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Adaptive Islanding to Prevent Cascading Failures

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PSERC Seminar

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Background

- This seminar reports on the work done in a recently completed PSERC project S-19 “**Detection, Prevention and Mitigation of Cascading Events**.”
- The portion of the work described in this seminar addresses the “**Mitigation**” part of the project and is used as a last resort if the “**Prevention**” part fails.
- Graduate students involved – Xiaoming Wang (Graduated now with MISO), Bo Yang(ASU)

Background

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- The "Detection" part dealt with detailed simulation of relay operation and an approach to detect whether an initiating disturbance could lead to other outages. This aspect of the work was lead by Mladen Kezunovic at Texas A&M.
- The "Prevention" part included the use of a wide area measurement based control to damp small signal oscillations that could result in cascading outages. This aspect of the work was lead by Mani Venkatasubramanian at Washington State University.

Motivation

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- Power systems are under increasing stress as restructuring introduces several new economic objectives for operation.
- When a power system is subjected to large disturbances, and the detection combined with prevention part of this project does not work, the system then approaches a potential catastrophic failure.
- Appropriate mitigation actions need to be taken to steer the system away from severe consequences, to **limit** the extent of the disturbance, and to **facilitate** power system restoration.

Mitigation Strategy

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- In our approach, the system is first separated into several smaller islands at a slightly reduced capacity by a controlled islanding approach. Second, an adaptive load shedding scheme is deployed to bring back the frequency to an acceptable level.
- The basis for forming the islands is to minimize the load-generation imbalance in each island, thereby facilitating the restoration process

Slow Coherency Grouping Based Islanding Using Minimal Cutsets

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- Given a system operating condition we determine the **slowly coherent** groups of generators.
- Depending on the disturbance location we then determine **minimal cutsets** using a graph theoretic approach which **minimizes load generation imbalance** in each island.
- In some situations we merge islands depending on the situation.

Slow Coherency Based Grouping

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- EPRI's DYNRED package was used to perform the slow coherency base grouping.
- This package has an option called tolerance based slow coherency which is used to determine the slowly coherent groups of machines.
- Important to note that this first step only gives us the machine groupings. It does not tell us where to form islands.
- I will not emphasize this aspect since I have provided details on this issue in a previous PSERC seminar.

Minimal Cutset Based Islanding

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- Once the slowly coherent groups of machines have been found the critical step in the process is to determine **what lines can be removed to** create islands.
- *MINIMAL CUTSET*: For a given graph $G = (V, E)$, a subset of edges $C \subset E$ is a minimal cutset if and only if deleting all edges in C would divide G into two connected components.

Minimal Cutset Based Islanding

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- Minimal cutsets have been widely used in network topology, maximum flow, and power system reliability analysis.
- Power systems can be considered as directed graphs with weights at vertices. Once an island is formed, **the net flow in the lines tripped indicates exactly how different the real generation and load is within the island**.

Minimal Cutset Based Islanding

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- Therefore, the problem has been converted into **searching the minimal cutsets (MCs) to construct the island with the minimum net flow**.

- We can decompose the islanding problem into two stages:
  - Find Minimal Cutsets candidates
  - Obtain Optimal Minimal Cutset by various criteria

Minimal Cutset Based Islanding

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Network Reduction

- It is very difficult to enumerate all the possible minimal cutsets for the original network. Network reduction is the only option.

- Once the slow coherency machine grouping information is available, network reduction is applied to decrease the dimension of the network.
    - First Stage Reduction
    - Second Stage Reduction: ***Vertices Contraction***

Minimal Cutset Based Islanding

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- The first stage reduction is fairly straight forward. Once the weighted graph is created the degree of each node can be ascertained. In this stage we simply drop all nodes of a certain degree.
- At the second stage of reduction, vertices contraction is applied in which the network will be greatly reduced to a reasonable scale.

