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Reducing power grid cascading failure propagation by minimizing algebraic connectivity in edge addition

Key words: Network robustness; Cascading failure; Average propagation; Algebraic connectivity; Power grid

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Motivation

1. Because the edges are sparse in real-world power grids, during designing a robust topology, removing existing edges often has undesirable effects.

2. Although various methods for evaluating robustness exist, there is no widely acknowledged robustness metric and using different metrics often leads to different optimized networks.

3. Algebraic connectivity is sensitive to the connectedness in a broader spectrum of graphs.

4. Due to the large number of nodes in real-world power grids, a highly scalable algorithm is required.

Main idea

1. Average propagation is calculated to evaluate network robustness using MATCASC to simulate cascading failures.

2. A modified greedy algorithm is used to increase the efficiency of the process and to reduce the computational complexity.

3. The proposed model is evaluated with empirical analysis of cascading failures in several power grids based on algebraic connectivity.

Method

1. Design the network robustness by adding the optimal line to minimize the increase in its algebraic connectivity.

2. Calculate the average propagation using MATCASC to simulate cascading line outages in power grids to evaluate the network robustness.

Major results

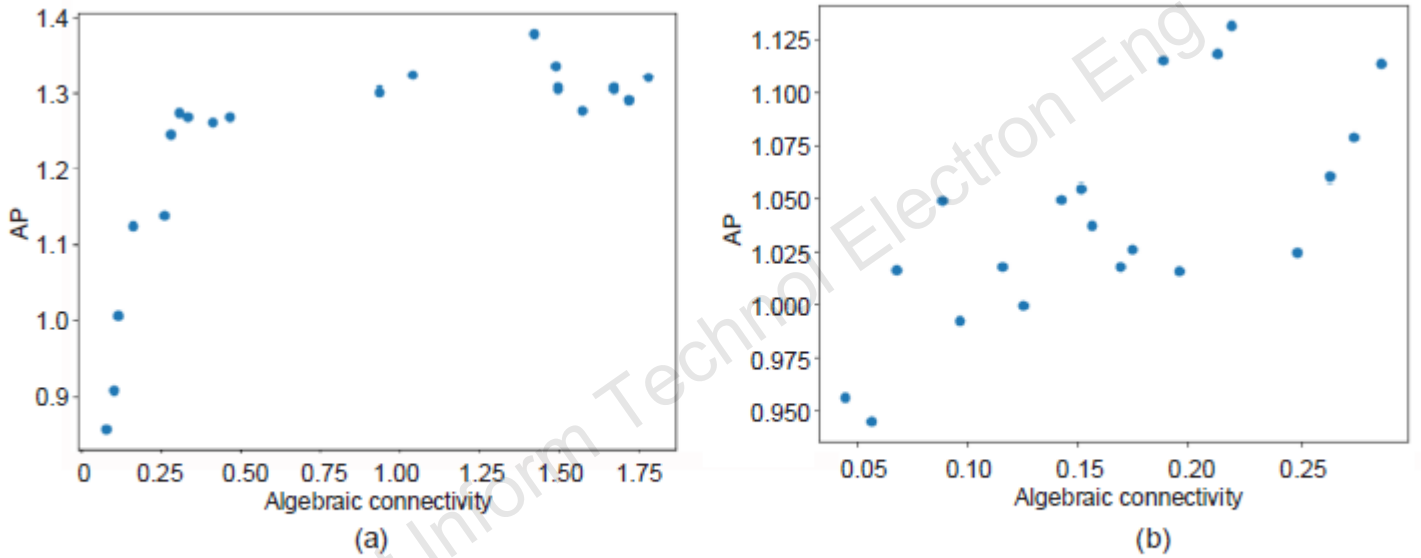


Fig. 3 Relationship between the algebraic connectivity and the average propagation (AP) in 20 simulations for the IEEE 39 network (a) and the IEEE 118 network (b)

Major results (Cont'd)

