EENG 581: Power System Operation and Management
Course Project, Fall 2024
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Course Project

A power utility is experiencing shortage of generation during summer peak load hours. This has resulted in several instances of involuntary load shedding, where multiple load areas (supplying hundreds of customers) have been left de-energized for several hours. Many residents have indicated their frustration during townhall meetings, especially because this summer has been one of the hottest on record. After investigating the matter, a task force formed by the utility concludes that even if the utility increases its main generation capacity, the situation will likely remain unsolved. This is, they argue, due to the long distances between the affected load areas and the main generation resources, coupled with the excessive heat that has negatively affected available line capacities. Hence, the task force recommends that the local network be reinforced by adding generation capacity so that it can operate as a standalone network, i.e., a microgrid, during summer months. As a result, the utility has now issued a request for proposal (RFP) and your company (come up with a cool name!) is planning to submit one.

A successful proposal must be able to achieve electrification with the lowest cost and least environmental and social consequences. It should provide a design, along with justification, and proof-of-concept simulation results. A literature review is not necessary but may be provided if your team believes that it helps your proposal.

Your options include:

- Installing new distributed generation resources in the network,
- Installing new or redundant overhead lines,
- Recommissioning the decommissioned coal-fired power plant,
- Implementing a demand response program to provide demand flexibility,
- Implementing localized (and perhaps rotating) load shedding.

System Description

Figure 1 illustrates the schematic diagram of the system under study[1]. The rated line-line system voltage is 24 kV_{rms}. For simplicity, assume that all lines are three-phase overhead conductors, with per phase resistance and reactance of 1.90 Ω/mile and 1.40 Ω/mile, respectively. For the purposes of this project, you can ignore the shunt impedances, i.e., use the short line model. The distances between nodes can be determined from the map. Table 1 lists the number of customers connected to each node along with their average corresponding load profile. You can use this information to estimate the total hourly demand at each node. Divide those customers equally among the three phases so that your system becomes as balanced as possible. For this project, you can model loads as *constant power*[2]. Line capacities for the different sections of the network are provided in Table 2. It can be seen that the system is under-designed because under peak conditions, some line sections may become overloaded. So far, the utility has been operating under those conditions, but the task force has identified this practice as one of the reasons behind the frequent outages.

The overlay of the distribution grid with the census tracts is provided in Fig. 2, with the relevant information on the tracts listed in Table 3. Note that tract data categories are listed for the purposes

[1] This is a modified version of the IEEE 34-bus test distribution system.
[2] For reactive power, assume that all loads operate with a power factor of 0.9 lagging.

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of this project, and not all categories are reported in US Census. Further, tract IDs and the corresponding attribute values are based on simulated data and do not reflect any actual location.

Table 4 lists the costs for various options and Fig. 3 illustrates the wind profiles. Data about the wind profiles and hourly solar irradiance are provided in the accompanying Excel file. Notice that a decommissioned transmission line exists between the decommissioned coal-fired power plant and the center of the network. Figure 4 illustrates the topography and land classification of the local area. A river is also available as a potential source of energy. The cross-sectional area of the river is 80 m^2, and during summer months, the water speed averages at 2 m/s. State regulations do not allow the installation of a reservoir-based plant, but a run-of-river plant may be installed.

You also have the option to implement demand response or variable energy pricing. However, price elasticity level is not known from historical data, and you would need to make assumptions by consulting the literature.

