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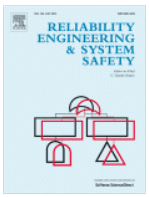

Optimizing protections against cascades in network systems: A modified binary differential evolution algorithm

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Abstract

This paper addresses the optimization of protection strategies in critical infrastructures within a complex network systems perspective. The focus is on cascading failures triggered by the intentional removal of a single network component. Three different protection strategies are proposed that minimize the consequences of cascading failures on the entire system, on predetermined areas or on both scales of protective intervention in a multi-objective optimization framework. We optimize the three protection strategies by devising a modified binary differential evolution scheme that overcomes the combinatorial complexity of this optimization problem. We exemplify our methodology with reference to the topology of an electricity infrastructure, i.e. the 380 kV Italian power transmission network. We only focus on the structure of this network as a test case for the suggested protection strategies, with no further reference on its physical and electrical properties.

Keywords

Critical infrastructure; Network protection; Line switching; Cascading failure; Differential evolution algorithm; Multi-objective optimization

Figures and tables from this article:

Fig. 1. The 380 kV Italian power transmission network (TERNA, 2002; [32]).

Figure options

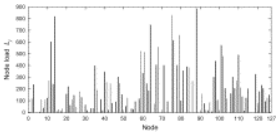

Fig. 2. Loads on each node in the unperturbed configuration.

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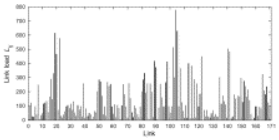

Fig. 3. Loads on each line in the unperturbed configuration.

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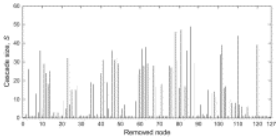

Fig. 4. The cascade size, S, caused by the removal of each node (abscissa) in the power transmission system of Fig. 1.

Figure options

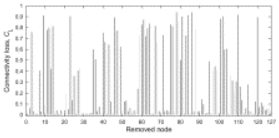

Fig. 5. The connectivity loss, C_L, caused by the removal of each node (abscissa) in the power transmission system of Fig. 1.

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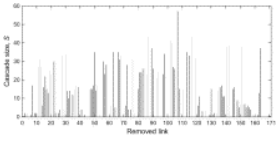

Fig. 6. The cascade size, S, caused by the removal of each link (abscissa) in the power transmission system of Fig. 1.

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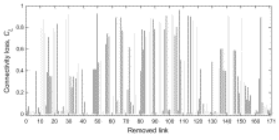

Fig. 7. The connectivity loss, C_L, caused by the removal of each link (abscissa) in the power transmission system of Fig. 1.

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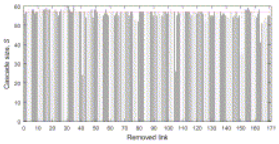

Fig. 8. The cascade size, S, resulting from the initial attack on the line 107 followed by the operator intervention of opening a line (abscissa). Horizontal line S=57 represents the reference cascade size, i.e. obtained without any further intervention after the attack.

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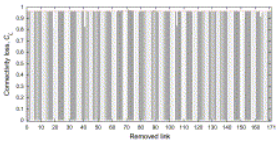

Fig. 9. The connectivity loss, C_L, resulting from the initial attack on line 107 followed by the operator intervention of opening a line (abscissa). Horizontal line C_L=0.96 represents the reference connectivity loss, i.e. obtained without any further

intervention after the attack.

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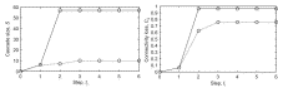

Fig. 10. The cascade evolution in terms of cascade size, S, and connectivity loss, $C_{L,t}$, after the failure of line 107 and with no intervention at t=1 (solid lines) or optimal operator intervention at t=1 (dotted lines).

Figure options

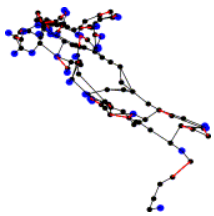

Fig. 11. The dash dotted lines in this graphical representation of the network are the optimal set of 27 edges to be switched-off to optimally contain the failure cascade, in the global optimization approach to protection.

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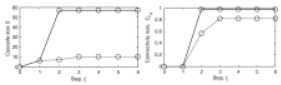

Fig. 12. Cascade evolution in terms of cascade size, S, and local-area connectivity loss, $C_{L,t}$, after the failure of line 107 and with no intervention at t=1 (solid lines) or optimal operator intervention at t=1 (dotted lines).

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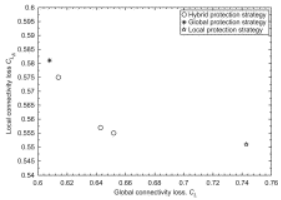

Fig. 13. The Pareto frontier identified at t=1 after the multiple-line switching optimal operator intervention.

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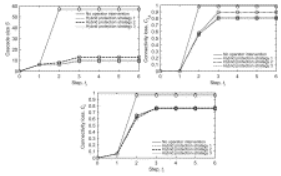

Fig. 14. Cascade evolution in terms of cascade size, S, and connectivity loss, C_L and $C_{L,t}$, after the failure of line 107 and with no intervention at t=1 (solid lines) or with optimal operator intervention at t=1 (dashed and dotted lines for the three hybrid strategies resulting from the MO optimization).

Figure options

Table 1. The parameters of the MBDE algorithm.

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Table 2. Best optimal global switching scheme.

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Table 3. Comparison of different protection strategies (values in bold denote the results obtained at $t=2$, values in italics denote the results obtained at the end of the cascade after the operator intervention).

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