Electric Power Markets **Spring 2023** **ENV 717**

Nicholas School of the Environment Duke University

Assignment # 10 - Solution

1. (25%) Develop a Transmission constrained Economic Dispatch Model in Python Pyomo to solve problem 6.6. of the textbook. Submit a knitted HTML file to SAKAI.

See Python Notebook in the Github repository of the course.

2. (30%) Read Chapter 7 of the textbook and solve problems 7.1 (5%), 7.2 (5%), 7.3 (5%), 7.4 (10%) using the method presented in the Book. How does this approach compare to the LCOE methodology proposed by NREL in the ATB? (5%).

See Excel file "ENV_717_A10_Q1_Solution" for calculations.

7.1. Calculate the IRR for an investment in a 400MW power plant with an expected life of 30 years._The plant costs 12000 $/kW to build and has a heat rate of 9800 Btu/kWh. It burns a fule that costs 1.10 $/MBtu. On Average, it is expected to operate at a maximum capacity for 7446 h per year and sell its output at an average price of 31 $/MWh. What should be the average price of electrical energy if this investment is to achieve a minimum acceptable rate of return (MARR) of 13%.

IRR = 12.14%. For an investment is to achieve a MARR of 13%, the average price of electrical energy should be 32.28 $/MWh

7.2 What would be the Internal Rate of Return of the unit of Problem 7.1 of the utilization rate drops by 15% after 10 years and by another 15% after 20 years.

IRR would be 11.36%

7.3 What would be the IRR of the unit of Problem 7.1 if the price of electrical energy was 35 $/MWh during the first 10 years of the expected life of the plant before dropping to 31 $/MWh? What would be the value to the IRR if this price was 31 $/MWh during the first 20 years and 35 $/MWh during the last 10 years. Compare these results with the IRR calculated in problem 7.1 and explain the differences.

In the first case (price of electrical energy was 35 \$/MWh during the first 10 years of the expected life of the plant before dropping to 31 \$/MWh) the IRR would be 14.13% if the.
In the second case (the price of electrical energy was 31 \$/MWh during the first 20 years and 35 \$/MWh during the last 10 years), IRR would be 12.33%.

When we compare these IRRs with Problem 7.1, we can see that IRRs both in cases are higher than the IRR in 7.1. This is because in 7.3, we have higher electricity prices for 10 years. In Problem 7.1, electricity price was always 31 \$/MWh. This means higher revenues and higher IRR values.

When we compare Case 1 vs Case 2 in 7.3, we can see that the IRR in the first case is higher. This happens because we have higher electricity prices in the first 10 years; while in the second case, we have higher electricity prices in the last 10 years. Since the value of money changes over time, higher net income in the first years increases the value of the IRR.

7.4 In an effort to meet its obligation under the Kyoto agreement, the government of Syldavia has decided to encourage the construction of renewable generation by guaranteeing to buy their output at a fixed price of 35 \$/MWh. Greener Syldavia Power Company is considering taking advantage of this program by building a 200-MW wind farm. This wind farm has an expected life of 30 years and its building cost amounts to 850 \$/kw. On the basis of an analysis of the wind regime at the proposed location, the engineers of Greener Syldavia Power Company estimate that the output of the plant will be as shown in the table below:

Output as a fraction of capacity (%)	Hours per year
100	1700
75	1200
50	850
25	400
0	4610

Given that the Greener Syldavia Power Company has set itself a Minimum Acceptable Rate of Return of 12%, should it take the government's offer and build this wind farm?
The IRR for this project is 12.49%. Greener Syldavia Power Company should take advantage of the government's offer and build this wind farm because its MARR (12%) is below the IRR.

<u>Comparison of this approach with LCOE method of NREL in ATB</u>

According to NREL, the Levelized Cost of Energy (LCOE) is a metric that uses capital costs, operational costs, and capacity factor. LCOE can be used to estimate the cost of generating one unit of electricity of different technologies. It accounts for the energy part of the electricity grid planning and operation activities. However, LCOE may not be suitable to compare different technologies as it does not take into consideration some important parameters that are different between different types of generators[1]. NREL calculates LCOE as[2]:

$$LCOE = \frac{FCR \times CAPEX + FOM}{CF \times 8{,}760\ hours/year} + VOM + FUEL$$

where,

FCR = Fixed charge rate
CF = Capacity factor
CAPEX = Capital expenditures
FOM = Fixed operation and maintenance cost
VOM = Variable operation and maintenance cost
FUEL = Fuel cost

The LCOE approach includes some variables that are considered in the IRR calculation of 7.4 such as the capital costs, annual generation (capacity factor), and fuel cost. Additionally, LCOE includes fixed charge rate, fixed and variable operation and maintenance costs, and the IRR approach from the textbook exercise doesn't include it.