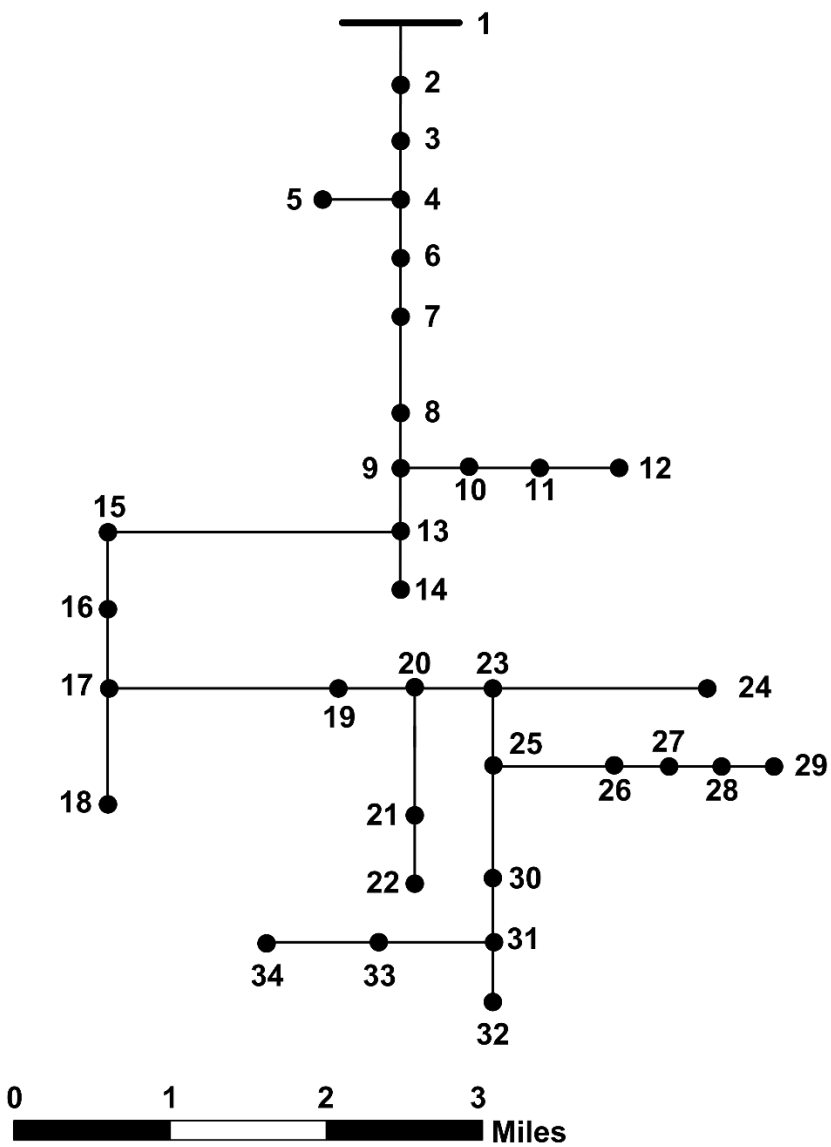

Fig. 1. Schematic diagram of the system under study.

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Table 1. Characteristics of customers connected to each node.

Node	No. of Customers	Dominant Demand Profile per Household
1	150	5
2	200	5
3	200	5
4	200	5
5	150	5
6	100	1
7	90	1
8	100	1
9	100	2
10	84	2
11	73	2
12	50	2
13	65	2
14	60	2
15	30	3
16	45	3
17	28	3
18	35	3
19	200	4
20	210	4
21	210	4
22	55	6
23	150	2
24	160	2
25	210	2
26	220	4
27	180	4
28	185	4
29	265	4
30	50	6
31	75	6
32	42	6
33	40	6
34	35	6

Table 2. Line capacity (kVA, three-phase value).

Section	Capacity
1 – 13	4,000
4 – 5, 9 – 12	500
13 – 14	200
9 – 13, 13 – 23	2,800
17 – 18	500
20 – 22	1,000
23 – 32	800
23 – 24, 25 – 29	1,100
31 – 34	800

