Planning of Grid and Supply Restoration in the Distribution Grid with a High Proportion of Renewable Energies and Distributed Generation

Yasir Shamim

Hendrik Vennegeerts

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Motivation

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Background

- Decommissioning of conventional plants
- Decentralized shift of generation to Distribution System Operator (DSO) grids
- Intermittency of renewable energy sources (RES)

Challenges

- Power system states closer to stability margin
- Decrease in available balancing energy in Transmission System Operator (TSO) grid
- Time dependency of available generation

- **Impact of high share of renewables not only in normal grid operation but also needs to be coped in emergency situations**

Grid and Supply Restoration (1/2)

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Present

- **Classical restoration approach**
  - Voltage from neighboring TSOs
  - Using own black start (BS) units
- **Switching on start-up grid**
  - Start BS unit
  - Synchronization of secured energy
  - Switching of secured loads

Future trend

- **RES:** Provide necessary functions
  - Grid operators require additional tools
  - Compensation for ancillary services
- **TSO↔DSO:** Intensive co-operation
  - TSO: Involve DSO in grid restoration
  - DSO: Develop concepts to integrate renewables

- **Focus on advanced restoration concepts (build-up/build-together)**
- **Shift from sequential to parallel system restoration approach**

Grid and Supply Restoration (2/2)

Preparation

- Assessment of the post-blackout status
- Definition of a suitable sectionalizing strategy (SS)
- Energization of the BS units

Note: The adequate assessment of the system and the selection of a suitable SS are critical

System Restoration

- Reconnection of lines within each island ▭ energization paths between the BS and NBS units
- Reconnection of load blocks ▭ stabilize frequency and voltage

Note: Load restoration in this step can optionally be applied to stabilize generators

Restoration time: Improvement potential

Load Restoration

- Mass load restoration in each island
- Load pick-up with lagging power factor ▭ control overvoltage

Note: Load restoration is the objective

Idea: Parallel Restoration ▭ **Approach:** Sectionalization Strategy ▭ **Objective:** Reduced total restoration time

Methodology

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Sectionalization planning

- Network modelling
  - Graph theory
  - K-shortest path algorithm

Heuristic initialization

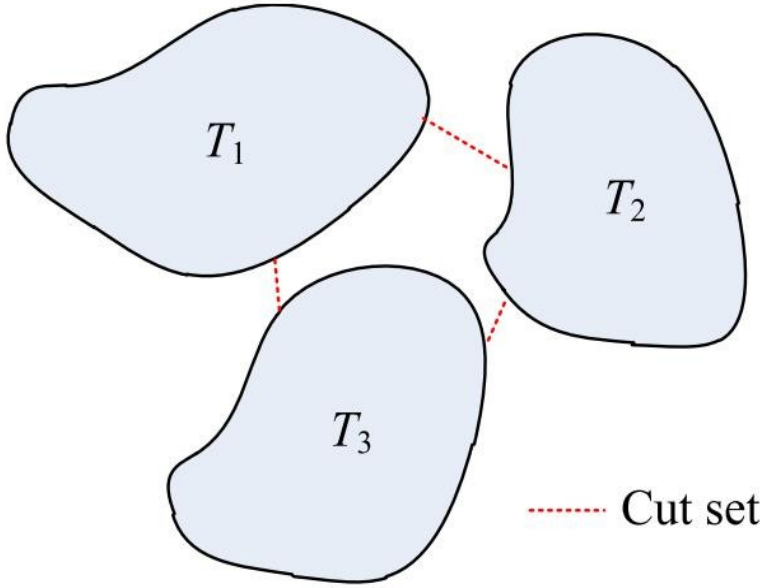
- Expert's knowledge and experience
  - Generator grouping
  - Searching movement

Discrete Evolutionary Programming (DEP)

- Discrete optimization technique
  - Minimal cut sets
  - Similar restoration times among islands

Sectionalization Planning (1/2)

- **System resynchronization time** ▭
- **Objective function :** Produce 'n' islands similar restoration times and minimal cut



