Virtual Power Plant Commitment in Energy Market Problem

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Participation in Virtual Power Plant in the Energy Market: Managing Interruptible and Non-Interruptible Loads

1. Introduction

The energy market is evolving with the growing integration of renewable energy sources and distributed energy resources (DERs). Virtual Power Plants (VPPs) play a significant role in this transition, aggregating these resources to provide reliable and flexible electricity. This report focuses on VPP participation strategies, examining the challenges and solutions related to interruptible and non-interruptible loads.

2. Overview of Virtual Power Plant (VPP)

A Virtual Power Plant (VPP) is a network of decentralized, medium-scale power generation units such as wind farms, solar parks, combined heat and power (CHP) units, and flexible consumers and batteries. The primary goal of a VPP is to integrate these units for efficient energy generation and distribution, acting as a single entity in the energy market.

2.1. Interruptible and Non-Interruptible Loads

- **Interruptible Loads**: These loads can be temporarily reduced or disconnected to provide demand response services. They are essential for maintaining grid stability during peak demand or supply shortages. Examples include industrial processes that can be paused and large commercial buildings that can adjust their HVAC systems.

- **Non-Interruptible Loads**: These loads require a continuous power supply. They are critical for operations where any interruption can lead to severe disruptions or damage. Examples include hospitals, data centers, and residential areas.

2.2. Challenges in Load Management

1. **Forecasting and Planning**: Accurate demand and supply forecasting is essential. VPPs require advanced algorithms to predict the availability of renewable resources and the load patterns of interruptible and non-interruptible loads.
2. **Coordination and Control**: Ensuring seamless coordination among different DERs and loads requires advanced control systems. Interruptible loads must be managed without compromising the reliability of non-interruptible loads.
3. **Compliance with Regulations**: VPPs must adhere to market regulations and standards, which may vary significantly across regions.

2.3. Optimal Load Participation Strategies

1. **Demand Response Programs**: VPPs can participate in demand response programs using interruptible loads, providing additional services to the grid. This helps balance supply and demand, generating extra revenue.
2. **Advanced Energy Management Systems (EMS)**: Implementing advanced EMS can optimize the operation of DERs and load management. These systems can dynamically adjust interruptible loads based on real-time network conditions.
3. **Machine Learning and Artificial Intelligence**: Using machine learning and AI can enhance forecasting and decision-making for load management. These technologies can analyze large amounts of data and optimize the participation of interruptible and non-interruptible loads.

2.4. Case Studies

- **Case Study 1: Industrial Interruptible Load Management**: This case study examines how an industrial VPP uses interruptible loads in demand response programs, providing flexibility to the grid while maintaining operational efficiency.

- **Case Study 2: Integration of Residential and Commercial Loads**: This case study explores how a VPP integrates residential and commercial loads, balancing the needs of non-interruptible loads with the flexibility of interruptible loads.

2.5. Implications for the Energy Market

- **Enhanced Grid Reliability**: VPPs improve grid reliability by providing flexible resources that can respond to grid needs.
- **Market Participation**: VPPs allow smaller distributed energy sources to participate in the energy market, increasing competition and potentially reducing energy costs.
- **Sustainability**: By optimizing the use of renewable energy resources and reducing reliance on fossil fuels, VPPs support a transition to a more sustainable energy system.

2.6. Conclusion

Virtual Power Plants are essential in the modern energy landscape, providing flexibility and reliability through the management of interruptible and non-interruptible loads. By leveraging advanced technologies and strategies, VPPs can optimize load participation, enhance grid stability, and support the integration of renewable energy resources.

3. Problem Description

3.1. Objective Function

$$\text{minimizing} \sum_{t=1}^{24} \left[\sum_{i=1}^{k} F(P_{LS_i}) + \sum_{j=1}^{n} F(P_{DG_j}) \right] \tag{1}$$

The objective function is defined as minimizing the total costs over a 24-hour period. The function F is applied to two sets of power variables: interruptible load power (P_{LS_i}) and distributed generation power (P_{DG_j}).