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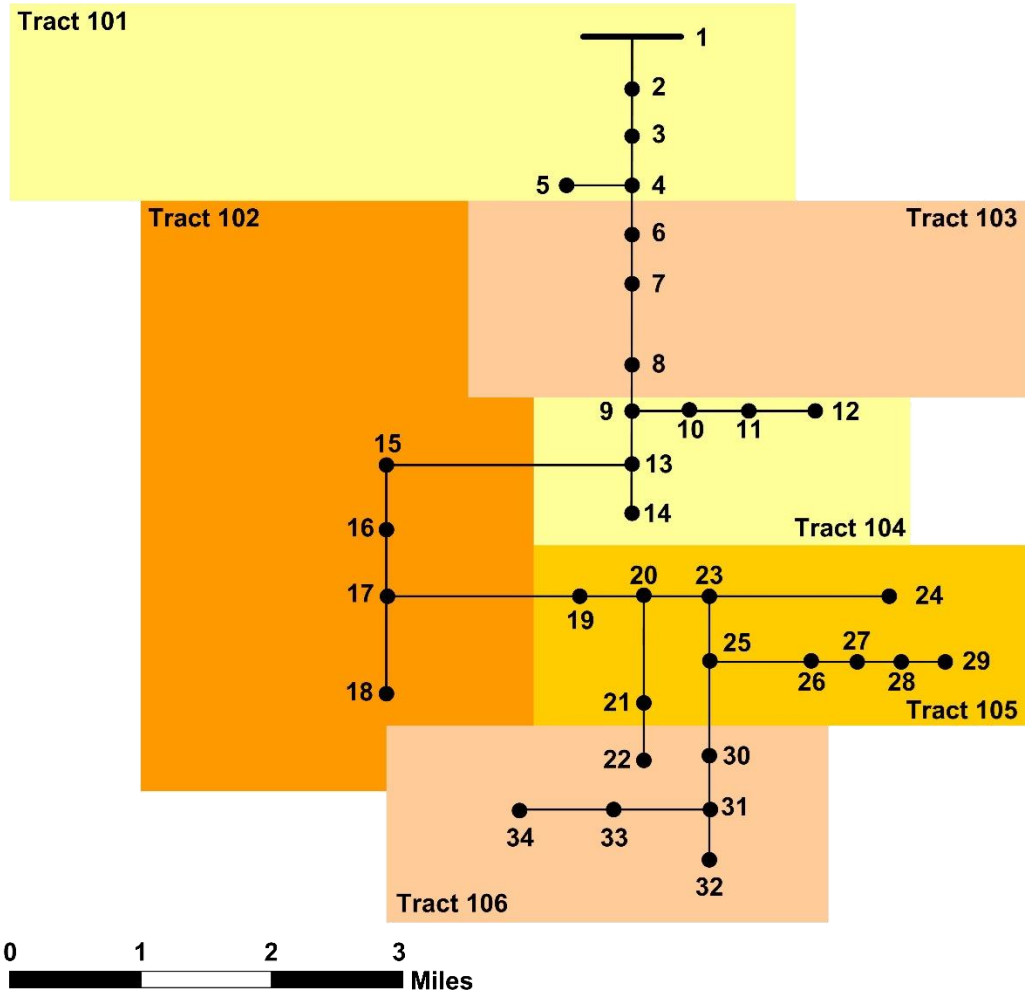

Fig. 2. Overlay of the system under study with US Census tracts.

Table 3. Census tract data.

Tract ID	Population above 65 yrs. (%)	Population below 5 yrs. (%)	Homeownership Ratio (%)	African American Population (%)	Household Median Income ($)	Median Age of Homes (yrs.)	Average House Size (sq. ft)	Average Size of Household
101	12	21	28	48	46,000	52	1,000	6
102	25	10	92	5	178,000	10	4,500	4
103	21	14	56	12	72,000	25	2,500	3.2
104	15	7	44	21	61,000	29	2,100	3
105	5	4	21	63	57,000	66	1,200	2.5
106	20	16	78	8	134,000	28	3,800	4

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Table 4. Cost of various grid reinforcement options (these values are provided for the purpose of this project and may not be accurate for all studies).

Technology	Capital Cost ($/kW)	O&M Cost ($/MWh)
Low-Emission Coal-Fired Plant (new)	3,800	110
Coal-Fired Plant (recommissioning)	Negligible	180
Gas Turbine	700	80
Combined Cycle Power Plant	1,000	60
Nuclear	6,000	150
Wind Turbine	1,600	40
Solar PV (utility scale)	850	40
Hydro	2,500	Negligible
Battery	1,400	Negligible*
Fuel Cell	7,200	150
Line Reinforcement (e.g., reconductor)	200,000$/mile	Negligible
New Line Installment	400,000$/mile	Negligible

*Battery charge/discharge cycles affect its lifetime. Here, it is assumed that the number is embedded into the capital cost.