→ min

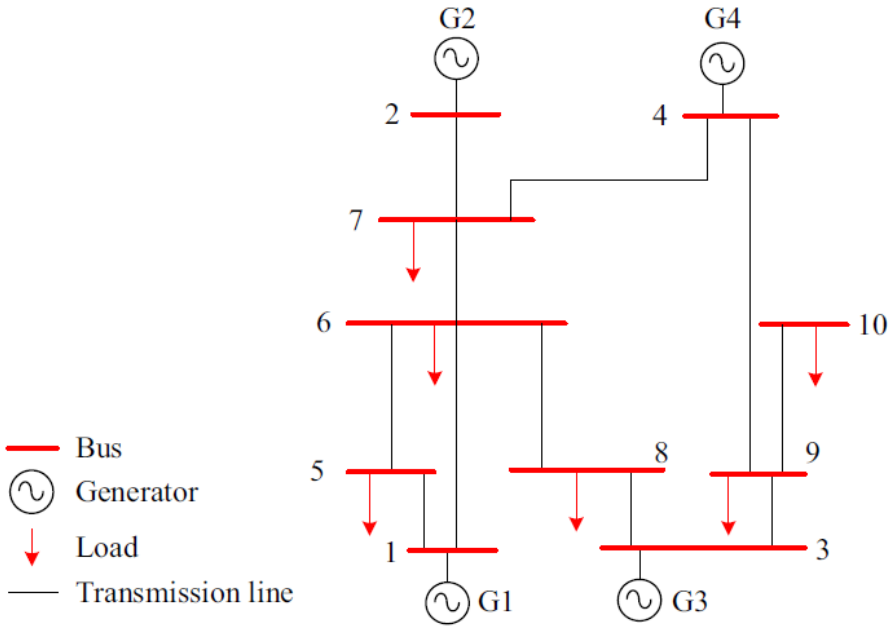
Restoration time of ‘n’ Islands

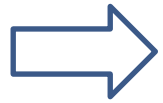
Cut set time to connect

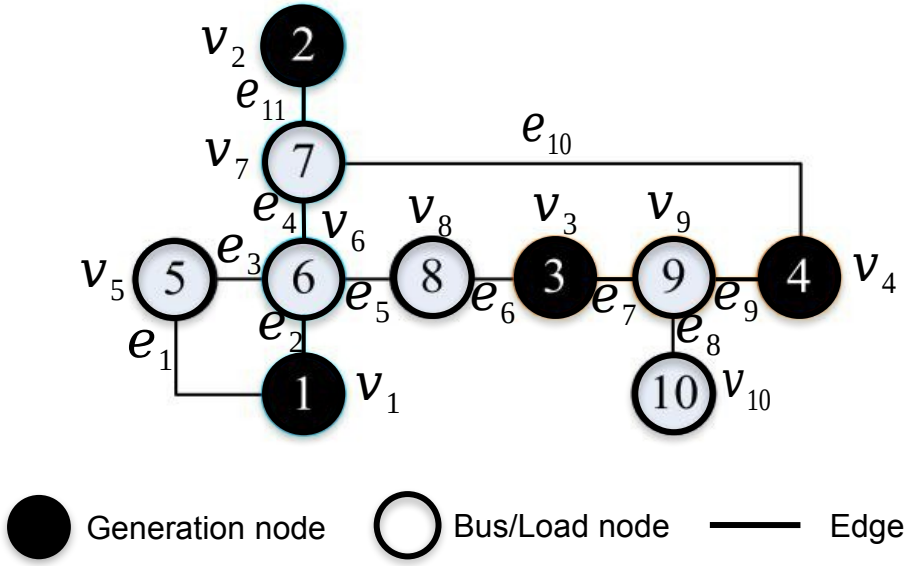
Cut set number

Sectionalization Planning (2/2)

- **Network modelling using Graph theory**
- **Post-blackout ⊟ Undirected network**
  - **V** = set of nodes, **E** = set of edges, **W** = weight factors of each edge connectivity







Heuristic Initialization Method (1/2)

- **Determination of reasonable initial cut set**
  - Reduction of search space for possible lines
  - Closer to optimal solution
- **Methodology**
  - Generator skeleton groups ▭ Number of BS units
  - Initial skeleton point generator nodes ▭ Connection of
  - Skeleton point expansion time ▭ Lowest restoration
  - Searching movement ▭ Initial cut set

Heuristic Initialization Method (2/2)