Based on the NREL definition and the textbook exercise, there are other differences between both approaches:

- LCOE includes more information than the IRR approach in the textbook.
- LCOE does not include the revenue from electricity sold.
- The IRR approach focuses on estimating the profitability of a project by estimating the cash flow (net income) of a project during a defined period and calculating the rate of return of the cash flow. The rate of return is compared with a minimum rate of return MARR to determine if the project could be profitable.
- LCOE shows how much it cost to generate one unit of electrical energy with a specific technology.

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[1] Source: https://atb.nrel.gov/electricity/2022/definitions#:~:text=Levelized%20Cost%20of%20Energy,operations%20expenditures%2C%20and%20capacity%20factor.

[2] Source: https://atb.nrel.gov/electricity/2022/equations_&_variables

3. (25%) Read the document "Energy Transition in PJM: Resource Retirements, Replacements & Risk" available at https://www.pjm.com/-/media/library/reports-notices/special-reports/2023/energy-transition-in-pjm-resource-retirements-replacements-and-risks.ashx
   a. (5%) What is the energy transition increasing reliability risk?

      The amount of generation resources retiring is much more certain than the timely arrival of new generation resources (most of which being renewables) and demand response. Hence, the energy transition poses an increasing reliability risk.

   b. (5%) How serious is this risk?

      It is a pretty serious risk because if PJM doesn't effectively correct the imbalances brought on by retirements, load growth, timely introduction of new generation, it would be in a position to shed the load or increase LOLE, both of which are very bad economically.

   c. (5%) Is a "Low New Entry" scenario overly pessimistic or realistic? Why?

      It is realistic because we'd need to take into account the mismatch in timing of generation assets that are retiring and incoming. While there is certainty on the retirement of generation assets, there is no certainty on the incoming assets due to the size of the interconnection queue and the long time a project takes to clear the queue. Despite the sizable capacity of the interconnection queue (290 GW for renewables), the rate of completion of these projects is very low (5%). Hence, the "Low New Entry" scenario is realistic.

   d. (5%) What are potential actions that PJM can take to reduce reliability risk?

      It is critical that all PJM markets effectively correct imbalances brought on by retirements or load growth by incentivizing investment in new or expanded resources. Such an asymmetrical pace in the energy transition also underscores the need to enhance the accreditation, qualification and performance requirements of capacity resources.

   e. (5%) Make a list of at least 3 concepts (e.g., "Resource Adequacy") mentioned or presented in the document and explain them.

      Resource adequacy: the ability of the electric system to supply the aggregate energy requirements of electricity to consumers at all times, taking into account scheduled and reasonably expected unscheduled outages of generation and transmission facilities.
      Installed Reserve Margin (IRM): the percent of aggregate generating unit capability above the forecasted peak load that is required for adherence to meet a given

adequacy level. IRM is expressed in units of installed capacity (ICAP). The PJM IRM is the level of installed reserves needed to meet the ReliabilityFirst criteria for a loss of load expectation (LOLE) of one day, on average, every 10 years.
Loss of Load Probability (LOLP): the probability that the system cannot supply the load peak during a given interval of time, has been used interchangeably with LOLE within PJM. LOLE would be the more accurate term if expressed as days per year. LOLP is more properly reserved for the dimensionless probability values. LOLP must have a value between 0 and 1.0.

4. (20%) There is an ongoing process to reform PJM's capacity market to address the high reliability risk posed by the energy transition and the generation outages observed during storm Elliot during the 2022 Christmas. Nevertheless, it is useful to understand how the current market works. A short summary is presented in: https://www.pjm.com/-/media/about-pjm/newsroom/fact-sheets/pjm-capacity-market-promoting-future-reliability-fact-sheet.ashx and a more detailed information is in Manual 18 available at: https://www.pjm.com/-/media/documents/manuals/m18.ashx. Read section 1 of Manual 18 and skim the other sections as needed. Then write a letter to your grandmother (around 1000 words) explaining to her in the simplest possible terms what is a capacity market, what is its purpose and how does it work in PJM. If your grandmother is very knowledgeable on the US electricity markets, has a degree in Energy Economics, or Power Systems, or happens to have worked at PJM or other RTO then please write the letter to your grandfather 😊.

*Optional readings for those interested in learning more about PJMs capacity market:
-Reliability Pricing Model fourth review conducted by the Brattle group in 2018 (https://pjm.com/-/media/library/reports-notices/reliability-pricing-model/20180425-pjm-2018-variable-resource-requirement-curve-study.ashx and the presentation on the fifth review in 2021 https://www.pjm.com/-/media/committees-groups/committees/mic/2021/20210806-special/20210806-item-03-brattle-approach-to-assessing-the-vrr-curve.ashx
-The calculation of the cost of new entry CONE of 2022 https://www.pjm.com/-/media/library/reports-notices/special-reports/2022/20220422-brattle-final-cone-report.ashx
-An ICF report on the results of the last PJM Capacity Market Auction available at: https://www.icf.com/insights/energy/pjm-2023-2024-bra-analysis