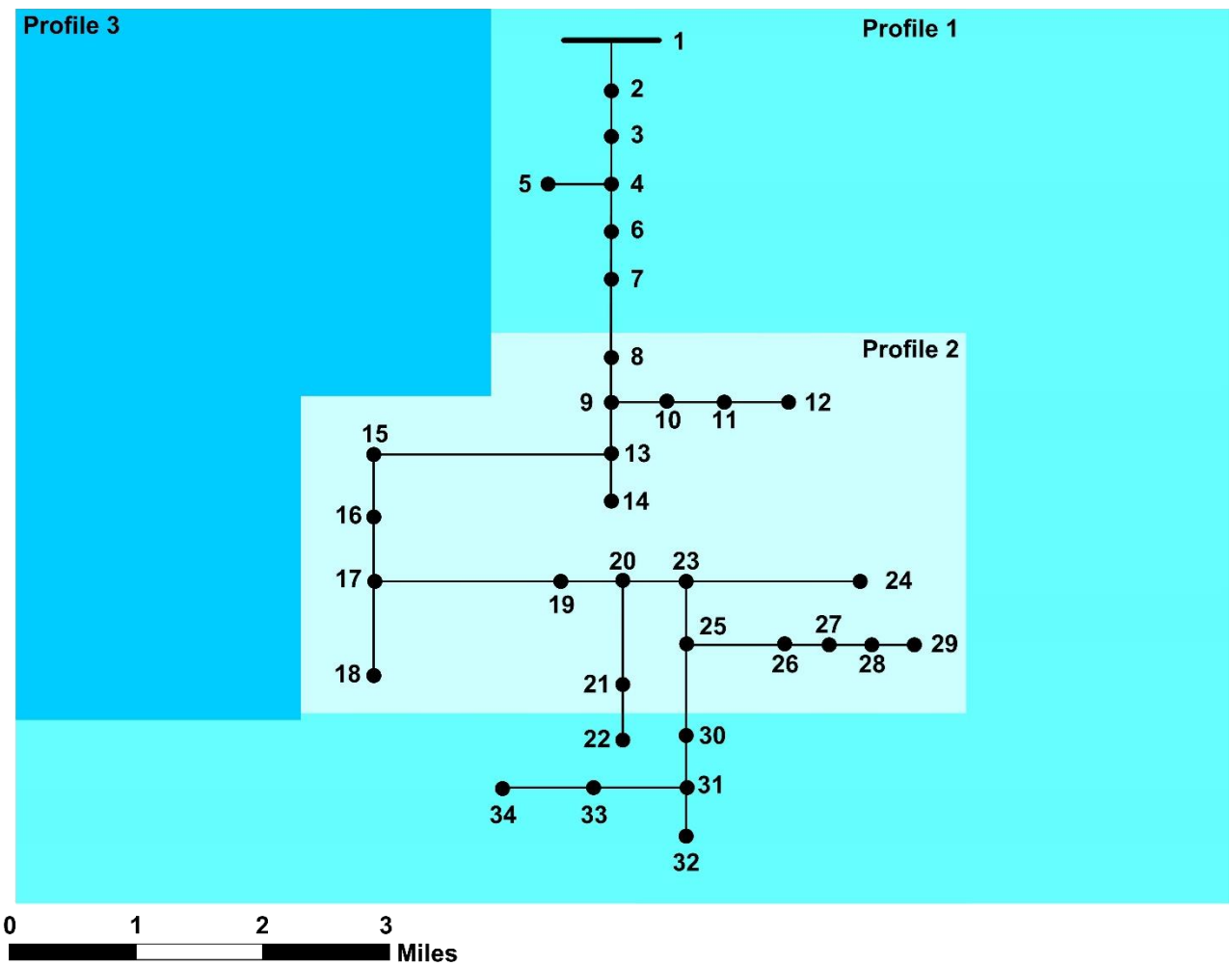

Fig. 3. Wind profiles in the area under study.

