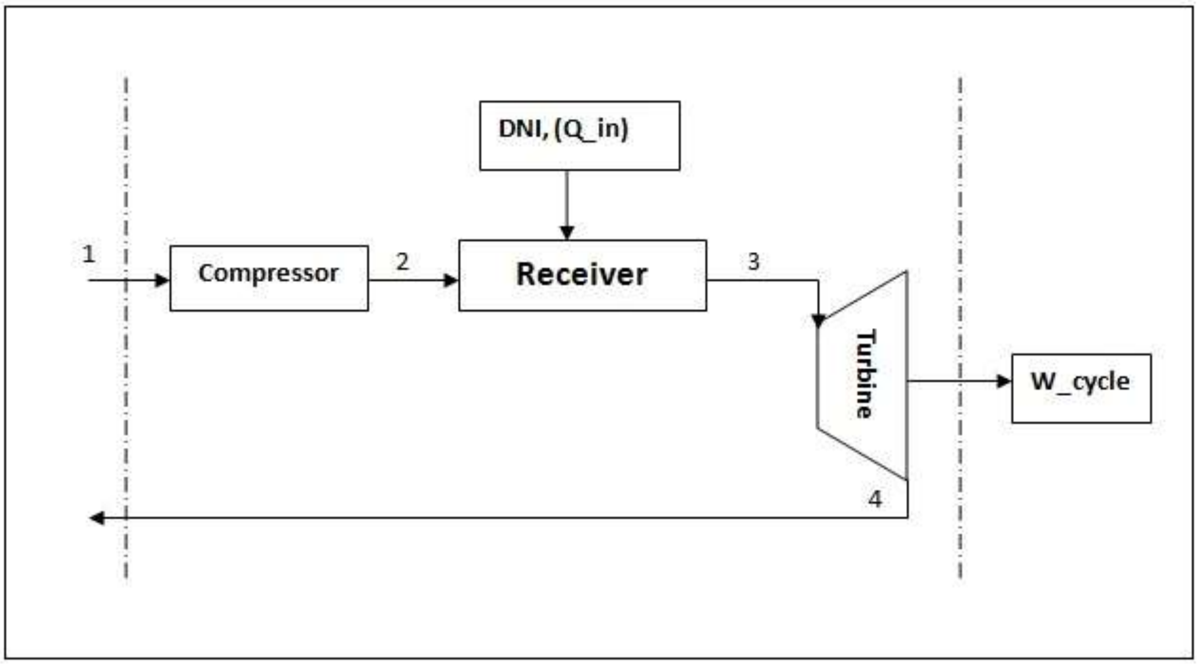

Figure 1. The Brayton cycle for solar thermal tower power system

1. **(part of Homework 7)** Start by considering the simple power cycle in Fig. 1. Assume i) heat exchange occurs at constant pressure; ii) kinetic and potential energy effects are negligible; iii) The working fluid is air modeled as an ideal gas, iv) solar mirrors (heliostats) have conversion efficiencies of 87%. The inlet air is ambient air with the following properties, T1=290 K, P1=100 kPa. At the other states: T4=900 K, P4=100 kPa, Mass Flow=330.6 kg/s. The compression ratio of the Compressor (P2/P1) is 4.5: 1. In order to achieve 100 MW power output, determine the necessary surface area for heliostats. Compute the efficiency of the power cycle.

2. Improve the design to achieve a power cycle conversion efficiency of at least 36%. Explore either one (but not both) of the following options
   a. **Add a heat regenerator with an efficiency of 89% and recompute the power cycle efficiency.**
   b. **Surface area / power plant size**: Consider increasing the size of the heliostat field. However, individual mirror efficiency changes as a function of mirror angle and distance to the central tower. With the same optical design accuracy, mirrors farther away from the central tower reflect a smaller portion of sunlight onto the receiver. For this project, assume that as distance from the central tower increases, efficiency of individual heliostats decreases as

$$\eta_i = 0.9 \qquad r \le 0.5 \text{ km}$$
$$\eta_i = C exp(-\tau r) \qquad \text{Otherwise}$$

