Network Reconfiguration to Improve Reliability and Efficiency in Distribution Systems

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Introduction

Proposal of a new method to improve reliability and also efficiency (minimization of active power losses) in radial distribution systems through a process of network reconfiguration;

To evaluate reliability is used the Monte Carlo simulation ($MC$) and an historical data of the network (level of reliability and the severity of potential contingencies in each branch);

Two Perspectives of optimization:
- $1^{st}$ (no investment) – using only the switches presented in the network;
- $2^{nd}$ (with investment) – possibility to place a limited number of tie-switches (only in certain branches), defined by a decision agent.
Genetic Algorithm Approach (IGA)

– Main Features of the IGA (Improved Genetic Algorithm)

- List of non-admissible solutions (reveals loads not energized; transformers capacity and heat capacity of all the branches not satisfied; bus voltage limits violation);
- Two-termination criterion (Number of generations and a convergence threshold);
- Adaptive Crossover and Mutation probabilities according to the genetic diversity in the population;
- Suitable coding and decoding technique (obtains a small chromosome length and can assure the radiality of the network);
- Elitist selection (the best individual at the early generation \((k)\) is maintained in the next generation \((k+1))\).
Distribution System Reliability

Branch Reliability

- A fundamental element of the network to assure continuity of service. To define the reliability level of each network branch it was considered the following:

<table>
<thead>
<tr>
<th>Level</th>
<th>Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very unlikely</td>
</tr>
<tr>
<td>2</td>
<td>Unlikely</td>
</tr>
<tr>
<td>3</td>
<td>Likely</td>
</tr>
<tr>
<td>4</td>
<td>Very likely</td>
</tr>
</tbody>
</table>

- To better characterize the possible contingencies, were defined degrees of severity (based on historical data) each with different average interruption durations (“D_{av}”);
Distribution System Reliability

– Monte Carlo Simulation method

- The method considered \( N \) trials and, in each trial, an annual number of contingencies, in locations according to the reliability level of each branch;

- The interruption duration of each contingency is variable and follows a normal density curve with a standard deviation (\( \sigma \)) and average (\( \mu \)).

\[
f(x; \mu, \sigma) = e^{-\frac{(x-\mu)^2}{2\sigma^2}}
\]

- Estimation of the annual reliability indexes in the considered network configuration. In this study, the total energy not distributed (TEND) is used as the reliability index to minimize.
Evaluation of the solutions

- *Multi-objective fitness assignment*

A fitness function we want to minimize is used to evaluate the performance of the solutions and considers two objectives:

\[
\text{fitness} = (\alpha_1 W_{\text{Loss}} + \alpha_2 T\text{END}) \times 100
\]

- 1\textsuperscript{st} part – represents the annual active energy loss \(W_{\text{Loss}}\);

- 2\textsuperscript{nd} part – represents the annual total energy not distributed \(T\text{END}\), obtained through the MC simulation.

Due to the difference between the values of \(W_{\text{Loss}}\) and \(T\text{END}\) it was used a normalization method (parameters \(\alpha_1\) and \(\alpha_2\)) also capable to reflect the importance of both objectives to the decision agent.
Case Study – MV network (12.66 kV)

**Characteristics:**
- 69 nodes
- 73 branches
- 1 substation (8 MVA)
- 48 transformation units (P =3.8 MW; Q= 2.7 MVAr)
- 7 sectionalizing switches
- 5 tie-switches

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Test Results – 1st Solution

– 1st perspective: Optimization without investment

- Same weight to efficiency and reliability ($w_1 = 0.5; w_2 = 0.5$);

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_{Loss}$ (MWh)</td>
<td>3157.5</td>
<td>2953.1</td>
</tr>
<tr>
<td>$TEND$ (MWh)</td>
<td>4.2924</td>
<td>4.1801</td>
</tr>
<tr>
<td>Fitness value</td>
<td>100</td>
<td>95.45</td>
</tr>
</tbody>
</table>

- Annual Energy Loss reduction ($W_{Loss}$) of 6.5 % and Total ENergy not Distributed ($TEND$) reduction of 2.6 %.
Test Results – 2\textsuperscript{nd} Solution

– 2\textsuperscript{nd} perspective: Optimization with investment (1 new tie-switch)

- Same weight to efficiency and reliability ($w_1 = 0.5; w_2 = 0.5$);

<table>
<thead>
<tr>
<th></th>
<th>Base network</th>
<th>2\textsuperscript{nd} Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Branches</td>
<td>[69-70-71-72-73]</td>
<td>[15-56-61-69-71]</td>
</tr>
<tr>
<td>$W_{Loss}$ (MWh)</td>
<td>3157.5</td>
<td>2613.19</td>
</tr>
<tr>
<td>$TEND$ (MWh)</td>
<td>4.2924</td>
<td>3.0706</td>
</tr>
<tr>
<td>Fitness value</td>
<td>100</td>
<td>77.15</td>
</tr>
</tbody>
</table>

- 2\textsuperscript{nd} Solution:
  - $W_{Loss}$ reduction of 17.2 % and $TEND$ reduction of 28.5 %.

- 1\textsuperscript{st} Solution (Without investment and same weight):
  - $W_{Loss}$ reduction of 6.5 % and $TEND$ reduction of 2.6 %.

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Test Results – 3\textsuperscript{rd} Solution

– 2\textsuperscript{nd} perspective: Optimization with investment (1 new tie-switch)

- Different weight to efficiency and reliability ($w_1 = 0.3; w_2 = 0.7$);

<table>
<thead>
<tr>
<th>Open Branches</th>
<th>Base network [69-70-71-72-73]</th>
<th>3\textsuperscript{rd} Solution [19-45-56-69-73]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_{Loss}$ (MWh)</td>
<td>3157.5</td>
<td>2898.69</td>
</tr>
<tr>
<td>$TEND$ (MWh)</td>
<td>4.2924</td>
<td>2.6758</td>
</tr>
<tr>
<td>Fitness value</td>
<td>100</td>
<td>71.17</td>
</tr>
</tbody>
</table>

- 3\textsuperscript{rd} Solution (reliability with higher importance):
  $W_{Loss}$ reduction of 8.2 % and $TEND$ reduction of 37.3 %.

- 2\textsuperscript{nd} Solution (With investment and same weight):
  $W_{Loss}$ reduction of 17.2 % and $TEND$ reduction of 28.5 %.
Test Results

– Dynamic Adjustment of genetic operator probabilities

Network Reconfiguration to Improve Reliability and Efficiency in Distribution Systems
Conclusions

- Possibility of obtaining network solutions that allow the simultaneous optimization of losses and reliability considering different weights;

- Good performance of IGA (convergence speed and stability increased) due to the introduction of new features (dynamic “pc” and “pm”, …);

- Two-perspective approach was used, giving to the decision agent the possibility to compare the benefits achieved with both solutions (with and without investment);

- Through network reconfiguration it is possible to make the distribution system more efficient (in terms of load balancing and voltage stability) considering only the reduction of the electrical losses.
Inclusion of new objectives in the field of reliability (minimization of number and duration of the interruptions (NI,DI) according to the geographic zone of each consumer);

Annual energy loss estimation considering the daily load diagram of each consumer (LV or MV);

Consider different network configurations throughout the year (Winter, Summer and Half-Season);

Use of Multi-objective optimization techniques (MOO) allowing to capture multiple solutions of the Pareto front ("Decision Maker" will decide after search).