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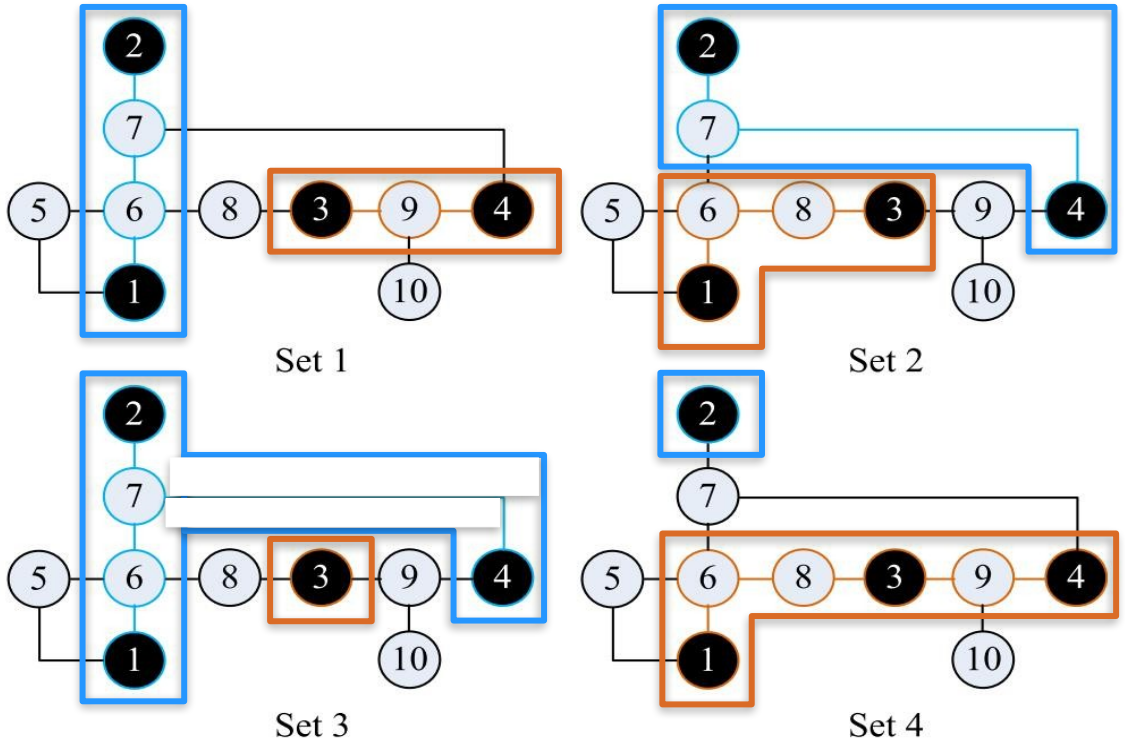
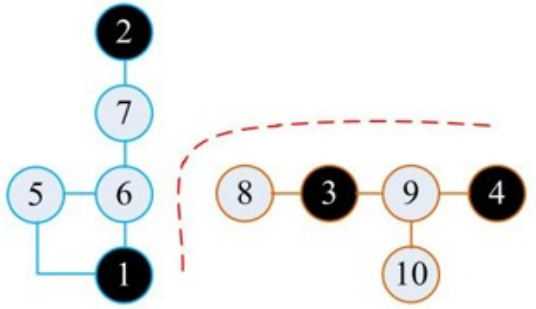
- **Generator grouping & initial cut set**



= 40MW, = 20MW, = 40MW, = 20MW

Set of groups	Generator node (Group 1)	Generator node (Group 2)			
1	1, 2	3, 4	60	60	0
2	2, 4	1, 3	40	80	40
3	1, 2, 4	3	80	40	40
4	2	1, 3, 4	20	100	80



Skeleton point group 1 | Skeleton point group 2 | Generator node | Group 1, BSG at node 2; | Group 2, BSG at node 3;

Discrete Evolutionary Programming

- **Objective:** Similar restoration time among the islands with minimal cut sets
- :
  - Initialization population ▭ objective function calculation
  - Mutation (new population) ▭ objective function calculation
  - Combination ▭ New and initial population
  - Selection ▭ Minimal objective function value