3.2. Constraints

$$\sum_j P_{DG_j} + \sum_i P_{LS_i} = P_{vpp} \quad \text{for} \quad j = 1, 2, \ldots \tag{2}$$

The total distributed generation power (P_{DG_j}) and the total interruptible load power (P_{LS_i}) must equal the virtual power plant power (P_{vpp}).

$$P_{min} \leq P_{DG_j} \leq P_{max} \tag{3}$$

The distributed generation power (P_{DG_j}) must be within minimum and maximum power limits.

$$P_{min} \leq P_{LS_i} \leq P_{max} \tag{4}$$

The interruptible load power (P_{LS_i}) must also be within minimum and maximum power limits.

Table 1: Cost Functions of Generation Units

Unit	bus	a_i (\$/MWh^2)	b_i (\$/MWh)	c_i (\$)	P_{min} (MW)	P_{max} (MW)
1	1	0.02	15	0	15	80
2	2	0.0175	14.75	0	15	80
3	13	0.025	16	0	5	40
4	22	0.0625	14	0	5	50
5	23	0.025	16.1	0	5	30

Table 2: Cost Functions for Units and Interruptible Loads Based on Non-Interruptible Load

Unit	a_i (\$/MWh^2)	b_i (\$/MWh)	c_i (\$)	P_{min} (MW)	P_{max} (MW)
DG1	0.03	16.5	0	0	10
DG2	0.0177	16.35	0	0	10
DG3	0.0235	17.5	0	0	3
DG4	0.0635	16.5	0	0	3
DG5	0.022	17.6	0	0	3
LDG3	0.03	18	0	0	2
LDG4	0.0177	17.85	0	0	2
LDG5	0.022	19.1	0	0	1

Table 3: Integrated Cost Function of Virtual Power Plant

a_i (\$/MWh^2)	b_i (\$/MWh)	c_i (\$)	P_{min} (MW)	P_{max} (MW)
0.0292	15.863	1.9083	0	34

Table 4: Cost Functions for Controllable Loads

Unit	a_i (\$/MWh^2)	b_i (\$/MWh)	c_i (\$)	P_{min} (MW)	P_{max} (MW)
LDG3	0.03	18	0	0	2
LDG4	0.0177	17.85	0	0	2
LDG5	0.022	19.1	0	0	1

Table 5: Non-Interruptible Loads

Unit	Power (MW)
LDG1 (MW)	2
LDG2 (MW)	2
LDG3 (MW)	0
LDG4 (MW)	0
LDG5 (MW)	1

4. Code and Simulation Results

4.1. Code

The code was written in Python using the VS Code environment. Additionally, the Pyomo library was used for optimization. There are 3 simulation files with a .py extension.

Running the ‘virtual power plant‘ file offers two options: with load control (Option 1) and without load control (Option 2). Choosing Option 1 saves the results with load control in an Excel file, while Option 2 does this without load control.

Two other files named ‘nlc.py‘ and ‘wlc.py‘ simulate the no-load control and load control approaches, respectively, and are called within the ‘virtual power plant‘ file.

4.2. Code Overview

4.2.1. nlc.py (Without Load Control)

The ‘nlc.py‘ file addresses the VPP participation problem without considering load control. This script uses the Pyomo library for mathematical modeling and optimization. Here's a detailed breakdown of the script:

- **Data Loading**: The script loads cost and demand data from an Excel file (‘VPP input.xlsx‘) using specific sheets for the no-load control scenario.

- **Model Creation**: A Pyomo model is created, including sets for generators (‘i‘) and time periods (‘t‘).

- **Parameters**: Cost parameters (‘cost a‘, ‘cost b‘, ‘cost pmax‘) and demand data are initialized.

- **Variables**: Power generation variables (‘pdg‘) and an overall objective variable (‘Z‘) are defined.

- **Constraints**: Upper and lower constraints for the power generation variables are set based on maximum power capacities.

- **Objective Function**: The objective function is defined to minimize the total power generation cost over the time periods, including quadratic and linear cost terms for each generator.

- **Constraints**:

- Constraints ensure that the total generated power for each time period matches the demand.

- Power generated by each unit must be within its capacity range.

- **Solver**: The model is solved using the IPOPT solver.

- **Results Collection and Visualization**: Results are collected in a DataFrame and displayed using a stacked bar chart.

4.2.2. wlc.py (With Load Control)

The ‘wlc.py‘ file extends the ‘nlc.py‘ script by adding load control. The changes are as follows:

- **Data Loading**: Similar to 'nlc.py', but using different sheets for load control.