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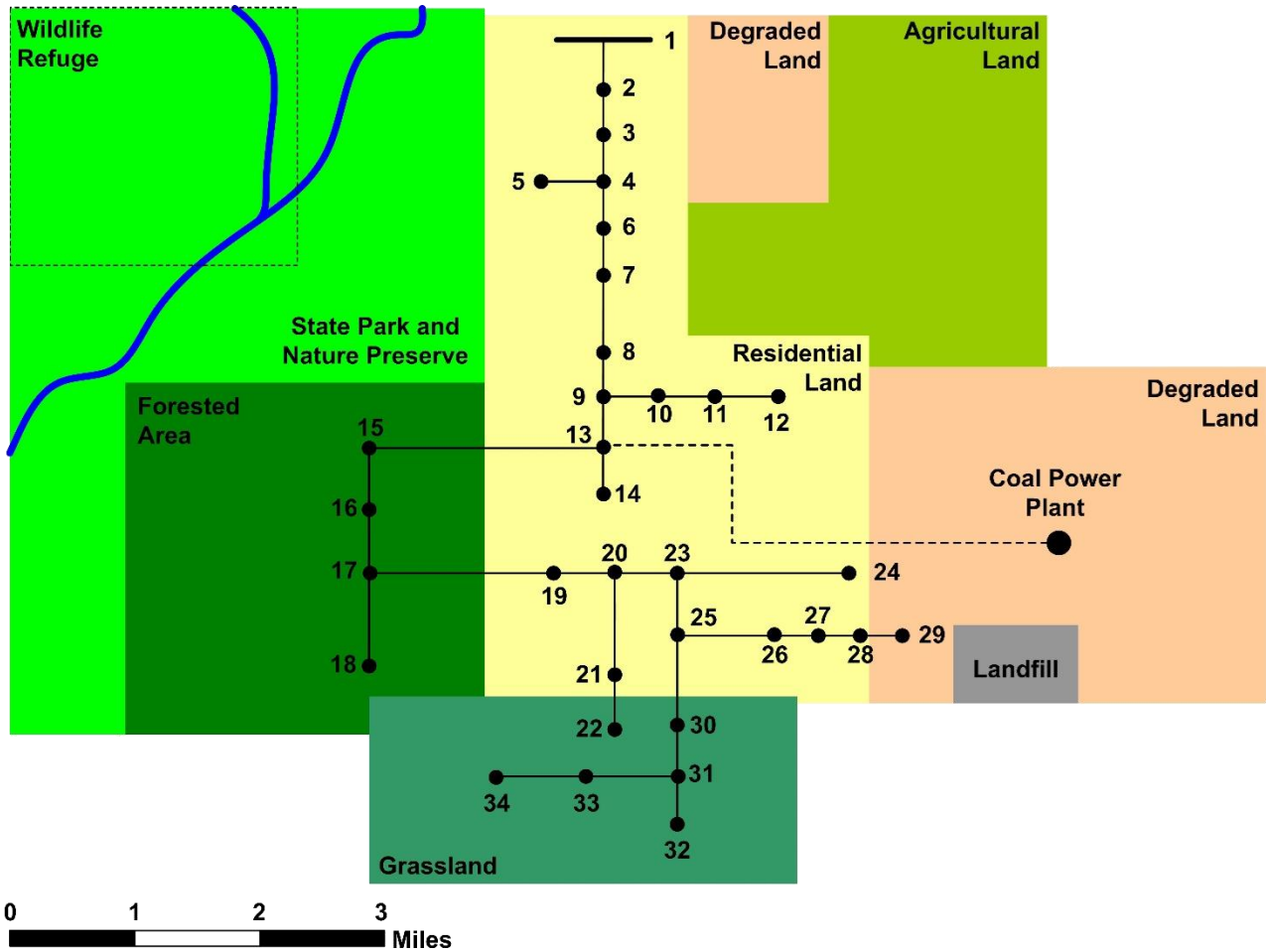

Fig. 4. Land classification of the area under study.

