Power System Restoration - The Graceful Degradation Phase

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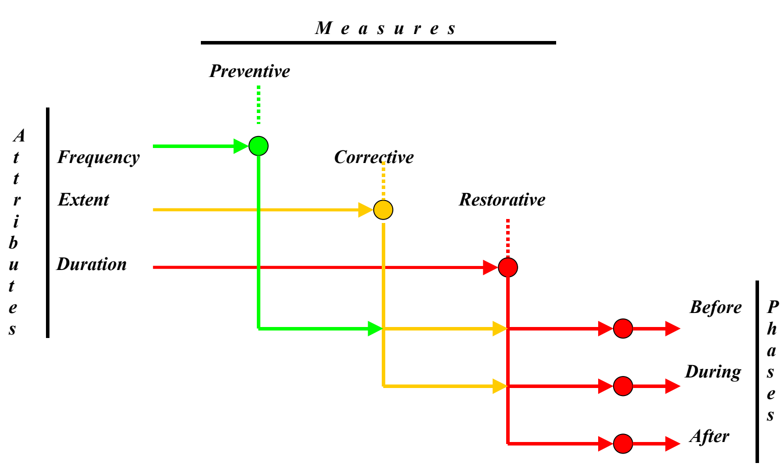
Major Power System Disturbances



Major Power System Disturbances

Given: that blackouts are likely to occur,

What can be done to: reduce their impact (i.e., their extent, intensity and duration)?

Major Power System Disturbances Sequence of Events

System	===➔	Northeast	PJM
Year	===➔	1965	1967
Event	Initial	0	0
Islands	Numbers	5	3
Formed	Seconds	7	5
Blackout	Minutes	12	9
Restored	Hours	13	8

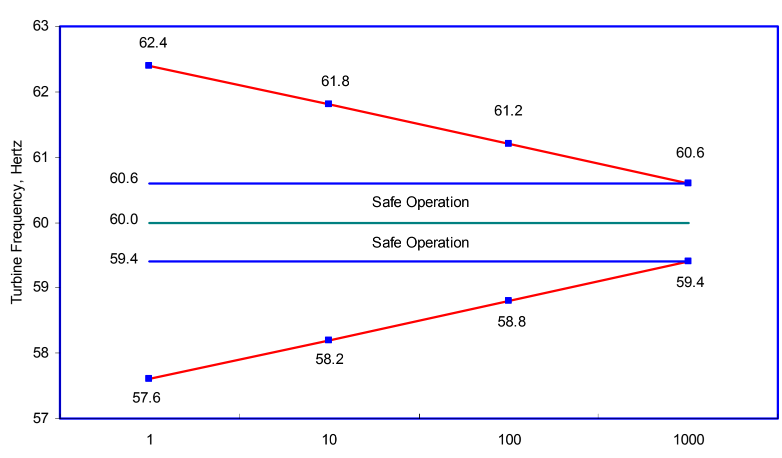
Federal Power Commission Reports

Major Power System Disturbances
After the Initial Cause

They may result in islands with:

- Insufficient generation (load-rich) experiencing a decay in system frequency, or
- Insufficient load (generation-rich) experiencing a rise in system frequency

Turbine Blade Damage
Bucket Limit Calculation



Immediately After the Initiating Cause

Frequency rise and decay are automatically arrested by:

- Load rejection,
- Load shedding,
- Low frequency isolation scheme, and
- Controlled islanding.

Immediately After the Initiating Cause

Success rate:

Over fifty percent !

Challenge:

Coordination of control and protective systems between power plants and electrical system.