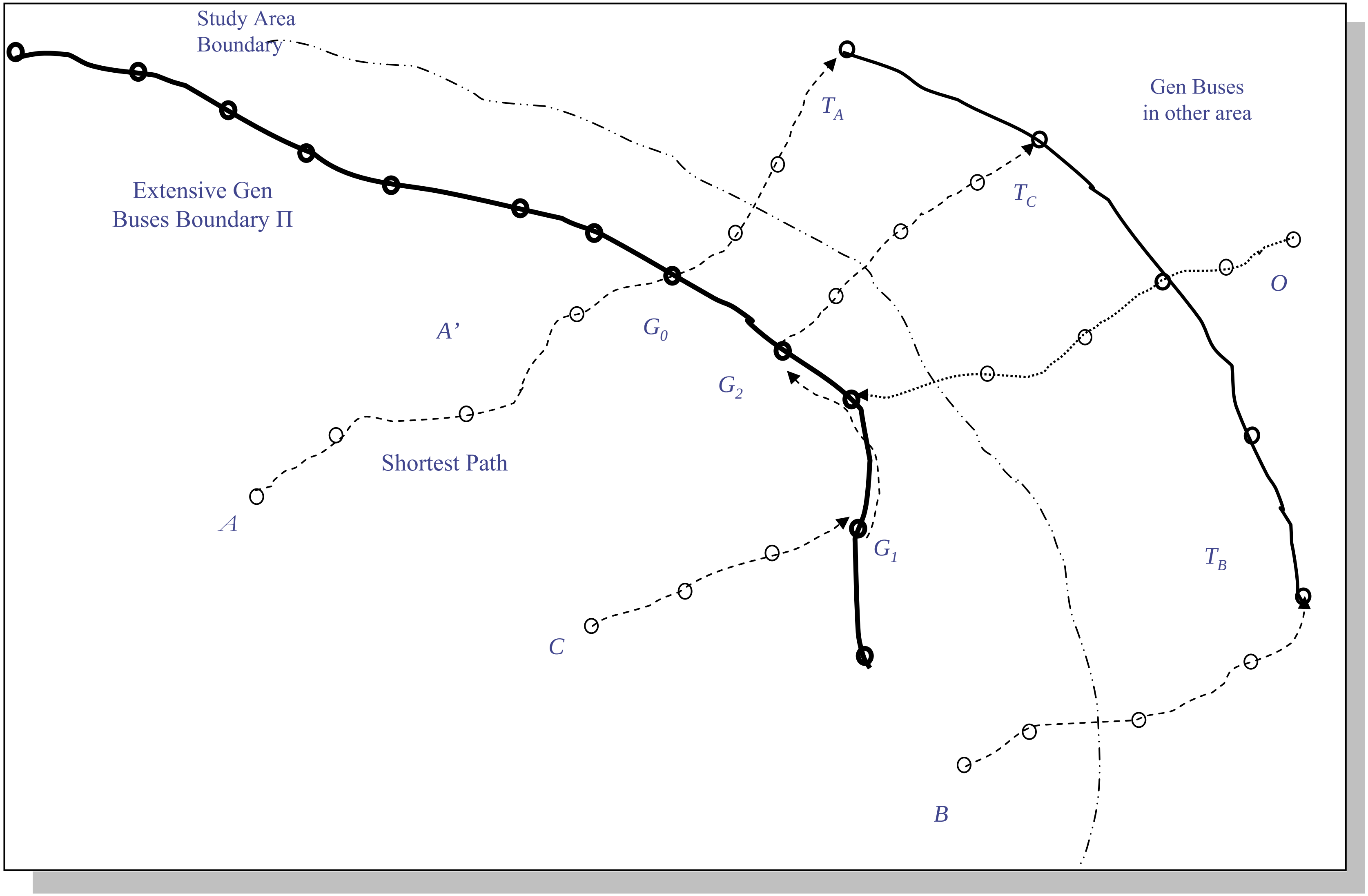
Minimal Cutset Based Islanding

Vertices Categorization Process

- Vertices categorization basically investigates each system vertex and decides which generator group it belongs to.

- This is also referred to Generator Bus Extension Process, after which, the uncategorized vertices constitute the area from which the minimal cutsets will be obtained.

Minimal Cutset Based Islanding



Controlled System Islanding Realization

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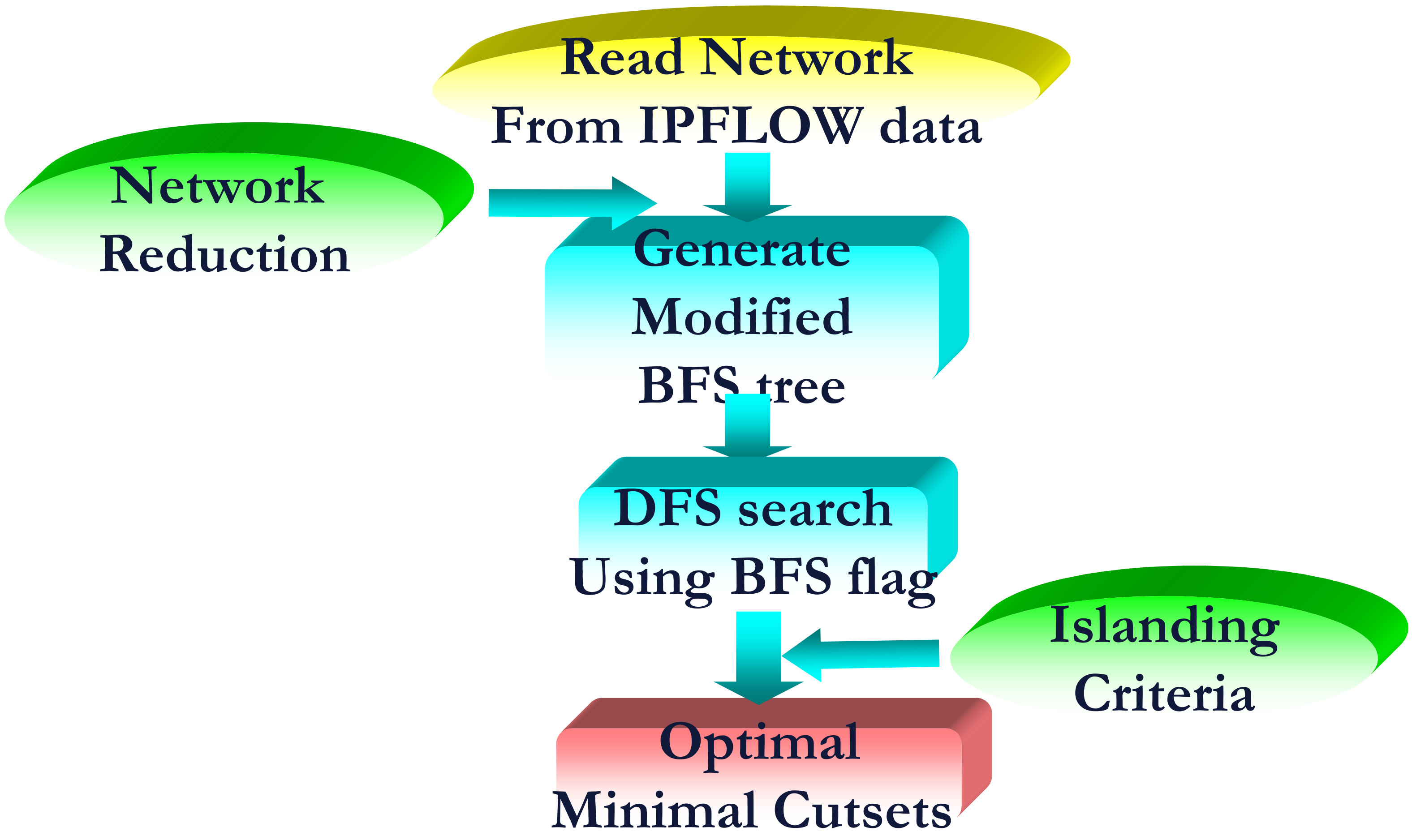
- An approach developed to automatically determine where to create the island using Minimal Cutsets and Breadth-First searching (BFS) flag based Depth-First searching (DFS) technique in Graph Theory.
  - Network reduction
  - Generate modified BFS tree with no offspring in sink vertex
  - With BFS flag, DFS search will be conducted to enumerate all possible MCs
  - Islanding criteria will be applied to select the optimal MC.