1. Minimizing algebraic connectivity using greedy edge addition

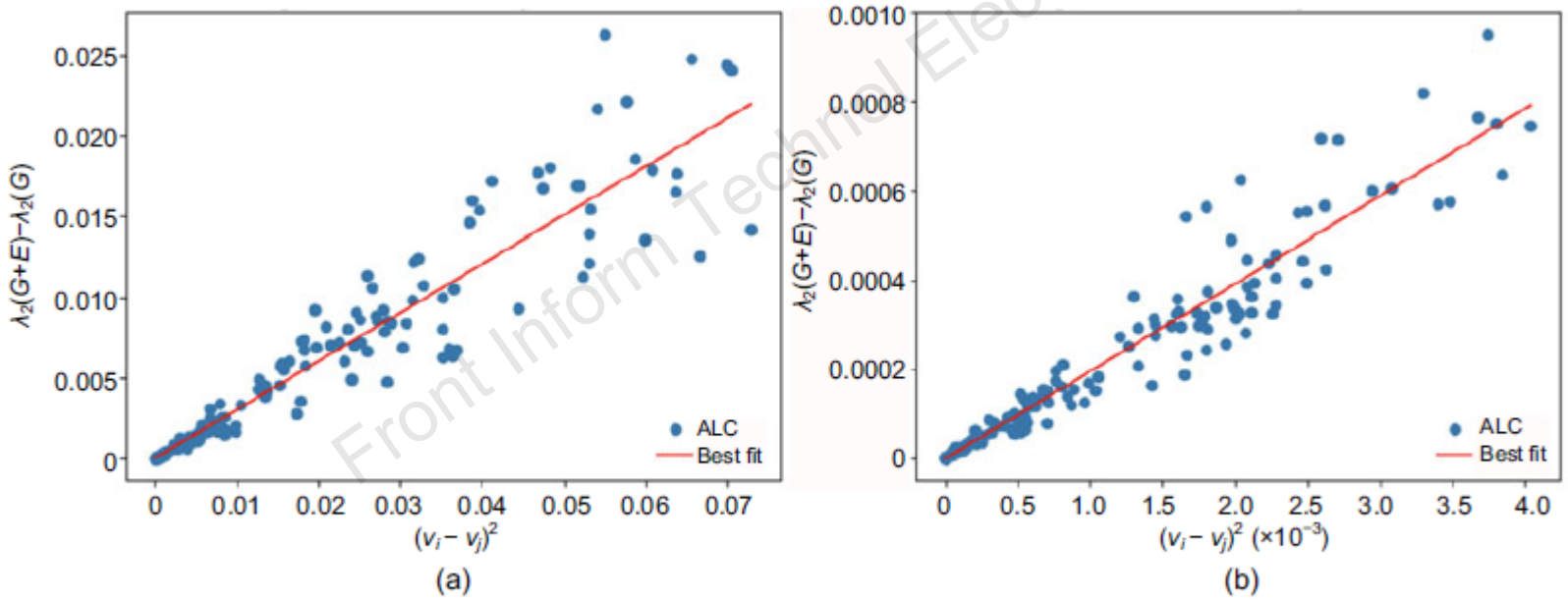


Fig. 4 Relationship between the value of $(v_i - v_j)^2$ and the increase in algebraic connectivity after edge addition for the IEEE 118 network (a) and the IEEE 2383 network (b)

Major results (Cont'd)

2. The computational complexities of our method and other methods

Table 3 Summary of the strategies and their computational complexities

Strategy	Edge addition criterion	Complexity
RD	Random selection	$O(kM)$
DP	$\arg\min_{i,j}(d_i d_j)$	$O(kN^2)$
BT	$\arg\min_{i,j}((C_B(i)+1)(C_B(j)+1))$	$O(kN^3)$
ER	$\arg\max_{i,j}(R_{ij})$	$O(kN^3)$
MGEA	$\arg\min_{e_{ij}\in P}(v_i - v_j)^2$	$O(kN^3)$

k is the number of edges to be added; N is the number of nodes; M is the number of edges in the initial grid. RD: random; DP: degree product; BT: betweenness; ER: effective resistance; MGEA: modified greedy edge addition

Major results (Cont'd)