- **Model Creation**: Model creation steps are similar, with the addition of extra controllable loads.

- **Parameters**: Additional parameters for load control are initialized.

- **Variables**: Power generation ('pdg') and load control variables are defined.

- **Constraints**: Constraints are adjusted to account for load control limitations.

- **Objective Function**: The objective function remains the same, focusing on minimizing total cost.

- **Constraints**:

- The total generated power and controllable loads must meet the adjusted demand for each hour.

- Power generated by each unit must be within its capacity range.

- Controllable loads must remain within their specific ranges.

- **Solver**: The model is solved using the IPOPT solver.

- **Results Collection and Visualization**: Similar to the results collection in 'nlc.py', with additional data for load control.

These scripts illustrate how a VPP can optimize its operations by considering different scenarios, either simply meeting demand or dynamically adjusting demand with load control. The results of both scenarios are displayed to compare the effectiveness of load control in minimizing costs and efficiently meeting demand.

4.3. Simulation Results

4.3.1. Without Load Control

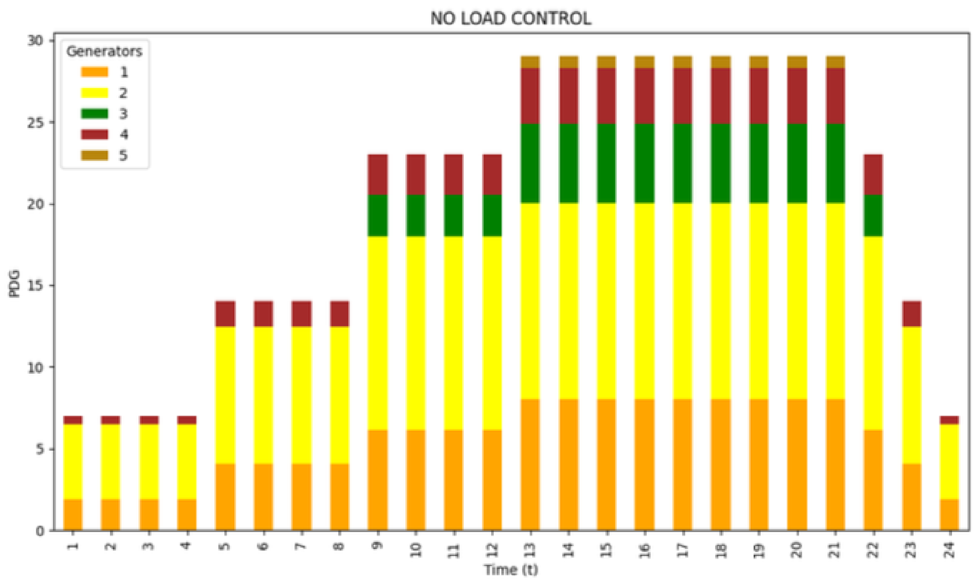
In the first chart titled "Without Load Control," the power generation (PDG) from five different generators is shown over a 24-hour period. Each bar represents the total generated power each hour, shown as stacked segments for each generator. A detailed explanation of the results is as follows:

- **X-axis (Time t)**: Represents each hour of the day from 1 to 24.

- **Y-axis (PDG)**: Indicates the amount of generated power in megawatts (MW).

- **Colors**: Each color represents a different generator (1 to 5).

Observations: 1. Generator 1 (Orange): Operates continuously throughout the day, with variable output. Its output is higher during peak demand periods (e.g., hours 12 to 21).



2. Generator 2 (Yellow): Also operates continuously, increasing output significantly during peak hours, similar to Generator 1.

3. Generator 3 (Green): Has a variable output and operates more during peak periods.

4. Generator 4 (Brown): Operates more during medium demand periods and less during very low or very high demand periods.

5. Generator 5 (Dark Gold): Has the smallest share, usually filling in during high-demand periods.

Interpretation:

- Total power demand fluctuates throughout the day, with significant peaks and valleys.