Schematic of Approach



Two approaches to islanding

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- We have also developed two independent approaches to merge the slowly coherent groups as necessary and created optimal islands. These approaches are termed:
  - Tuning Trial-Error Iterations
  - Aggregated Island Approach

Adaptive load shedding

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- In the load rich islands we will have to perform load shedding
- Load shedding schemes used before 1980s were almost all based on frequency decline (UFLS). This conventional load shedding scheme has the following disadvantage: 1) longer low frequency system operation caused by slower UFLS action; 2) possible over amount of load shed associated frequency overshooting.
- An adaptive load shedding scheme is used by taking **rate of frequency decline** into consideration.

Testing of Approach

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- In this project we applied the results to a 29-Generator 179-Bus WECC test system.
- The results of the testing are available in the final report that is on the web
  http://www.pserc.org/cgi-pserc/getbig/publicatio/reports/2005report/vittal_pserc_report_s19.pdf
- After the project was completed we were able to get a large 2004 Summer Peak Load case for the Eastern Interconnection. The results will be demonstrated on this system.

Large Scale Test Case

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- This was a study case obtained from Dr. Navin Bhatt from AEP.
- It is the 2004 Summer Peak Load Case for the Eastern Interconnection.
- It has 35,000 buses and nearly 5000 generators.
- All the modeling detail provided in the base case was **retained without any change**.
- The proposed approach was applied to the August 14th, 2003 scenario.

Application to the August 14th, 2003 Blackout Case

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- Important to note that what will be shown **should be viewed as a qualitative demonstration** of the approach developed and **not a quantitative analysis**.
- This is because the Summer 2004 peak case that was sent was considered and the August 14th, 2003 scenario was recreated from the joint US-Canada task force final report.
- Since no other details were available **this may not be an exact recreation.**
- Our analysis is done to show the efficacy of the method and to demonstrate it on a large realistic test case.

Preparation of Case

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- The conditions given in the joint US-Canadian final report were implemented in the base case obtained.
- The power flow was then obtained.
- **<u>This shows the state of the system before the final set of disturbances occurred.</u>**
- The details of changes implemented are shown in the next few slides.

Preparation of Case

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Generator	Rating		Reason for Outage
Davis-Besse Nuclear Unit (FE:202)	934 MW	481 Mvar	Prolonged NRC-ordered outage beginning on 3/22/02
Eastlake Unit 4 (FE:202)	267 MW	150 Mvar	Forced outage on 8/13/03
Monroe Unit 1 (DECO:219)	780 MW	420 Mvar	Planned outage, taken out of service on 8/8/03
Cook Nuclear Unit 2 (AEP:205)	1,060 MW	460 Mvar	Outage began on 8/13/03
Conesville 5 (AEP:205)	400 MW	145 Mvar	Tripped at 12:05 on August 14 due to fan trip and high boiler drum pressure while returning a day early from a planned outage.