Load Rejections

Generation Rich

To match generation with load, load rejections are used

Full-load Rejection:

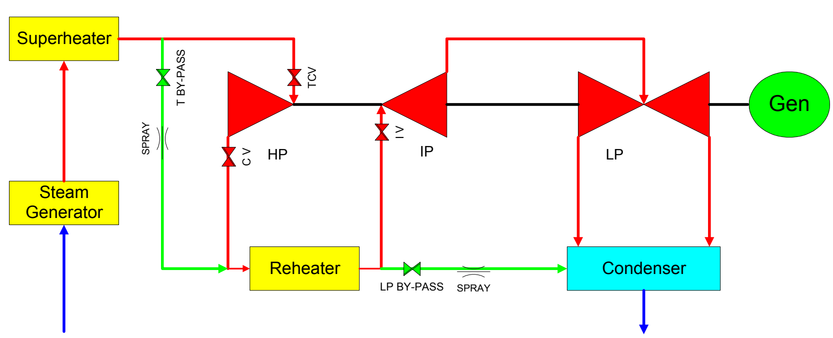
- The main generator breaker trips
- Loss of synchronization and full-load
- Steam generators runback from full-load to no-load (7%).

Partial-load Rejection:

- The main generator breaker remains closed
- Loss of partial load (10 to 30%)
- Steam generator usually requires no-runback

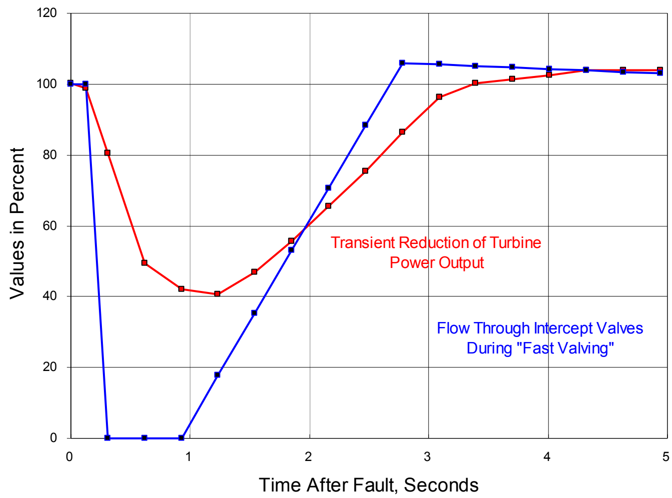
Basic System for Load Rejection

(Boiler: 10^6 pph, >3,000 psi, >10^3 °F)



TCV: Turbine Control Valve,
IV : Intercept Valve,
CV : Check Valve

Intercept "Fast Valving"



Load Rejection Performance

Depends on % of PLR

- Germany: One in two (50%)
- France: One to four in five (20 to 80%)
- Ontario Power: Eight in twelve reactors (66%)[1]
- Italy: Few thermal units successfully load-rejected[2]
- USA: Analysis of 50 BTG trips, 30% due to TG, 42% due to BT & 28% due to operators[3]

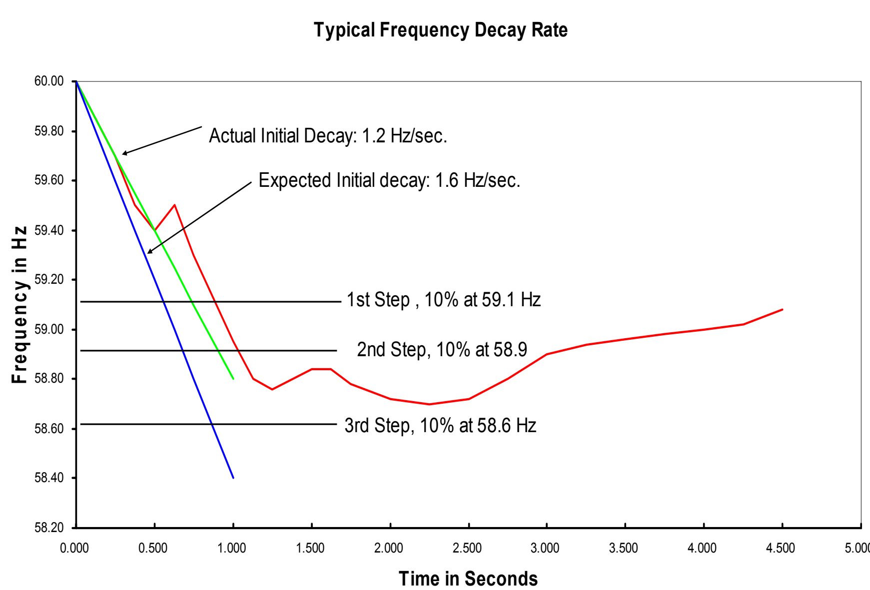
1. Blackout of August 14, 2003
2. Blackout of September 28, 2003
3. Very few operational, primarily due to conservative operating philosophy