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Phase 1: Design Criteria

Submit a report outlining your design criteria relevant to the problem, justification behind each one (i.e., why it is important and/or relevant), and how you will be modeling them. To model the criteria, think about whether they should be included as an objective function to be minimized or maximized, a penalty factor in the objective function, an equality constraint, or an inequality constraint. One example is provided below for clarification purposes.

Your report must be limited to one page, with Times New Roman font of 11 or larger, providing information in a table as follows[3]:

ID.	Criteria Description (Explain what it is)	Justification (Why is it important or relevant?)	How will this criteria be modeled?
1	Project cost must be minimal	Excessive cost, either during installation or operation, may be unsustainable in the long run	In the form an objective function (cost function) to be minimized within a multi-objective framework

Rubric (total of 25 points):

Category	Points	Full Credit	Partial Credit
Design Criteria	5	At least 5 criteria are considered that cover relevant technical, environmental, and social aspects	Less than 5 criteria are considered and/or they do not properly cover technical, environmental, and social aspects of the problem
Justification	10	Justification provided behind each criterion is comprehensive and detailed	Justification behind one or more criteria is incomplete, pretentious/exaggerated, with not enough detail, or missing important factors
Modeling	5	The proposed approach to model each criterion is reasonable and well-thought-out	The proposed approach to model one or more criteria is not reasonable, practical, or correct
Novelty	5	Criteria identified are novel. Modeling approach is novel. Team demonstrates outside-the-box thinking in their presented justifications	Team's deliverable is reasonable and detailed but is standard and lacks in innovative and outside-the-box thinking in one or more categories

Phase 2: Proposed Design

In this phase of the project, you need to present your design. Your proposal must include the following:

- Technologies/strategies you will adopt,
- Technologies/strategies that you will <u>not</u> adopt,
- Justification behind your choices,
- Relevant locations and capacities (if applicable) associated with your adopted solutions.

The most systematic way to do this would be through solving a multi-objective optimization model, where your design criteria are incorporated in the form of various objective functions and constraints. This way, your solution will be objective and (assuming it has been modeled correctly) will provide the truly optimal design solution. Of course, such an approach can become complex

[3] Include the names of the team members in your report.

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and challenging. Therefore, for the purposes of this course project, your team may instead provide an analysis and a solution based on expert knowledge, qualitative analysis, and/or standalone calculations. For instance, you may decide against an option because your calculations indicate the energy resource to be insufficient or unreliable, causing unwanted side-effects, and/or uneconomical. Such a solution will not be optimal but would be acceptable for this project.

Remember: This is a multidimensional problem. There are different objectives that are at times contradictory to one another, i.e., cost, feasibility, environmental impacts, and social impacts. In such problems, it is impossible to find a solution that achieves all targets – a realistic solution will be a tradeoff between different objectives. What those tradeoffs are is a design decision that you need to make[4].

Your report must be limited to two pages (excluding Appendices), with Times New Roman font of 11 or larger. First, report your analysis in two tables as shown below[5]:

ID	Technology/Strategy Adopted (Generation technology, reinforcement strategy, load control strategy, etc.)	Justification (Why it is considered suitable)
1		
2		

ID	Technology/Strategy <u>Not</u> Adopted (Generation technology, reinforcement strategy, load control strategy, etc.)	Justification (Why it is considered unsuitable)
1		
2		

The rest of your report should reflect your calculations, i.e., at what location the technologies will be implemented and what their size/capacity will be. Make sure you keep your basic calculations within the 2-page limit. Non-essential calculations, graphs, or other supplementary material can be provided in the Appendix.