Simulation Results IEEE 39-Bus System

- **Heuristic Initialization**
  - Initial cut set definition
  - searching step
  - searching step
- **DEP application**
  - Final network expansion
  - Optimal cut set solution
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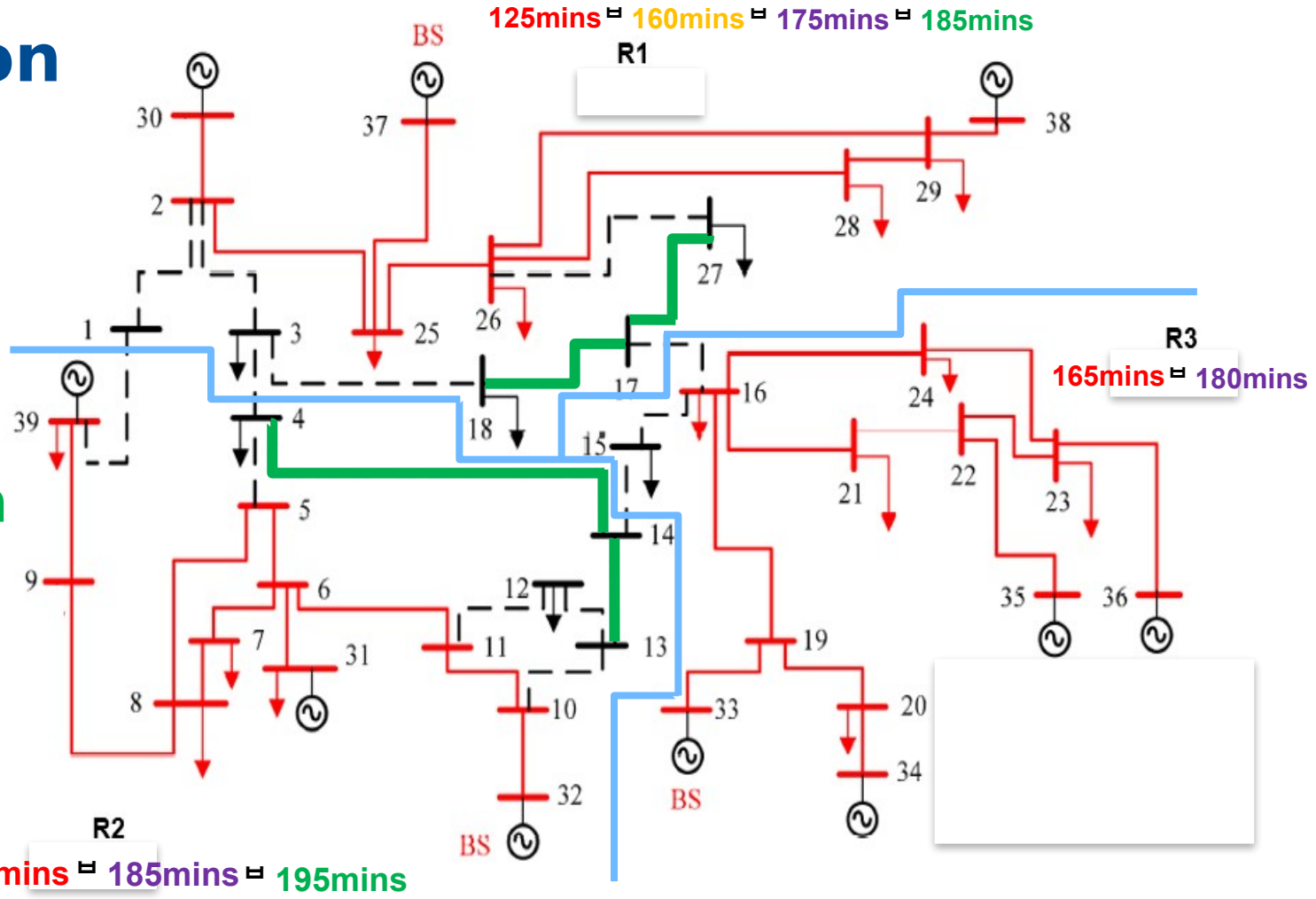

Adaptation for Distribution Network

- **Extended forecasting and control procedures**
  - Compliance with specified power bands
- **Additional restoration constraints**
  - DG dynamics and safety operational procedures
- **Time dependency of available generation**
  - Fast calculation of optimal islands
- **Location of the remote controllable stations**
  - Efficient island creation

Conclusion

- **Parallel restoration approach is effective to handle energy transition**
- **Optimal restoration solution for network planning and reconfiguration**
- **Framework for extension of restoration concept for DSO**
- **Potential challenges in the distribution grid to be adapted**

Thank you for your attention