Under-frequency Load Shedding

Load Rich

To match load with generation, under-frequency load shedding is used:

- Number of frequency step, 3
- Frequency set points, 59.3, 58.9 and 58.5Hz
- Load shed per step, 10%
- Fixed time delay per step, 5-8 cycles
- Correct operation of over 50%



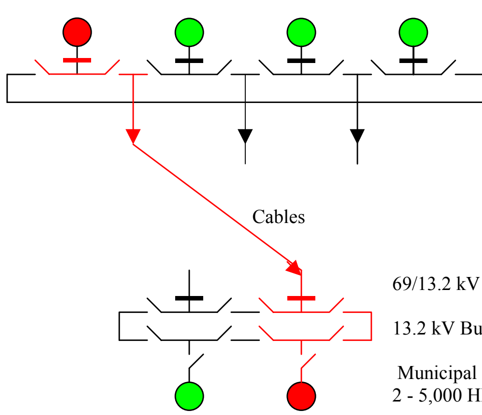
Under-frequency Load Shedding

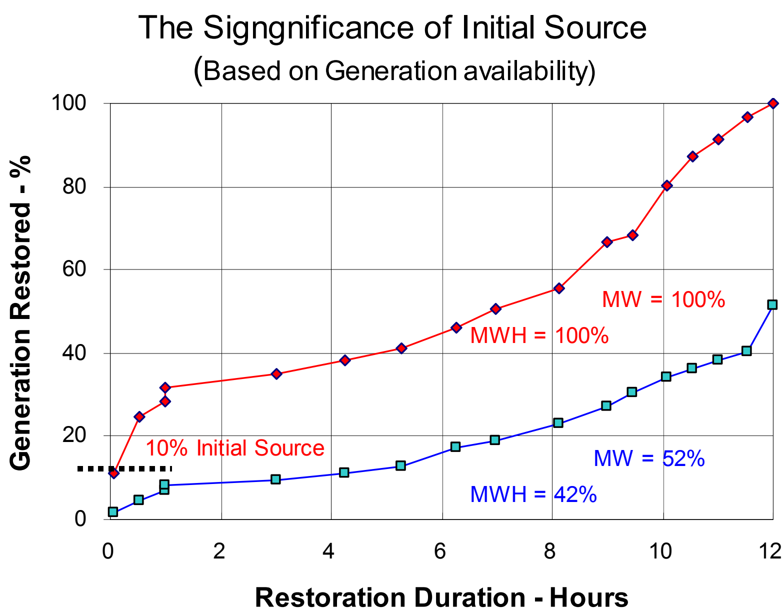
- Shed radial feeders, interrupting many small loads
- Restore the interrupted load manually at about 59.3 Hz
- Have experienced incorrect operation at high and low temperatures
- Have observed difference in frequency as much as 0.2 Hz
- Assume the change in load as 0.5% per 0.1 Hz

Low Frequency Isolation Scheme

After the Initial Event

4 - 100 MW, 13.8 kV Generators





Low Frequency Isolation Schemes

Performance

Over 50 US utilities have successfully used LFIS to isolate one or more generators with matching loads.

The majority:

- Use automatic under-frequency relay to initiate the action,
- Select generators for isolation,
- Set the under-frequency relay between 58 and 58.5 Hz., &
- Allow time delay of 6 to 8 cycles, and

Controlled Islanding

After the Initial Event

- Initial Events: Faults occur and are cleared
  in milli-seconds
- Subsequent Effects: Systems separate into islands
  in seconds
- Final Results: Load & gen. imbalance causes blackout
  in minutes

Conjectures

(Not Fully Verified)

- Out-of-Step Location:

  Depends on the prevailing system configuration and load level,
  Is independent of initial fault location or fault intensity, and
  Occurs one operation at a time (cascades) with adequate time interval.