3. The results after edge addition of our method and other methods for the IEEE39 network

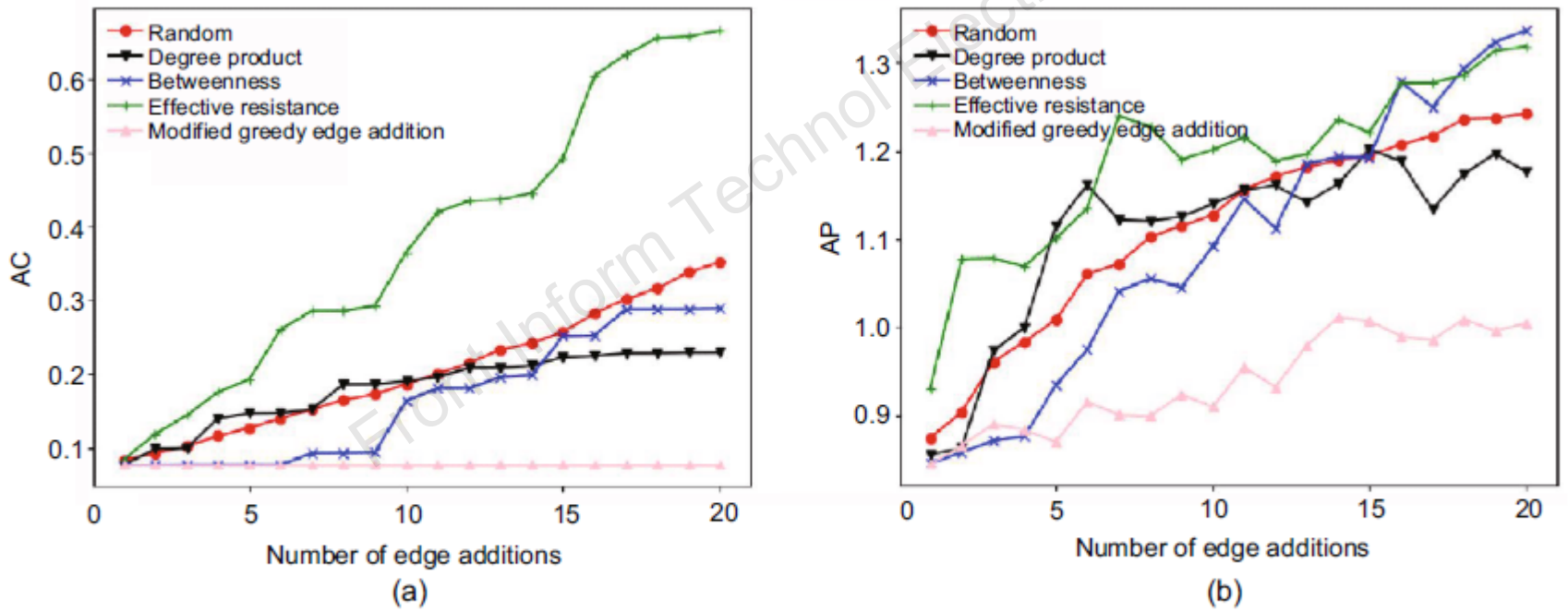
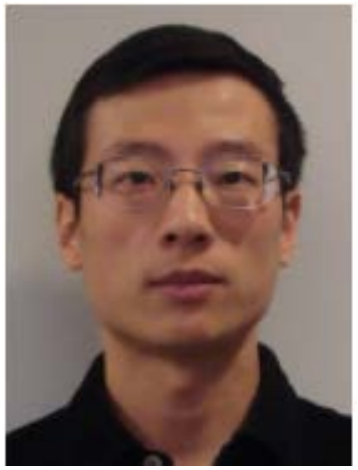


Fig. 5 Algebraic connectivity (AC) (a) and average propagation (AP) (b) after edge addition for the IEEE 39 network

Conclusions

1. Algebraic connectivity is a topological measurement that is widely used to assess network characteristics.

2. Due to its high scalability, the proposed method outperforms all the compared algorithms.



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