Here, *r* is distance from the power tower in km, C = 6.75, and τ = 4 km^{-1}**. Plot η_i as a function of *r***. Q_{in} should be calculated as the sum over all mirrors of the irradiance *I* times the area *A* and efficiency of each mirror. To simplify the calculation, use $Q_{in} = IA\eta_{eff}$, where

$$\eta_{eff} = \frac{C \int r\exp(-\tau r)dr}{\int rdr}$$

Plot the effective heliostat efficiency η_{eff} against r (hint: If you cannot solve the integral use $\eta_{eff} = \frac{C}{(\tau r)^2}[1-(1+\tau r)\exp(-\tau r)]$). **Find Q_{in} and plot. Finally, determine how the power cycle efficiency (η_{cycle}) changes as a function of *r*. What is the minimum area necessary to achieve maximum η_{cycle}? Compare η_{cycle} against the Carnot efficiency. What is the minimum array area necessary to produce W_{net} > 0? What are the advantages and disadvantages of a large system?**

Next, consider that larger power plants are more expensive. For this application, the cost function is given by $cost = 1000 + 150r^2$, where r is in km and cost is in US$ Million. **Determine the lowest ratio of cost to W_{net}. For this point, calculate η_{eff}, W_{net}, and any other potentially useful information. If the power plant were to be paid off in 15 years, how much should be charged per kW-hr over operating costs?**

For this problem, include all relevant plots from each step as a function of *r* or *A*.

3. Discuss how the **variability of solar irradiance** over the day (Fig. A1) affects the operation of the power plant. Specifically, discuss performance, environmental, and grid integration issues and make recommendations for addressing these issues.

Please review the sample and grading rubric on the course website. As usual follow the standard homework format. In addition:

- State objectives and describe background
- Show the cycle on a T-s and p-v diagram with respect to saturation lines
- Discuss results (with reasoning and verification). This should be more extensive than in homework problems (at least 1 paragraph).

Appendix

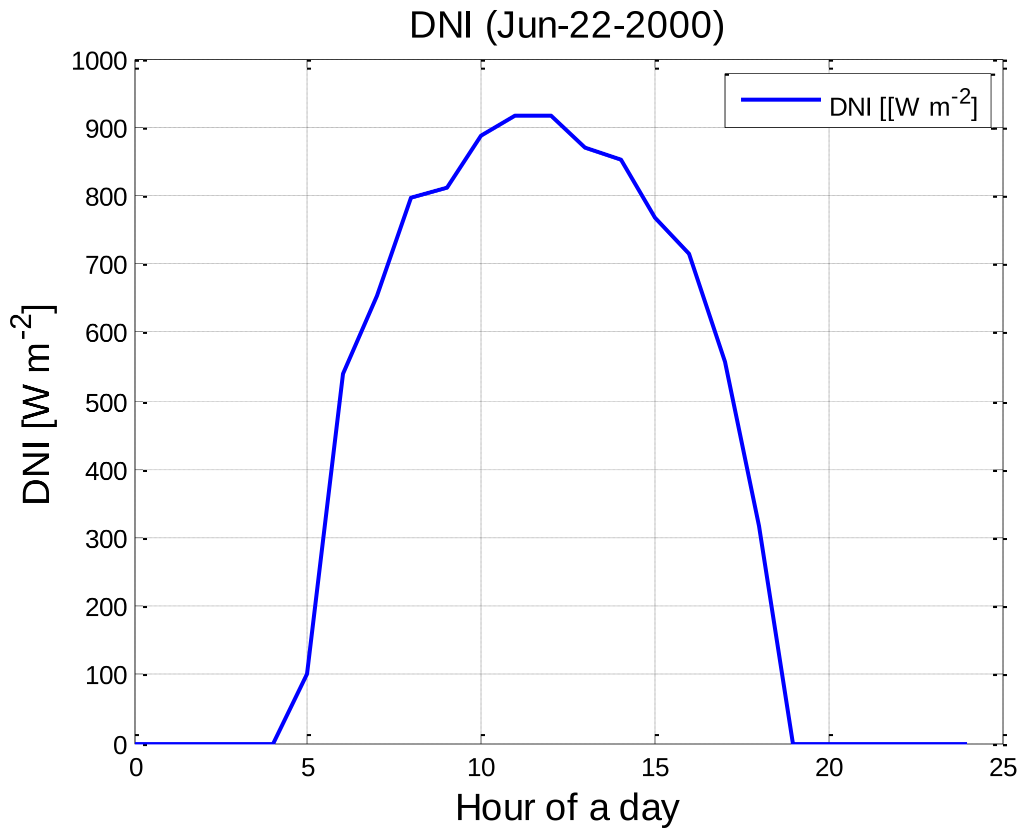

Figure A1. Direct Normal Irradiance on June 22, 2000 in the Imperial Valley (Lat: 32.7772 N, Lon: -115.8194 W).