- Transfer Tripping Locations:

  Split the system into two parts (islands), and
  Each part having minimal load and generation imbalance.

Figure 2 - Swing Curves Under Heavy-Load Condition

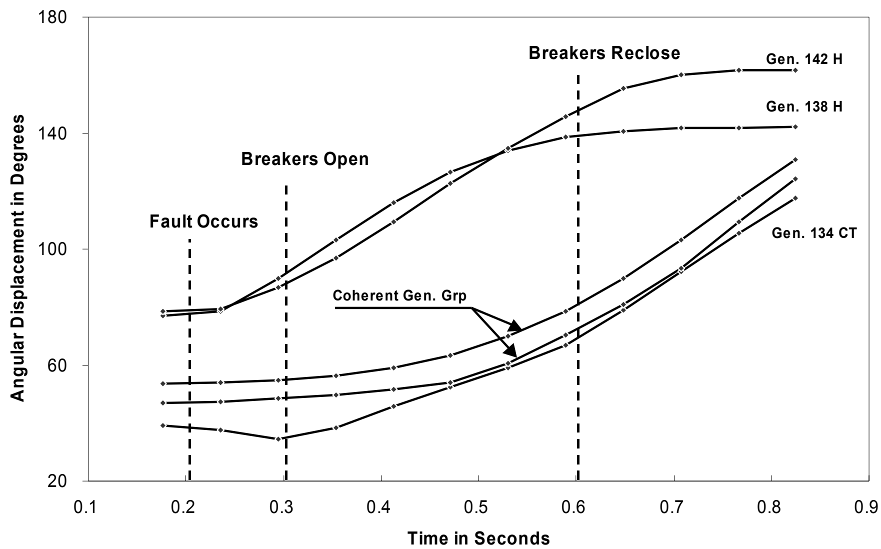
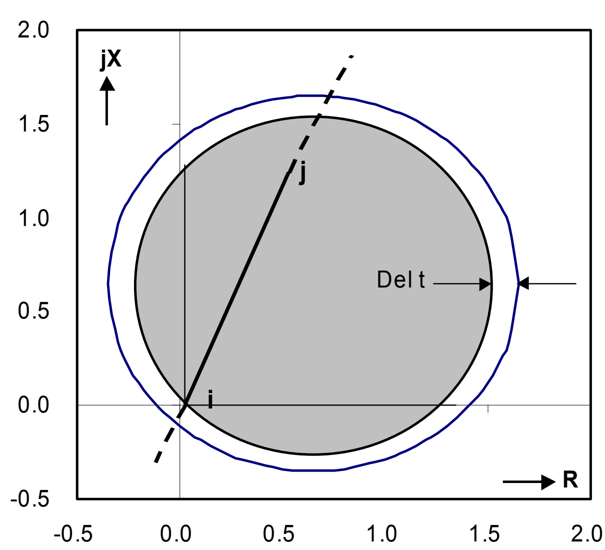


Figure 6 - Angle-Impedance relay (Buffer or Blinder)