Preparation of Case

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- Adjust generation from AEP to compensate for this loss of generation in FE
- Remove Columbus-Bedford 345 kV Line
- Remove Bloomington- Denois Creek 230 kV line
- Trip Eastlake 5 generation
- Remove Chamberlin – Harding 345 kV Line
- Remove Stuart-Atlanta 345 kV Line
- Remove Hanna- Juniper 345 kV Line
- Remove Star-South Canton 345 kV Line

Preparation of Case

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- Remove the following 138 kV lines
  - Cloverdale-Torrey
  - E. Lima – New Liberty
  - Babb – W. Akron
  - W. Akron – Pleasant Valley
  - Canton Central Transformer
  - Canton Central – Cloverdale
  - E. Lima – N. Findlay
  - Chamberlin- W. Akron
  - Dale – W. Akron
  - West Akron-Aetna
  - West Akron-Granger-Stoney-Brunswick-West Medina
  - West Akron-Pleasant Valley
  - West Akron-Rosemont-Pine-Wadsworth

Preparation of Case

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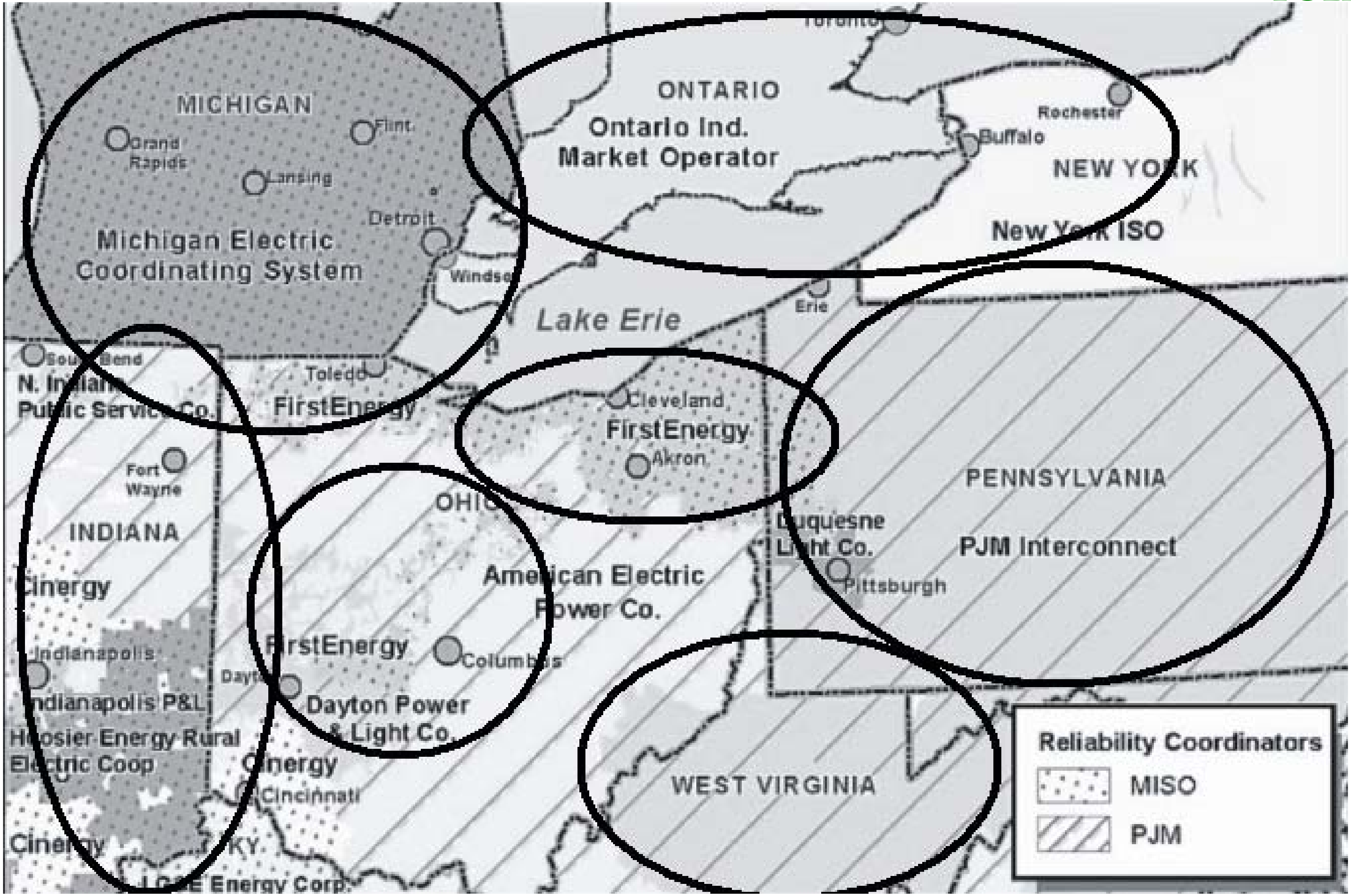
- EPRI's slow coherency program was then run using the solved power flow case and the dynamic data provided to obtain the **slowly coherent groups**.
- All the modeling details provided in the data were included.
- No simplifications were made.
- **One of the slowly coherent groups identified was the entire FE area.**

Coherent generator groups identified in the Eastern Interconnection



Identifying island within slowly coherent group

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- Within the slowly coherent group identified, we then applied the graph theoretic approach to determine the island with the smallest generation load imbalance.

- This island is shown on the next slide.

