Expansion Planning of Low-Voltage Grids Using Ant Colony Optimization

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Agenda

1. Problem (7 min) → Q&A
2. Solution (9 min) → Q&A
3. Evaluation (4 min) → Q&A
Example
Example: Additional Lines

Transformer
• Bus
• Line
• Switch
Example: Overloading
Example: Expansion
Example: Invalid Topology
Example: Invalid Topology

- Transformer
- Bus
- Line
- Switch
Example: Invalid Topology
Constraints

Topological constraint:
Graph is a forest with one transformer per tree
Constraints

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Graph is a forest with one transformer per tree

Electrical constraints
Voltages & line loadings must not exceed given limits

→ Power Flow Analysis
Problem statement

• Inputs:
  • Grid $G_{\text{now}} = (B, E_{\text{now}})$
  • Expansion options $E_{\text{add}}$
  • Electricity generation & demand

• Outputs:
  • Expanded grid $G_{\text{exp}} = (B, E_{\text{exp}})$ with $E_{\text{exp}} \subseteq E_{\text{now}} \cup E_{\text{add}}$
  • Expansion cost $c(G_{\text{now}}, G_{\text{exp}})$

• Objective: Minimize $c(G_{\text{now}}, G_{\text{exp}})$

• Constraints: topological & electrical

• Degrees of freedom:
  • Installation, reinforcement, dismantling of lines
  • Opening & closing of switches
Q&A
Ant Colony Optimization [1]

• Set of heuristic concepts
• For combinatorial optimization problems
• Ant = simple agent
• Colony = group of ants
• Pheromones for communication

Example: Neighborhood

- Transformer
- Bus
- Line
- Switch
Example: Neighborhood

- Transformer
- Bus
- Line
- Switch
Example: Neighborhood
Example: Neighborhood
Example: A Solution

\[ c(G_{\text{now}}, G_{\text{exp}}) = 70 \text{K \€} \]
Example: Electrical Constraints
Example: Objective Function

\[ J(G_{exp}) = c(G_{now}, G_{exp}) + \text{Penalty} \]
Search Strategy

Adopted from *Ant Colony System* [2]

Search Strategy

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**Transition rule:**
- Probabilistic
- Exploration vs. exploitation

**Pheromone update:**
- Local update: "*I was here, go somewhere else*"
- Global update: "*Let’s focus on the best we found so far*"

Q&A
Degrees of Freedom

1. Installation of 5 line segments
2. Reinforcement 369 line segments
3. Dismantling of 369 line segments
4. Opening of 102 closed switches
5. Closing of 11 open switches
Baselines

Manual method
Heuristic procedure based on expert knowledge

Local search method
Simple, greedy search
# Results: Overview

<table>
<thead>
<tr>
<th></th>
<th>Manual method</th>
<th>Local search</th>
<th>AntPower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid Topology?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Overloaded lines</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Voltage violations</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Expansion cost</td>
<td>210K €</td>
<td>231K €</td>
<td>84K €</td>
</tr>
</tbody>
</table>
Results: Convergence of AntPower
Conclusion & Future Work

• Ant Colony Optimization can cut costs tremendously
Conclusion & Future Work

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• Further evaluation needed
  • More problem instances
  • Stronger baselines
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• Ant Colony Optimization can cut costs tremendously
• Further evaluation needed
  • More problem instances
  • Stronger baselines
• Promising: Add support for
  • Installation of switches, transformers
  • Different topologies
Q&A
References


Appendices
Example: Objective Function

\[ J(G_{exp}) = c(G_{now}, G_{exp}) + \text{Penalty} \]
Example: Objective Function

\[ J(G_{\text{exp}}) = c(G_{\text{now}}, G_{\text{exp}}) + k_{\text{vio}} \ast c(G_{\text{now}}, G^*) \]
Example: Desegmentation
Example: Desegmentation
Example: Desegmentation

- Transformer
- ● Bus
- — Line
- —— Switch

Diagram with nodes labeled as $c_1, c_2, c_3, c_4, c_5, c_6$.
Example: Desegmentation
Example: Desegmentation
Example: Local search method

\[ J(G_{exp}) = 150K \, \text{€} \]
Example: Local search method

\[ J(G_{exp}) = 140K \, \text{€} \]
Example: Local search method

\[ J(G_{exp}) = 180K \, \text{€} \]
Example: Local search method

\[ J(G_{exp}) = 140K \, \text{€} \]
Manual method
Local search
Results: Convergence of AntPower
Results: Convergence of Local Search

![Graph showing convergence of local search processes](image)
Pheromones Across Iterations