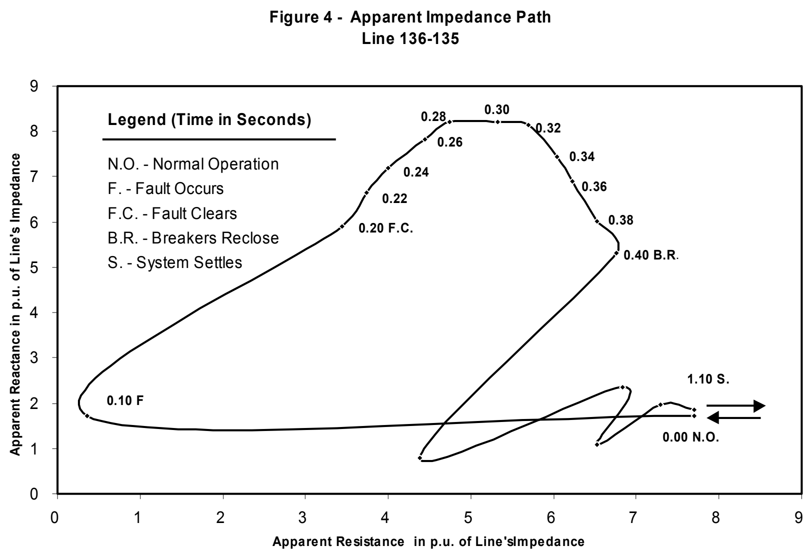


Figure 4 - Apparent Impedance Path
Line 136-135
Legend (Time in Seconds)
N.O. - Normal Operation
F. - Fault Occurs
F.C. - Fault Clears
B.R. - Breakers Reclose
S. - System Settles
0.28
0.30
0.32
0.26
0.34
0.24
0.36
0.22
0.38
0.20 F.C.
0.40 B.R.
1.10 S.
0.10 F
0.00 N.O.
Apparent Reactance in p.u. of Line's Impedance
Apparent Resistance in p.u. of Line'sImpedance

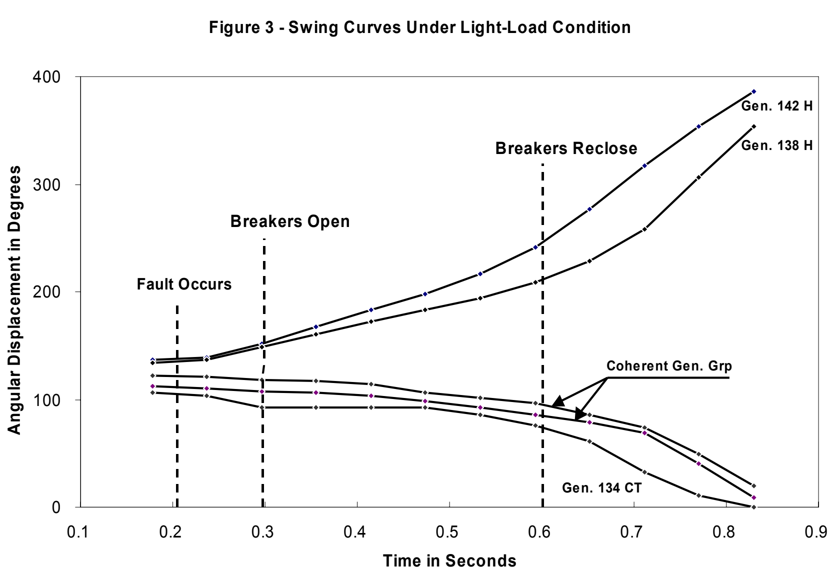
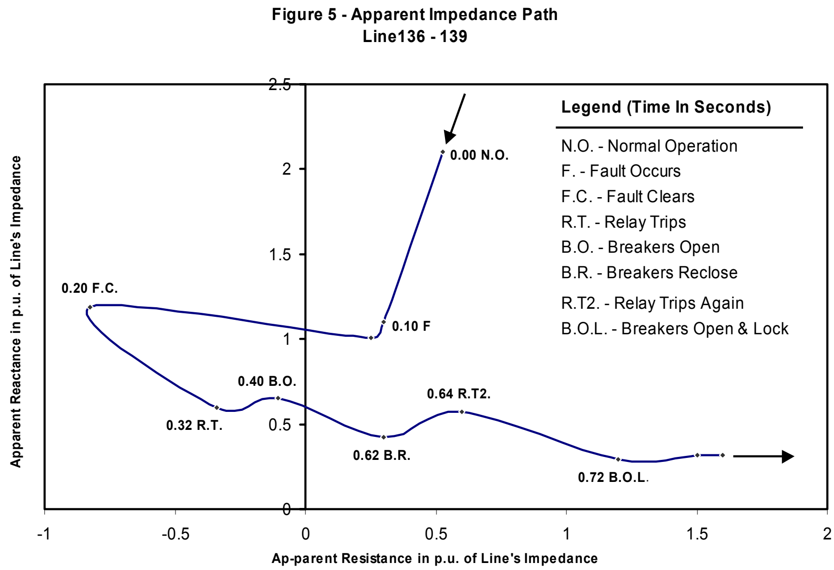


