Assignment 3: Economic Dispatch with Optimization

Introduction

An Economic Dispatch Model is a mathematical formulation (usually as an optimization problem) used in power system operation to ensure that the generation of electricity meets the current demand in the most economical (cost-effective) manner.

The core idea of economic dispatch is to determine the optimal output of various generation units so that the total power demand is met at the lowest possible cost. Each generation unit, like a power plant, has its own operational characteristics, including fuel costs, maintenance expenses, and output limitations. These factors are critical in deciding how much each unit should contribute to the total power supply.

Problem Formulation

The Economic Dispatch Problem can be formulated as a linear optimization problem with the objective of minimizing the total generation cost while meeting the demand and respecting the generators' constraints.

Objective Function

Minimize the total cost of electricity generation:

$$\text{Minimize} \quad C = \sum_{i=1}^{N} c_i \cdot P_i \tag{1}$$

where:

- C is the total generation cost.
- c_i is the marginal cost of the i-th generator.
- P_i is the power output of the i-th generator.
- N is the number of generators.

Constraints

Power Balance Constraint

The total generation must meet the demand. Power generated from wind and solar facilities should also be taken into account, although having negligible marginal costs:

$$\sum_{i=1}^{N} P_i + VRE_{feed\,in} = D \tag{2}$$

where D is the total demand and $VRE_{feed\,in}$ the total energy produced by wind and solar.

Generation Limits

Each generator must operate within its capacity limits:

$$P_i \leq P_{i,\max} \quad \forall i \in \{1, \ldots, N\} \tag{3}$$

where $P_{i,\max}$ is the maximum generation capacity of the i-th generator.

Task 1: Including temporal availability of resources

The provided economic dispatch model aims to minimize the total generation cost of a power system while satisfying demand and operational constraints. This model currently considers traditional generation units but does not account for the temporal variability of renewable energy sources like wind and solar power. Your task is to enhance the economic dispatch model to include the temporal availability of renewable energy sources. Consider the intermittent nature of these sources and how they impact the overall power system operation. To expand the original economic dispatch model to include multiple time steps and incorporate time-varying maximum availability for each generator.

Working Procedure

Step 1: Extend the Model to Multiple Time Steps

- Modify Decision Variables: Redefine the generation variable $P_{i,t}$ to include time t as an index, where i represents the generator and t represents the time step.
- Update the Objective Function: Adjust the objective function to sum over both generators and time steps.

$$\text{Minimize} \quad C = \sum_{t=1}^{T} \sum_{i=1}^{N} c_i \cdot P_{i,t} \tag{4}$$

- Revise the Demand Constraint: Modify the demand constraint to ensure that the total generation meets the demand at each time step. Be aware that the renewable energy feed-in will be given for each time step t:

$$\sum_{i=1}^{N} P_{i,t} + VRE_{t,feed\,in} = D_t \quad \forall t \in \{1, \ldots, T\} \tag{5}$$

  where D_t and $VRE_{t,feed\,in}$ are the demand and renewable generation at time step t respectively.

Step 2: Consider the minimum capacity of power plants

- Include a new parameter $\mathrm{p}_{i,min}$ representing the minimum power for generator i.
- Include binary decision variables $y_{i,t}$, indicating whether the generator i is active (1) or shut down (0) at time step t.
- Update Generation Limits: Modify the generation limits constraint to use $\mathrm{P}_{i,min}$ and $y_{i,t}$.

$$y_{i,t} \cdot P_{i,\min} \leq P_{i,t} \leq y_{i,t} \cdot P_{i,max} \quad \forall i \in \{1, \ldots, N\}, \forall t \in \{1, \ldots, T\} \tag{6}$$

Conclusion

This enhanced model allows for a more dynamic representation of power generation, accommodating demand fluctuations and generator availability variations over time. It is particularly relevant for systems with renewable energy sources.

Task 2: Adding a storage unit

Background

Energy storage systems play a crucial role in modern power systems, especially with the increasing integration of intermittent renewable energy sources. They help in balancing supply and demand, improving system reliability, and maximizing the utilization of renewable resources.

Task Description

1. **Identify Storage Characteristics**: Understand and define the operational characteristics of the storage system, including charging, discharging efficiencies, and capacity limits.
2. **Add Storage Decision Variables**: Introduce decision variables representing the state of charge (SOC) of the storage system at each time step.
3. **Modify the Objective Function**: Adjust the objective function to include the costs and benefits associated with operating the storage system.
4. **Introduce Storage Constraints**: Add constraints to govern the charging and discharging activities of the storage system, ensuring adherence to its operational limits.

Conclusion

By integrating a storage model, the enhanced economic dispatch model can more effectively manage the variability of renewable energy sources and improve overall system reliability and efficiency. This task will deepen your understanding of the synergies between energy storage and power generation in modern electric grids.

Task 3: Presenting your results

Conduct separate optimization analyses for the months of June and December for both Task 1 and Task 2. Compare the resulting market clearing prices with historical electricity prices in Germany, as provided in the input data.

Present the comparison visually through two plots:

1. June Plot: Displaying market clearing prices for Task 1, Task 2, and historical prices.
2. December Plot: Displaying market clearing prices for Task 1, Task 2, and historical prices.

Please ensure your submission includes a folder containing the necessary input files and a Python script for executing the analysis.