A GRAPH THEORY APPROACH FOR DETECTING LOOPS IN WIDE-AREA TRANSMISSION NETWORKS

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PROBLEM DESCRIPTION

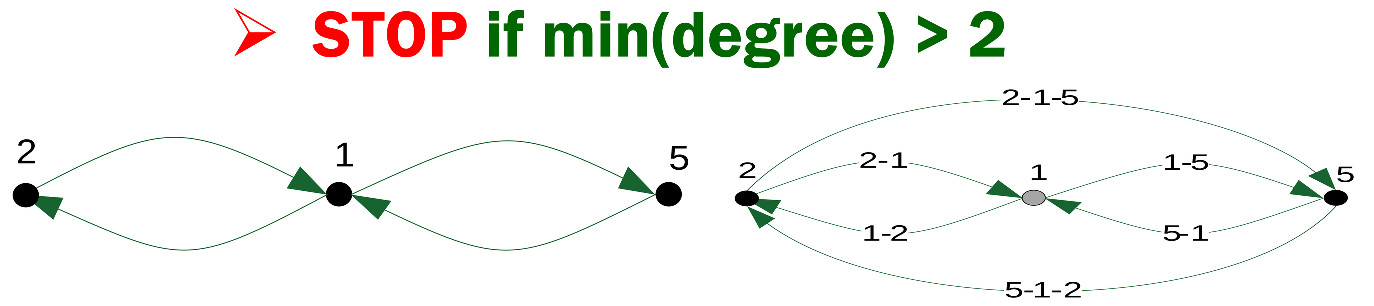
- **Power systems network** is a highly complex topological arrangement of electrical components
- **Transmission networks** can be classified as a multi-planar, bidirectional multi-graph with Hamiltonian cycles
- **Visual aid** fails to identify intricate features of the graph viz.. loops, cycles, minimum cost paths, etc.
- **Loops** or **Hamiltonian cycles** are essentials to accommodate unscheduled flows (USFs)
- **Objective:** Identification and selection of sufficient loops in a given network to accommodate USFs

LOOP DETECTION ALGORITHM

- Proposed algorithm is derived from A* heuristic algorithm and Dijkstra's algorithm
- Loop detection algorithm is agnostic to system size i.e. applicable to both test and practical systems
- Each transmission line is assumed to be a bidirectional edge
- **Sufficiency condition:** All the edges should be traced at least in one direction and no loop sequences be duplicated