Rubric (total of 35 points):

Category	Points	Full Credit	Partial Credit
Technologies/ Strategies Considered	5	At least 8 technologies/strategies are considered and at least 4 are chosen	Less than 8 technologies/strategies are considered or less than 4 chosen
Justification	10	Justification provided behind each choice (whether adopted or not) is comprehensive and detailed	Justification behind one or more choices is incomplete, incorrect, with not enough detail, or missing important factors
Location/Size Analysis	15	Locations and sizes of the adopted technologies/strategies are identified based on detailed and accurate calculations and reasonable assumptions	The calculations used to identify the locations/sizes of the adopted technologies/strategies are inadequate, not detailed enough, missing important factors, or incorrect

[4] Realistically, such problems are solved using multi-objective models that are formulated in such a way that they achieve Pareto optimality. This is a solution for which it is not possible to improve one objective without worsening one or more objectives. You may have more than one Pareto optimal solution – these lie on the Pareto front of the problem.
[5] Include the names of the team members in your report.

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Novelty	5	The choices made by the team are innovative and demonstrate outside-the-box thinking	The choices made by the team are mostly standard and common practice

Phase 3: Proof-of-Concept Simulations

The goal of this phase is to show that your solution works. Model the system and the new components in MATLAB/Simulink or PSCAD[6]. You may need to add components such as shunt capacitors and/or voltage regulators to help with reactive power support and maintaining an acceptable voltage profile. If applicable, you may need to implement a mechanism, for instance using controllable switches, for localized demand response or load shedding. Your report must not exceed 4 pages and must include the following[7]:

- A brief description of your modeling approach, no more than ½ page.
- A bar graph indicating the voltages of different nodes (one phase representative per node would suffice). All values must be in per unit. Only provide the graph corresponding to the peak load hour.
- A bar graph indicating the flows (in MVA) through each line section. Only provide the graph corresponding to the peak load hour.
- Graph of active power provided by each generation resource over the 24-hour dispatch period. One graph per resource, values in MW.
- Graph of reactive power provided by each generation resource over the 24-hour dispatch period. One graph per resource, values in Mvar.
- A table indicating the total number of customers without power or under demand response for each hour of the day.
- A table listing the reliability indices as outlined below[8]:
  - SAIFI = total number of power interruptions / total number of customers
  - SAIDI = sum of power interruption durations / total number of customers
  - CAIDI = sum of power interruption durations / total number of customer interruptions
  - CAIFI = total number of power interruptions / total number of customers affected
- Total costs associated with the system, broken down in terms of total capital costs and the O&M costs for 24-hour operation.
- Lessons learned, challenges identified, and recommendations for the utility (for instance, what other information or data sources could have helped your team with your decision-making). No more than ½ page.

Rubric (total of 40 points):

Item	Points
Voltage bar graph is provided and indicates that all node voltages are within ANSI limits during the peak load	5
Line flow bar graph is provided and indicates that all line flows are within limits	5

[6] If your team is interested in modeling the system in PSCAD, please contact me. I can provide you with an educational license for the duration of the course.
[7] Include the names of the team members in your report.
[8] In general, demand response is not counted as an interruption because unlike load shedding, it is based on an agreement between the utility and the customer, i.e., it is voluntary. However, for the purposes of this project, we consider it as an interruption. For a more detailed discussion, refer to: S. Mohagheghi, F. Yang and B. Falahati, "Impact of Demand Response on Distribution System Reliability," In Proc. IEEE Power & Energy Society General Meeting, Detroit, MI, USA, Jul. 2011.

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Graphs of active and reactive powers of generation resources are provided	5
Information regarding power interruptions (DR and load shedding) is provided	5
Reliability indices are correctly calculated and provided	5
Information regarding the cost of installation and O&M is provided	5
Discussion of lessons learned and challenges is well-thought-out and informative. Recommendations demonstrate outside-the-box thinking.	5
How the team's solution ranks among other teams' proposals in terms of cost, grid performance, and social/environmental impacts	5

Project Management

You will receive feedback after submission of each report. Your team is expected to choose a team lead who will be responsible for the management of the project and ensuring that the division of work is fair and that all team members contribute equally to various project tasks and deliverables. Failure of a team member to contribute to the project may result in her/him losing all or part of the project grade. Team leads are expected to notify me in a timely manner if any issues or concerns arise.