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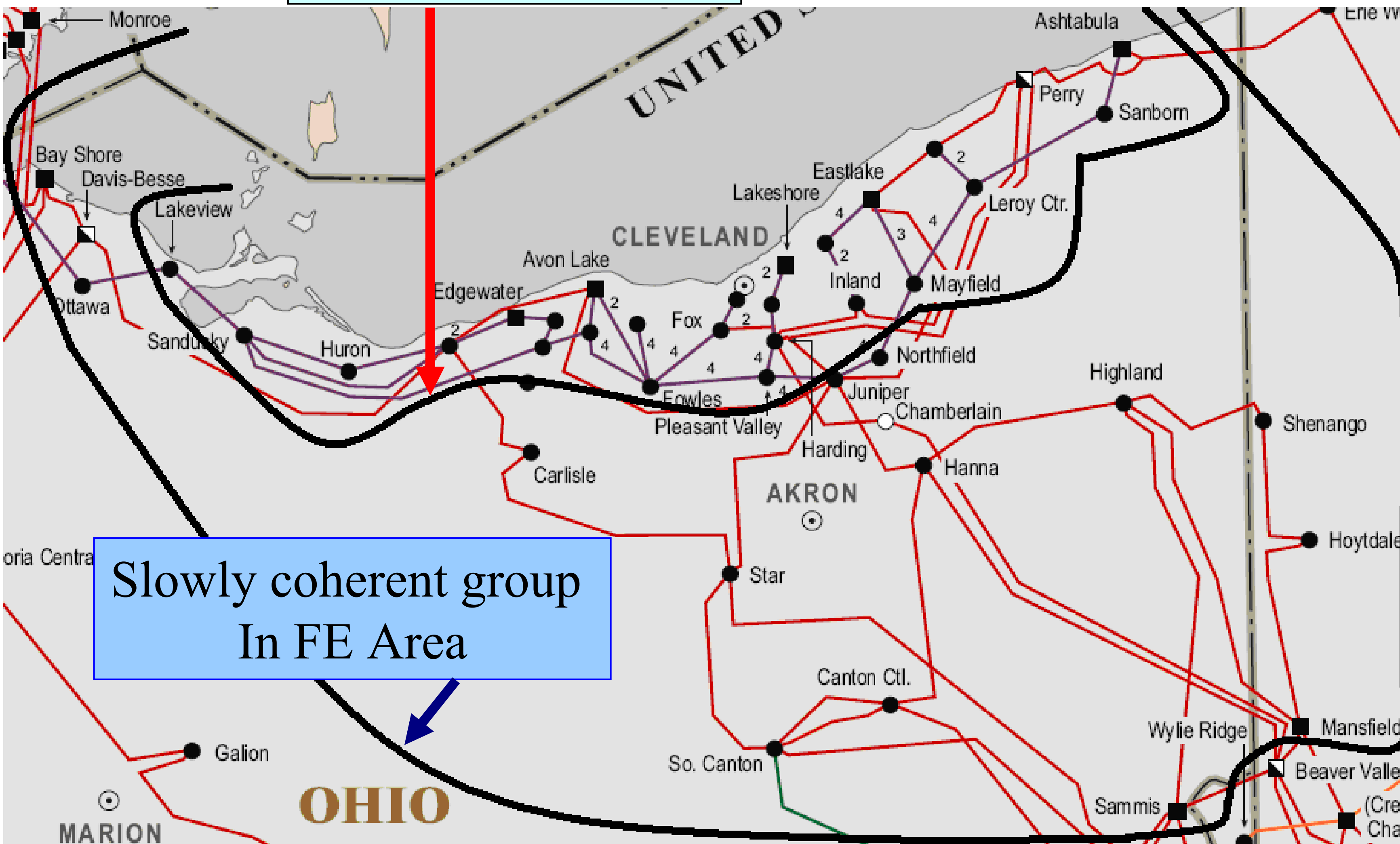
Island created by Automatic islanding program



Slowly coherent group In FE Area

August 14th, 2003 Scenario

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- The Dale-West Canton 138 kV line sags into a tree and trips.
- In 2s this led to the overloading of Sammis-Star 345 kV line which then tripped.
- This tripped on Zone 3.
- This was the start of the cascade.

Creation of Island

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- At time t=0s a three phase fault occurs at Dale and the Dale-West Canton 138 kV line is tripped.
- We then create an island near the Cleveland area.
- In order to create the island we have to trip 16 lines:
  - 6 - 345 kV lines
  - 5 – 138 kV lines
  - 5 – 69 kV lines
- This island has:
  - Total generation = **3688.3 MW**
  - Total load = **5950.4 MW**
- The rate of frequency decline base load shedding sheds **(32%)** or **1904 MW** of load in the island

Statement from Joint US-Canada Report

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- **“*The team found that 1,500 MW of load would have had to be dropped within the Cleveland-Akron area to restore voltage at the Star bus from 90.8%(at 120% of normal and emergency ampere rating) up to 95.9%(at 101% of normal and emergency ampere rating)*.”**

- Based on this suggestion a load shedding only approach is also examined.

- The load was shed in the Cleveland area immediately after the Dale-West Canton line had tripped.