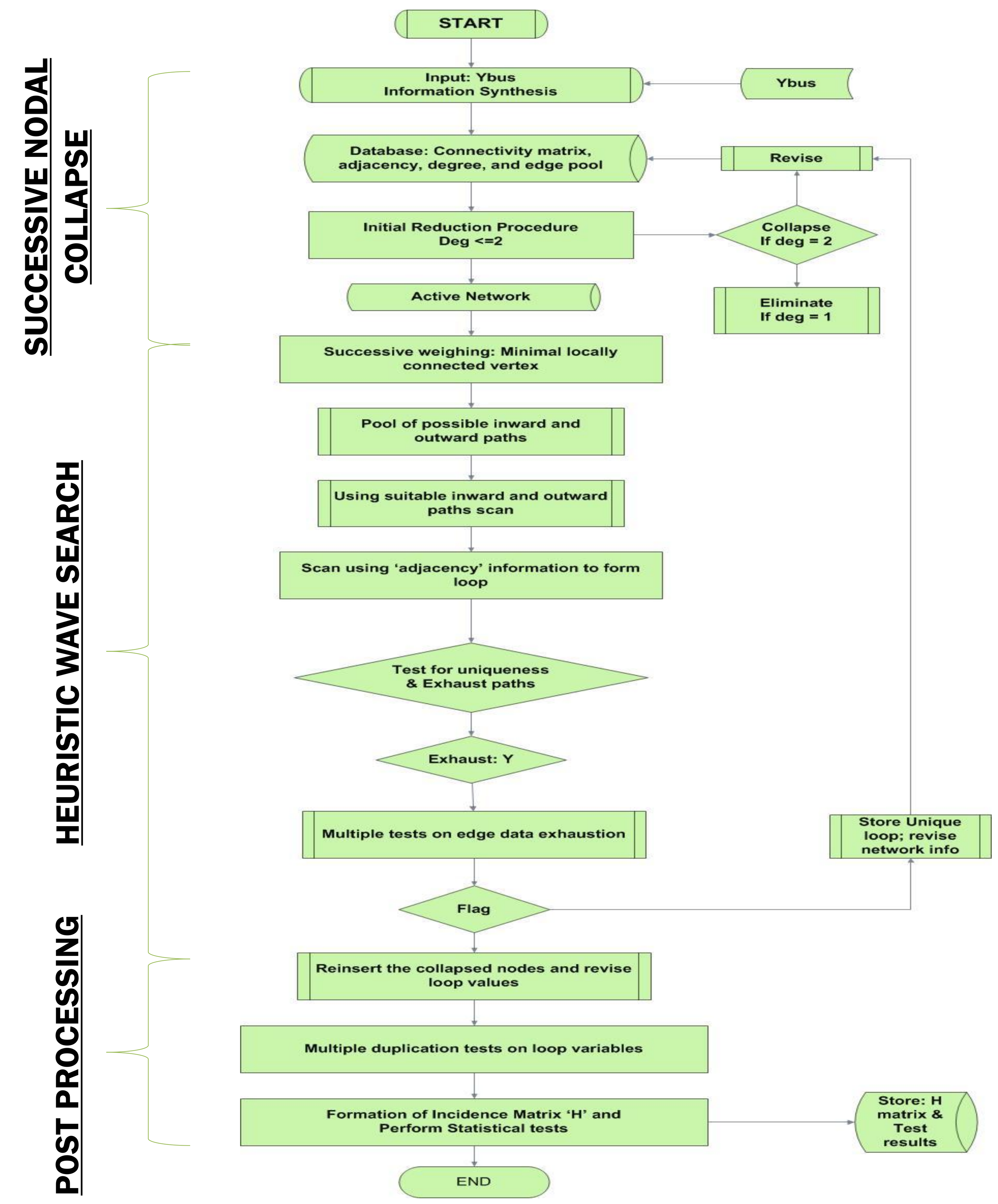
NETWORK REDUCTIONS

- Two major network reduction steps employed in are successive nodal collapse and heuristic wave search
- **Successive nodal collapse:** Forming smart adaptive edges by collapsing all 2 degree nodes successively
  - **STOP if min(degree) > 2**



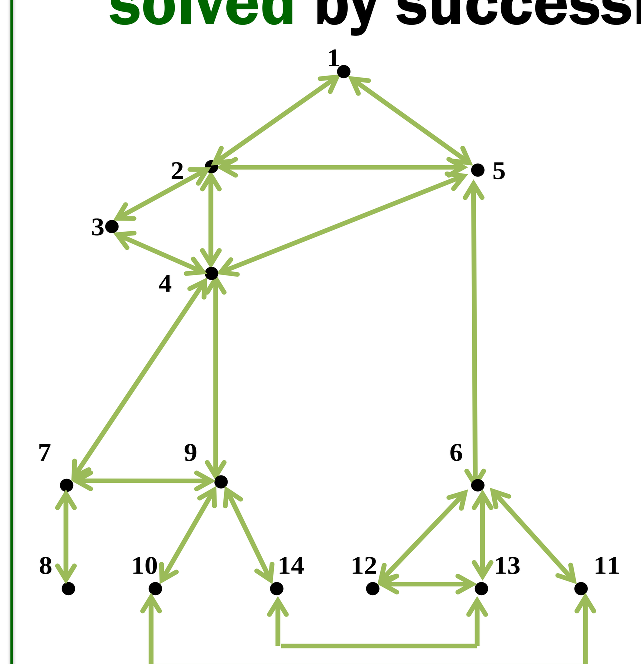
- **Heuristic wave search:** For an active network, determine the locally minimal complex node as the starting vertex
- On distinct outward and inward paths an intersection of imaginary waves is sought
  - **STOP first intersection of waves**
- **Cost function:** Minimum number of nodes in a loop are preferred

