Optimizing Power System Restoration Resources and Actions

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State of the Art

- Primarily manual work by operators
- Off line restoration planning
- Little progress has been made on system restoration methodology
- On line implementation limited
- Literature
System Restoration Stages

Load restoration is only a means to an end.

PREPARATION
Actions are time-critical

30-60 minutes

SYSTEM RESTORATION

3-4 hours

LOAD RESTORATION

Load restoration is the objective.
System Restoration Tasks

- Knowing status of the grid
- *Maximizing generation capabilities with the available black start resources*
- *Scheduling of tasks and resources during system restoration*
- Establishing transmission capability and paths while meeting operating constraints
- Picking up load while meeting operating constraints and load requirements
Example Restoration Strategies

- Build-upward
- Build-downward
- Other variations
First Stage

- Basic operations common to all strategies
- Sub-processes defining early stages of restoration process
- Minimal configuration of autonomous stable source with necessary transmission
Restoration Building Blocks

• May include non-autonomous BTG, connection transmission, necessary compensation & load blocks
• Associated with schedule of switching & control actions
Second Stage
Target System

- System state achieved by end of restoration process
- May not be pre-disturbance system
- Restrict set of post-restoration configurations
Restoration Constraints

- Physical constraints
- Scheduling constraints
- Policy constraints
Third Stage

Load Restoration – Pick Up Loads
Example – Generation Capabilities

(4 Different Generating Units)

G1

G2 (min int: 5)

G3 (max int: 4)

G4

TIME AFTER STARTUP

0 1 2 3 4 5 6 7 8

0 3 8 12 20
Example – *Optimal* Starting Sequence
Cranking Priorities

- **Units with critical maximum interval**
- **Critical max interval units with most urgent time constraint**
- **Units that can generate highest MWH within a given period**
## PECO-Energy Generating Units

<table>
<thead>
<tr>
<th>Unit</th>
<th>Type</th>
<th>MW Cap. (MW)</th>
<th>Ramp. rate (MW/hr)</th>
<th>Crank to paral. (hr)</th>
<th>Crit. max. int. (hr)</th>
<th>Crit. min. int. (hr)</th>
<th>Startup req. (MW)</th>
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MW Capability Curves
Restoration Strategy with Tie Lines
Crank NBS Units

System Restoration

Check If a Tie Line Can Crank an NBS Unit

- Check If There Is a Path Between Them
- Check If Tie Line Can Provide Enough Cranking Power
- Negotiate for More Power Import
- Check If Enough Load Can Be Found
- Negotiate for Less Power Import

Tie Line Utilization

Load Management

MW Management

Path Management
Respond to Request

System Restoration

Respond to Tie Line Request

- Check If System Can Provide Enough Power
- Negotiate for Less Power Export
- Check Transmission Capacity
- Decide Priority of Tie Line
- Check Load Restoration Condition
- Check NBS Units Restart Condition

Tie Line Utilization
Load Management
MW Management
MVAR Management
Path Management
Serve Load
Internal Units
to be Cranked by TLi
Internal Units to Provide TLe - TLi

Start time earlier than $t_{TL}$
Cranking Paths Affected
Induced MWh Increase

Diagram showing connections and time points between G1, G2, and G3.
Tie Line Utilization

**MWh Increase by S1**
- Increase from Earlier Startup of S1
- Increase *Induced* by S1

**MWh Decrease by S2 (S3)**
- Decrease from Delayed Startup of S2 (S3)
- Decrease *Induced* by S2 (S3)
Test Subsystem
System Generation Capability

![Graph showing System Generation Capability with and without Peach Bottom](image-url)

- **Without Peach Bottom**
- **With Peach Bottom**

**Axes:**
- X-axis: Min after blackout
- Y-axis: MW (Mega Watts)

**Legend:**
- Red line: Without Peach Bottom
- Green line: With Peach Bottom
System Generation Capability

From Peach Bottom
Generic Restoration Actions
(GRAs)

• `start_black_start_unit (X)`
• `find_path (X,Y)`
• `energize_line (X)`
• `pick_up_load (X)`
• `synchronize (X,Y)`
• `connect_tie_line (X)`
• `crank_unit (X)`
• `energize_busbar (X)`
Using GRAs to Construct RBBs
Using GRAs to Construct RBBs

- Find transmission path between BS & NBS
- Start black-start unit BS
- Build transmission path from busbar B1 to B3 and pick up loads for stabilization
- Crank non-black-start unit NBS
Using RBBs & GRAs to Build Restoration Strategies
Using RBBs & GRAs to Build Restoration Strategies

• **Select Two RBBs**
  - RBB1: Use BS1 to energize B1
  - RBB2: Use BS2 to energize B2

• **Build RBB1**
  - Prepare load
  - Start BS unit
  - Energize bus
Using RBBs & GRAs to Build Restoration Strategies (Cont.)

• Build RBB2
• Energize ring
• Restart non-black-start unit NBS
• Pick up loads along ring
Petri Net Algorithm to Optimize Sequence of GRAs
Schulykill-Southwark Subsystem
# Time to Complete GRAs

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<thead>
<tr>
<th>Generic Restoration Action (GRA)</th>
<th>Time (mins.)</th>
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<td>Restart BSU</td>
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<tr>
<td>Energize Busbar from BSU/busbar/line</td>
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<tr>
<td>Connect Tie Line</td>
<td>25</td>
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<tr>
<td>Crank a NBSU</td>
<td>15</td>
</tr>
<tr>
<td>Synchronize between Busbars/Lines</td>
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<tr>
<td>Pick up Load</td>
<td>10</td>
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Sequence of Actions for Schuylkill-Southwark

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<th>Time (min.)</th>
<th>Actions</th>
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<td>Connect BSU CT10</td>
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<tr>
<td>15</td>
<td>Energize bs2 from CT10</td>
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<tr>
<td>20</td>
<td>Energize bs3 from bs2</td>
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<tr>
<td>25</td>
<td>Energize bs4 from bs3</td>
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<tr>
<td>30</td>
<td>Crank NBSU ST3 from bs4</td>
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<tr>
<td>45</td>
<td>Synchronize ST3 with bs4</td>
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Sequence of Actions for Schuylkill-Southwark

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<th>Time (min.)</th>
<th>Actions</th>
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<td>15</td>
<td>Energize bs9 from CT3-4</td>
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<td>20</td>
<td>Energize bs10 from bs9</td>
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<td>25</td>
<td>Energize bs11 from bs10</td>
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<td>30</td>
<td>Crank NBSU ST1 from bs11</td>
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<tr>
<td>45</td>
<td>Synchronize ST1 with bs11</td>
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Restoration Building Block 2:
Sequence of Actions for Schuylkill-Southwark

---

65 Energize bs1 from bs2, bs14 from bs2, bs12 from bs3, bs5 from bs4, bs30 from bs9, bs8 from bs9, bs17 from bs11, bs15 from bs11, bs25 from bs10

70 Energize bs22 from bs1, bs19 from bs14, bs13 from bs12, bs7 from bs5, bs31 from bs39, bs21 from bs25, and synchronize bs14 with bs15

75 Energize bs32 from bs31, bs20 from bs21, bs23 from bs22, and connect bs7 with bs13, bs8 with bs7, and bs22 with bs21

80 Energize bs24 from bs23, bs26 from bs20

85 Energize bs27 from bs26

90 Energize bs28 from bs27

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Further Information