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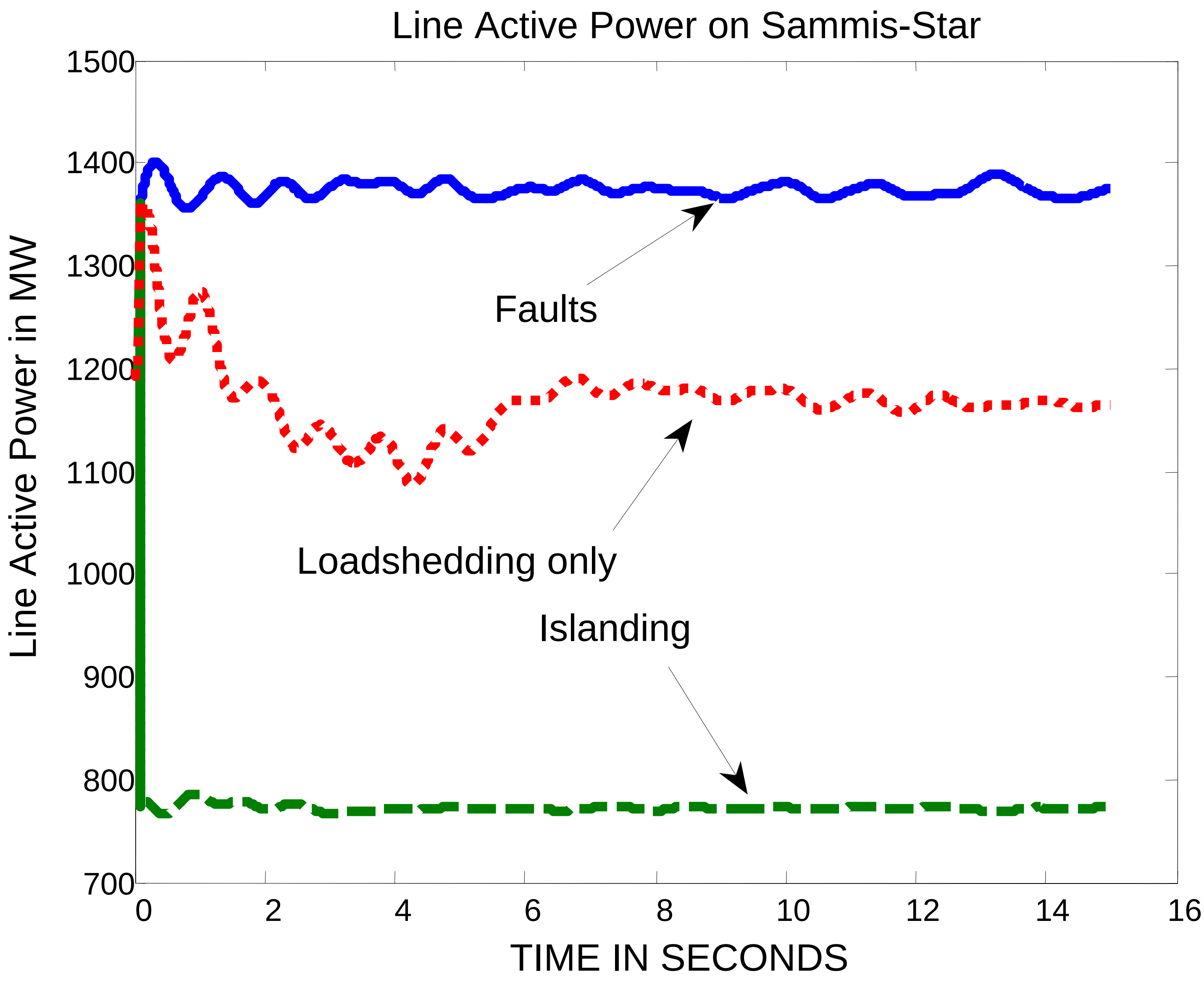
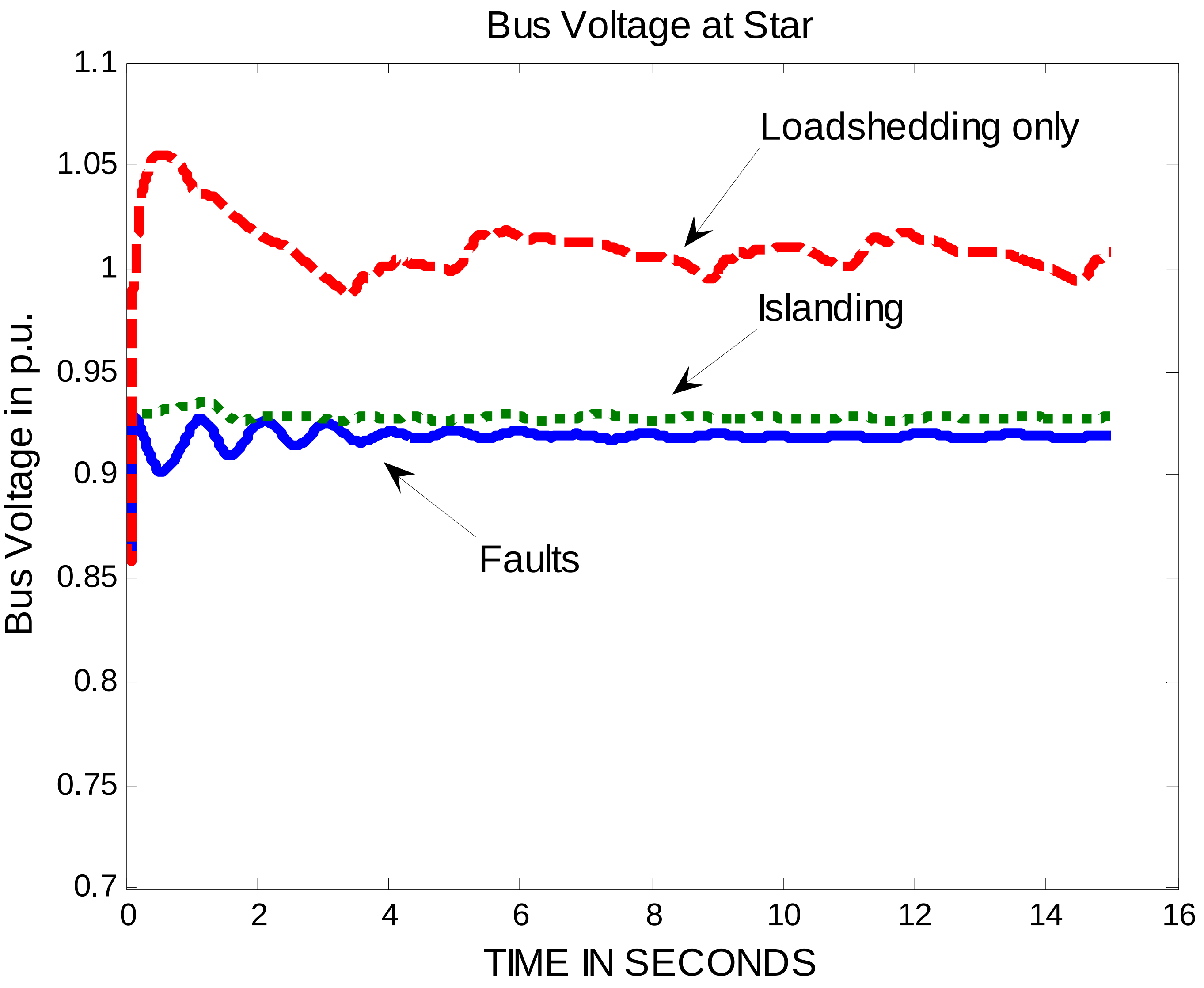