FLOWCHART

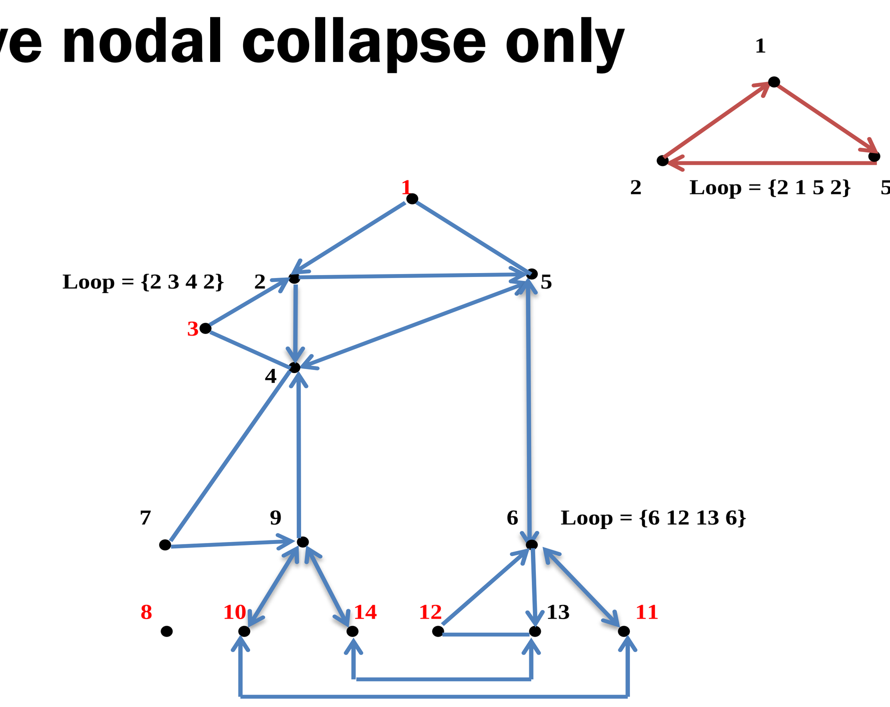


TEST NETWORK #1

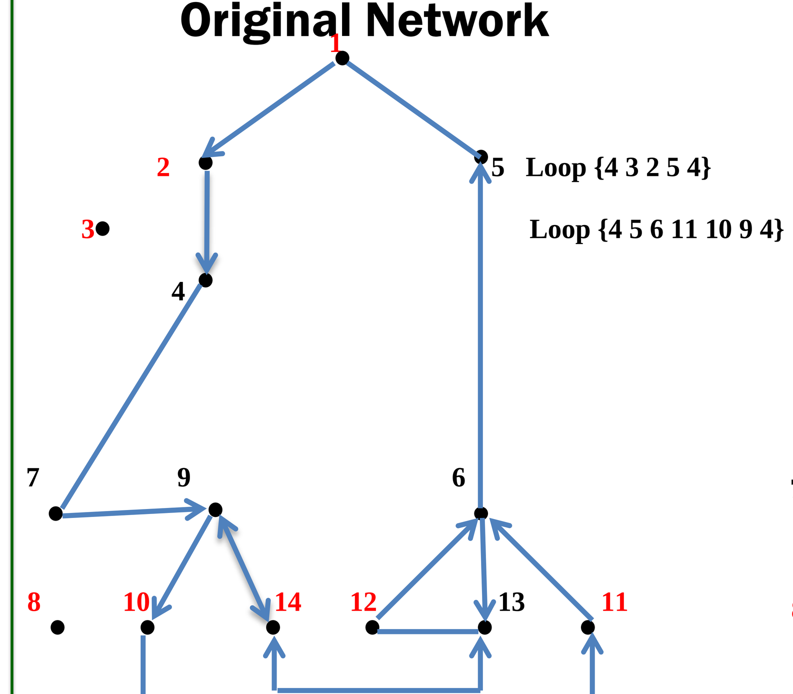
- IEEE 14 bus test system can be **completely solved** by successive nodal collapse only