Figure 3 - Swing Curves Under Light-Load Condition
Gen. 142 H
Gen. 138 H
Breakers Reclose
Breakers Open
Fault Occurs
Coherent Gen. Grp
Gen. 134 CT
Angular Displacement in Degrees
Time in Seconds



Real Time Controlled Separation

Out-of-step blocking relays:

- Prevent separation where there is heavy power flow (unbalanced load and generation).

Transfer tripping relays:

- Allow separation where there are light power flows (balanced load and generation).

The Graceful Degradation Phase

Past Experience:

The probability of success in retaining initial sources of power by:

- Full and Partial Load Rejections,
- Under-frequency Load Shedding
- Low Frequency Isolation Schemes,
- Controlled System Separation, and

has been greater than 50%.

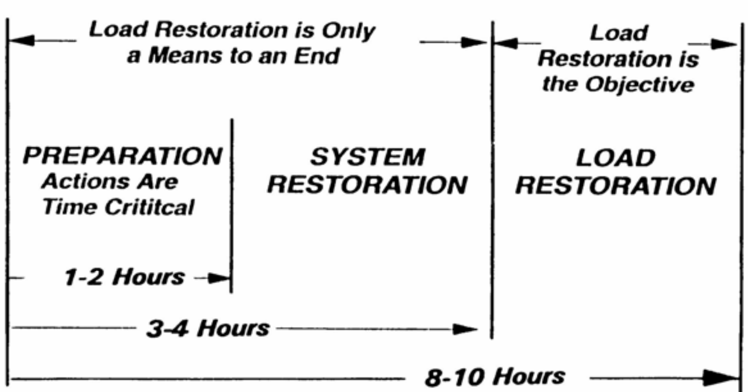
Future Challenge:

Need better control & protection coordination between:

- **Prime mover's (BTG), and**
- **Electrical systems.**

Restoration Stages

After Subsequent Effect



After the Subsequent Effect
Partial or Complete Blackout

Load and generation are manually balanced by:

- Starting with the initial sources of power, and
- Supplying the critical loads in the priority order.

After the Subsequent Effect
Partial or Complete Blackout

Success rate:

Complete blackouts need improvements.

Challenge:

Coordination of actions by power plants and electrical system operators.

Power System Restoration

After Subsequent Effect

The tasks are to:

- List and rank the critical loads by priority,
- List and rank the initial sources of power by availability, and
- Determine the most effective ways of bringing the two together.

Initial Critical Loads

After Subsequent Effect

	Priorities
• Cranking Drum-Type Units	High
• Pipe-Type Cables Pumping System	High
• Transmission Stations	Medium
• Distribution Stations	Medium
• Industrial Loads	Low*

- Is Used in the Initial Stage to An Advantage

Initial Sources of Power

After Subsequent Effect

	Minutes	Success Probability
Run-of-the-River Hydro	5-10	High
Pump-Storage Hydro	5-10	High
Combustion Turbine	5-15	Medium (50%)
Tie-Line with Adjacent Systems	Short	Not Relied On *

* Policy: Provide Remote Cranking Power

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Restoration After a Blackout

Preparation Stage (1 to 2 Hours)

- Evaluate Pre-Disturbance Condition & the Post-Disturbance Status
- Define the Target System
- Restart Generators & Rebuild Transmission Network

System Restoration (3 to 4 Hours)

- Energize Transmission Path
- Restore Load to Stabilize Generation and Voltage
- Synchronize Islands and Reintegrate Bulk Power System

Load Restoration (8 to 10 Hours)

- Load Restoration is the Governing Control Objective
- Load Pickup is Scheduled Based on Generation Availability
- Load Restoration is Effected in Increasingly Larger steps

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