# On Optimum Placement of Sectionalizing Switches in Radial Distribution Networks

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## Objectives

Development of fast algorithms for

- computation of the average undelivered energy for a given positions of switches,
- finding optimum allocation of switches to minimize the undelivered energy.

## Introduction

Reducing the frequency and duration of power interruptions to customers is one of the main objectives in the design of distribution networks. **Sectionalizing switches** may be used to improve reliability and to reduce costs associated with power outages.

## Assumptions

- The distribution grid contains $m$ distribution and load nodes and a single generator node.
- The network has a tree structure with the generator being the root and load nodes being leaves.
- $P_j \geq 0$ is the average (active) power dissipated at the $j$th node, $t_j$ is the average failure time in the given time unit of the node $v_j$ and the connection line between $v_j$ and its parent node.
- Denote by $E_{\text{nd}}(Q)$ the average undelivered energy for the network with switches at positions in the set $Q \subset \{1, 2, \dots, m\}$.
- Without sectionalizing switches the average undelivered energy is

$$E_{\text{nd}}(\emptyset) = \sum_{i=1}^{m} P_i \sum_{j=1}^{m} t_j.$$

- With sectionalizing switches, if a failure occurs behind one of the switches, we may disconnect a part of the grid preventing the remaining part from a power outage.

## Problem formulation

For given $p > 0$, find positions of $p$ sectionalizing switches to **minimize the average undelivered energy** $E_{\text{nd}}$.

## Existing solutions

- Brute-Force (BF) method: only for small networks and small number of switches.
- Heuristic approaches, e.g. [1]: long computation times, no guarantee that the optimum solution has been found.
- The Celli-Pilo (CP) algorithm [2]: may produce suboptimal results.

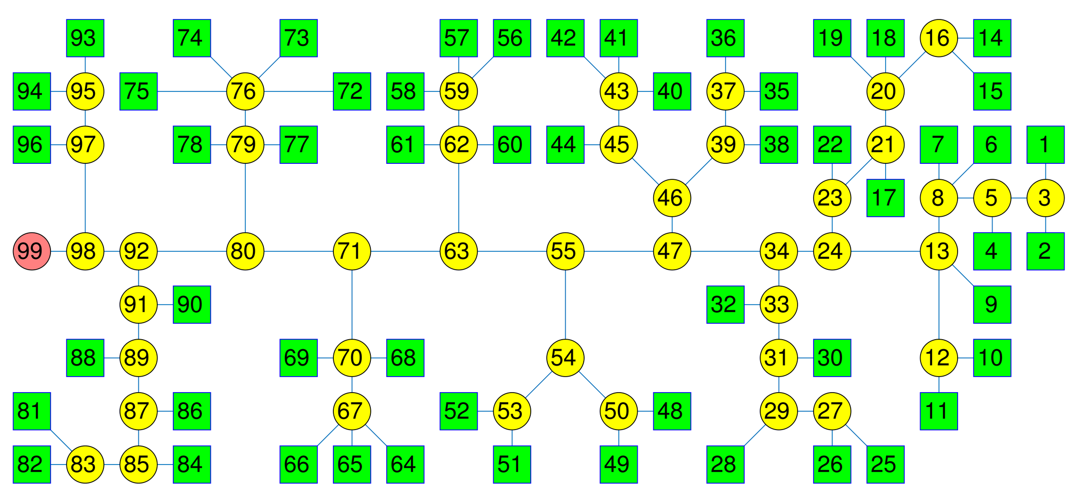
## Fast computation of average undelivered energy

- Saved energy: $E_{\text{sav}}(Q) = E_{\text{nd}}(\emptyset) - E_{\text{nd}}(Q)$.
- The idea: **compute saved energy recursively from leaf nodes (loads) to the root node (generator)**.
- Computations can be carried out in a single pass of the tree structure. In consequence, the algorithm is very fast.

## Tree algorithm (TA) for finding optimum allocation of switches

1. Visit nodes following the tree structure from leaf nodes to the root node.
2. For each node $v_j$ and for each $p \geq 0$ compute saved energy for all partial solutions with $p$ switches in $v_j$ and its descendants (based on results found for the descendants of $v_j$).
3. Avoid the exponential growth of the number of partial solutions by skipping solutions with a maximum contribution to the total saved energy smaller than the minimum contribution of another partial solution with the same $v_j$ and $p$.

## Radial network example



- 55 load nodes, 43 distribution nodes.

## Computation speed

- Exhaustive search results:

| $p$ | $N_{\text{ES}}$ | $t_{\text{ES}}$ [s] | $E_{\text{nd}}$ |
|---|---|---|---|
| 0 | 1 | 0.00 | **9566.6** |
| 1 | 98 | 0.00 | **7201.6** |
| 2 | 4753 | 0.02 | **6260.1** |
| 3 | 152096 | 0.80 | **5405.4** |
| 4 | 3612280 | 19.18 | **4619.2** |
| 5 | $6.79 \cdot 10^7$ | 362.54 | **3909.4** |
| 6 | $1.05 \cdot 10^9$ | 5683.84 | **3265.4** |

- Fast computations: approximately 185000 evaluations of $E_{\text{nd}}$ in one second (a single core 3.1 GHz processor).
- The algorithm may be useful in heuristic methods where the undelivered energy is evaluated for many selections.

## Optimization results

- Average undelivered energy $E_{\text{nd}}$ for best solutions found using various methods:

| $p$ | ES | TA | TA1 | CP |
|---|---|---|---|---|
| 1 | **7201.6** | **7201.6** | **7201.6** | **7201.6** |
| 2 | **6260.1** | **6260.1** | **6260.1** | **6260.1** |
| 3 | **5405.4** | **5405.4** | **5405.4** | **5405.4** |
| 4 | **4619.2** | **4619.2** | **4619.2** | **4619.2** |
| 5 | **3909.4** | **3909.4** | **3909.4** | **3909.4** |
| 6 | **3265.4** | **3265.4** | **3265.4** | **3265.4** |
| 7 | | **2651.9** | **2651.9** | **2651.9** |
| 8 | | **2175.9** | **2175.9** | **2175.9** |
| 9 | | **1775.2** | **1775.2** | 1887.3 |
| 10 | | **1542.5** | **1542.5** | 1669.9 |
| 11 | | **1427.4** | **1427.4** | **1427.4** |
| 12 | | **1370.4** | 1391.6 | 1384.4 |
| 20 | | **1126.5** | 1188.2 | **1126.5** |
| 40 | | **877.4** | 927.7 | 879.2 |

- Exhaustive search method (ES) works only for small $p$.
- The tree algorithm (TA) finds optimum solution for all $p \in \{1, 2, \dots, 99\}$; computation time 0.07 s.
- The Celli-Pilo algorithm (CP) produces suboptimal results for some $p \geq 9$.

## Conclusion

- An efficient algorithm for the computation of average undelivered energy due to power outages for radial distribution networks with sectionalizing switches has been presented.
- Its high efficiency makes it useful for solving switch allocation problems using the exhaustive search method and heuristic methods which require handling large number of test selections.
- A fast tree structure based algorithm to solve the switch allocation problem in radial distribution networks has been proposed.
- Algorithms have been tested with a network of a moderate size.

## References

[1] R. Billinton and S. Jonnavithula. Optimal switching device placement in radial distribution systems. *IEEE Trans. Power Delivery*, 11(3):1646–1651, 1996.

[2] G. Celli and F. Pilo. Optimal sectionalizing switches allocation in distribution networks. *IEEE Trans. Power Delivery*, 14(3):1167–1172, 1999.

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