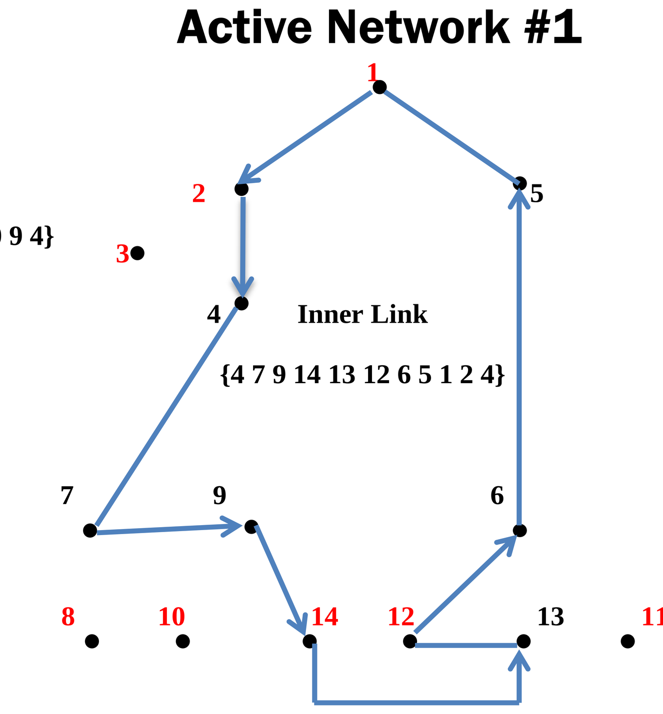
Original Network



Active Network #1



Active Network #2



Active Network #3

LOOPS IN TEST NETWORK

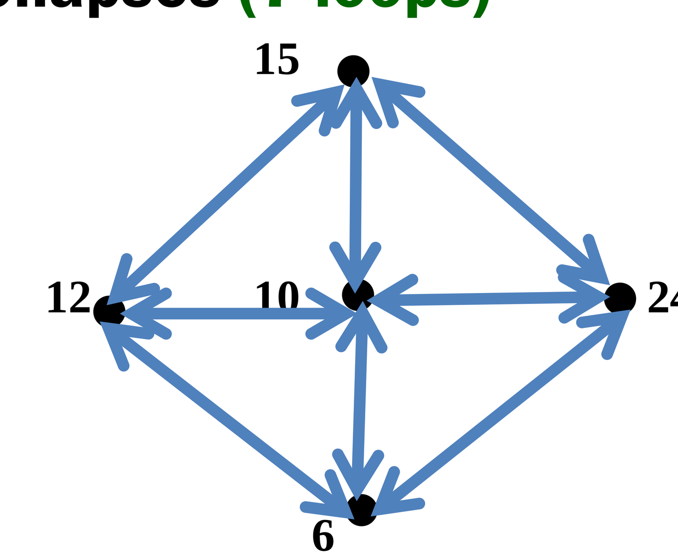
2 1 5 2	2 3 4 2
6 12 13 6	4 3 2 5 4
4 5 6 11 10 9 4	4 7 9 14 13 12 6 5 1 2 4
4 9 7 4	9 10 11 6 13 14 9

TEST NETWORK #2

- IEEE 30 bus test system under analysis **needs both** the reduction techniques
- Successive nodal collapse reduces the network significantly from 30 nodes to 5 nodes
- 4 loops are identified in addition to ones obtained in successive collapses (7 loops)

6 10 12 6
6 24 10 6
12 10 15 24 6 12
10 24 15 10

Wave Search Results



Active Network #1

CHALLENGES

- **Memory** management issues for bulk interconnections due to data sizes
- **No visual aid** available to troubleshoot for programming errors
- **Challenges:** Multicollinearity issues observed for system matrix formed for USF estimation

CONCLUSIONS

- Application of graph theory techniques to detect loops in power system networks
- **Accurate loops** detected for relatively simpler test systems
- Implementation on practical bulk interconnections under development
- **Alternating** between two reduction methods is the next step

REFERENCES

[1] R. Diestel, "*Graph Theory,*" 2nd ed,. Springer-Verlag: New York, Inc. 2000, pp. 1-25.
[2] A. Tucker, "*Applied Combinatorics,*" 4th ed., Wiley and Sons, 2002, pp. 129-165.

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