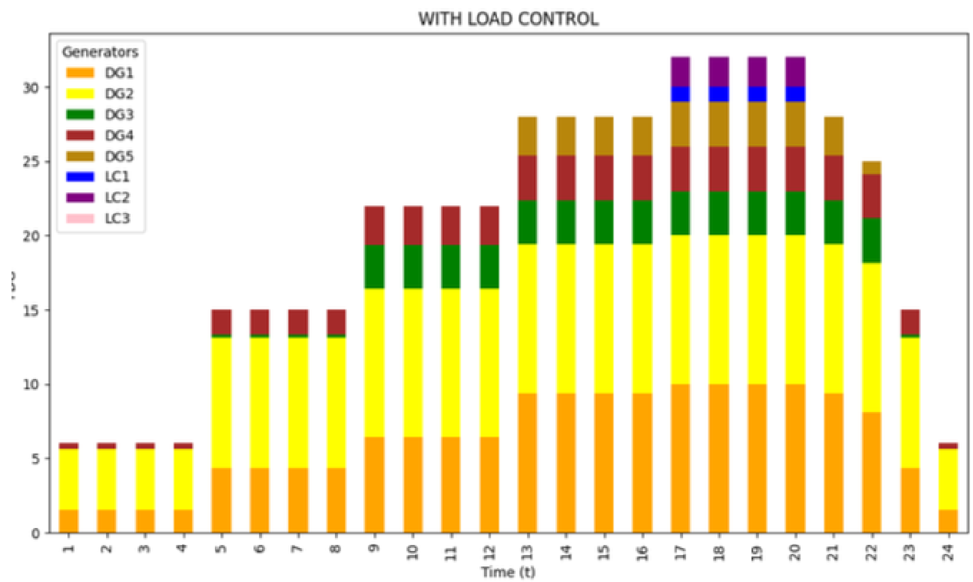
- Generators are used in a way that tries to meet demand in the most economical way, based on their cost functions.

- Without load control, all demand must be met by adjusting power generation output.

4.3.2. With Load Control

In the second chart, titled "With Load Control," power generation is again displayed over 24 hours, but this time, it includes the effects of load control. Here's a detailed explanation of the results:

- **X-axis (Time t)**: Represents each hour of the day from 1 to 24.



- **Y-axis (PDG)**: Indicates the amount of generated power in megawatts (MW).

- **Colors**: Different colors represent different generators (DG1 to DG5) and load control units (LC1 to LC3).

Observations:

1. Generators (DG1 to DG5): Their participation is similar to the no-load control scenario, with some differences during peak periods.

2. Load Control Units (LC1 in Blue, LC2 in Purple, LC3 in Pink): These units are activated during peak demand periods to help reduce the overall load.

Interpretation:

- The presence of load control units helps manage demand more optimally, reducing load during peak periods.

- This results in a smoother generation curve and reduces the need for frequent and large adjustments in generator output.

- The overall system can operate with lower costs and higher efficiency, as the load control units help smooth the demand curve and enable fuel optimization and reduced operational costs.

4.3.3. Comparison and Detailed Interpretation

1. Peak Demand Management:

- Without Load Control: Generators must meet all demand fluctuations, leading to higher peaks in generation and greater variations in generator output.

- With Load Control: Load control units help reduce peaks, making the demand curve more stable and manageable.

2. Generator Usage:

- Without Load Control: Generators are used to meet demand with more fluctuations, while Generators 4 and 5 have a smaller overall share.

- With Load Control: Generators still meet demand, but load control units help reduce severe fluctuations, achieving better efficiency.

3. System Efficiency:

- Without Load Control: Efficiency may be lower because generators require frequent and significant output adjustments, which can lead to higher fuel consumption and wear.

- With Load Control: The system can operate more efficiently as the need for extreme and frequent generator adjustments is reduced.

4.3.4. Conclusion

The introduction of load control in the power generation process significantly improves system efficiency and sustainability. By managing the demand side, pressure on generating units can be reduced, optimizing fuel usage and potentially lowering operational costs. The comparison between the two scenarios clearly demonstrates that incorporating load control in a VPP setup offers substantial advantages.

Biography

Amirreza Shafiei received the B.Sc. degree from Amirkabir University of Technology, Tehran, Iran, in 2022, in Electrical Engineering. He is currently a junior graduate student of Electrical Engineering at Shahid Beheshti University, Tehran. His main research interests include the Transient Stability Assessment, Operation, and Planning of Power Systems combined with Renewable Energy and Smart-grids.