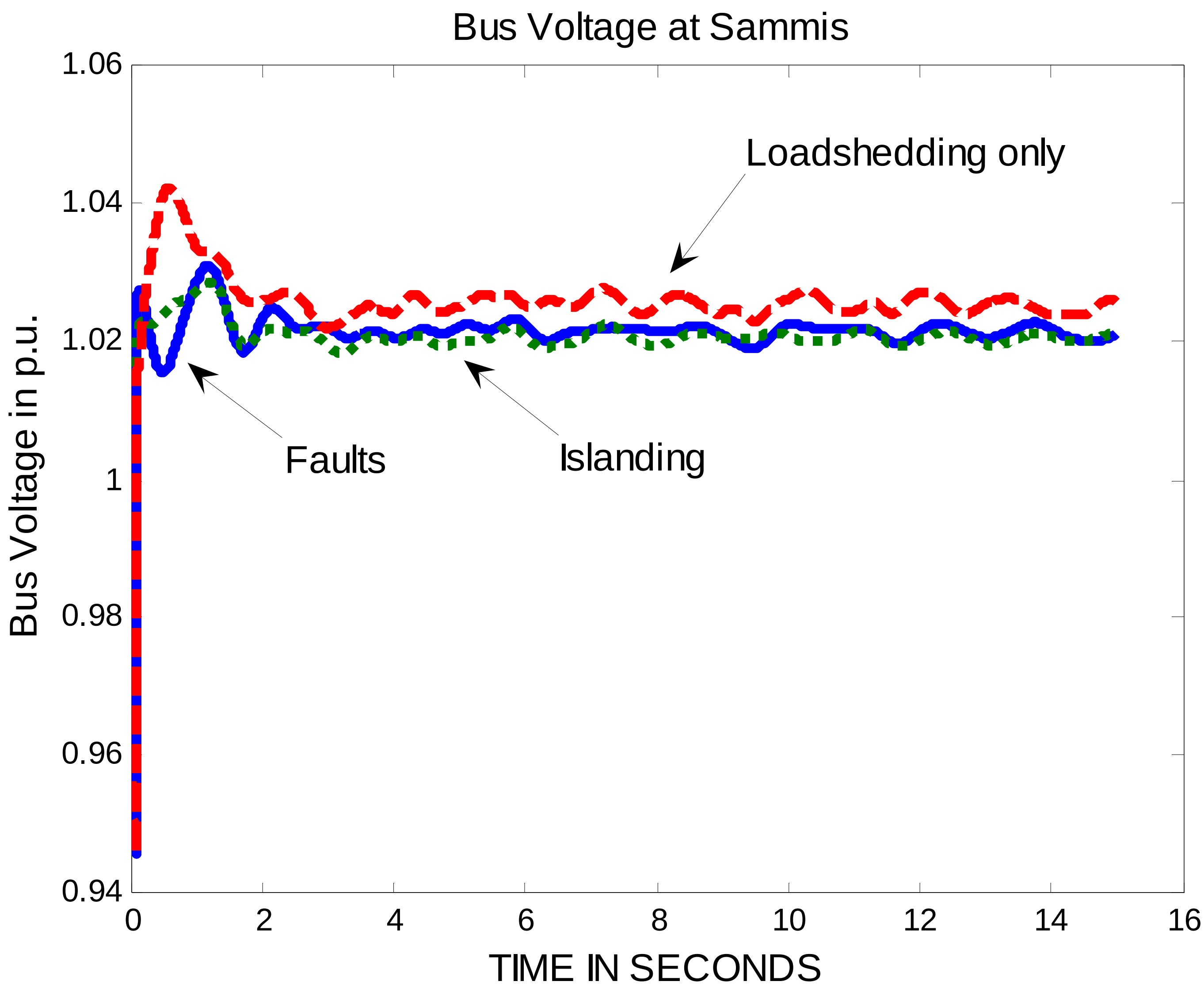
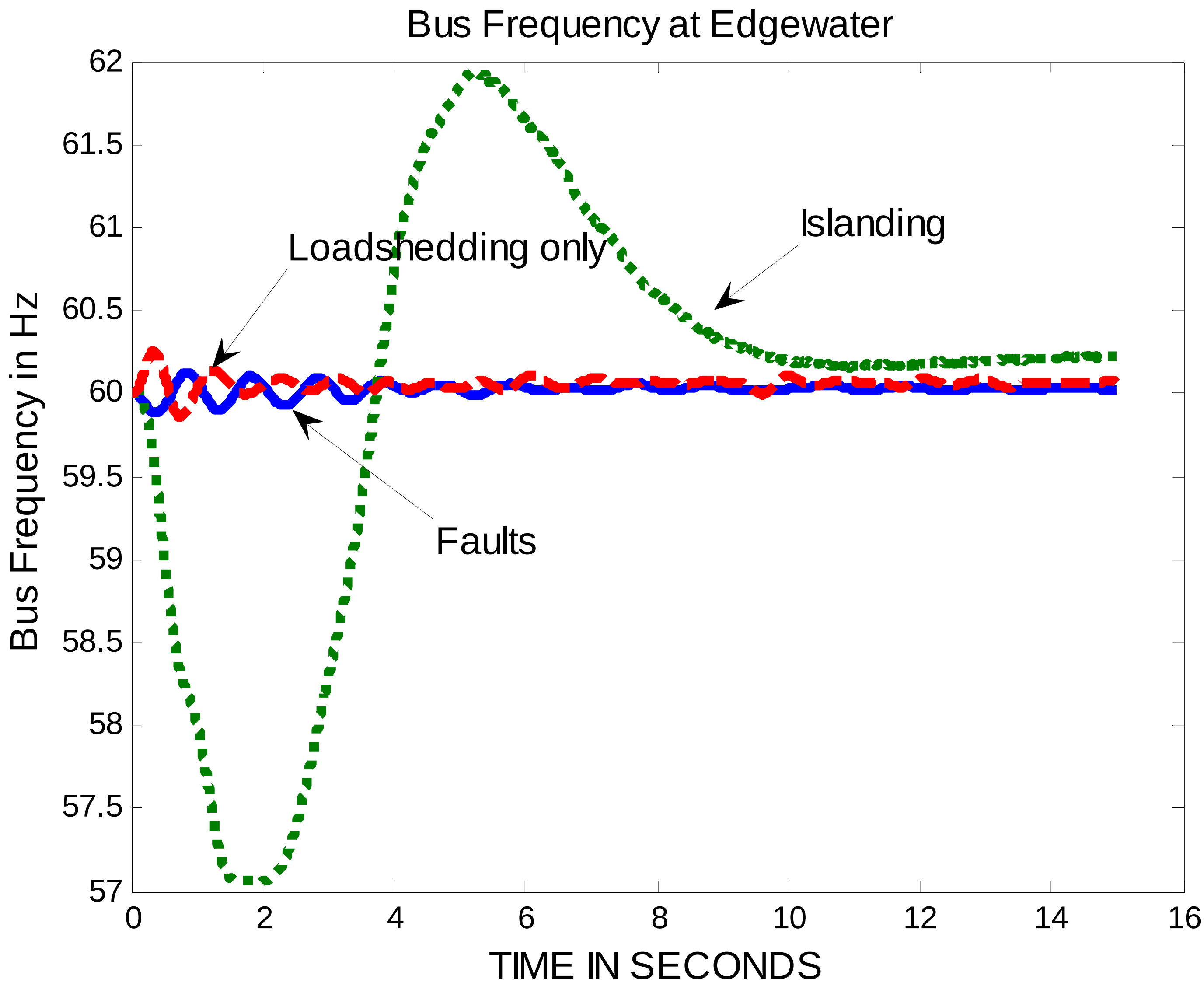
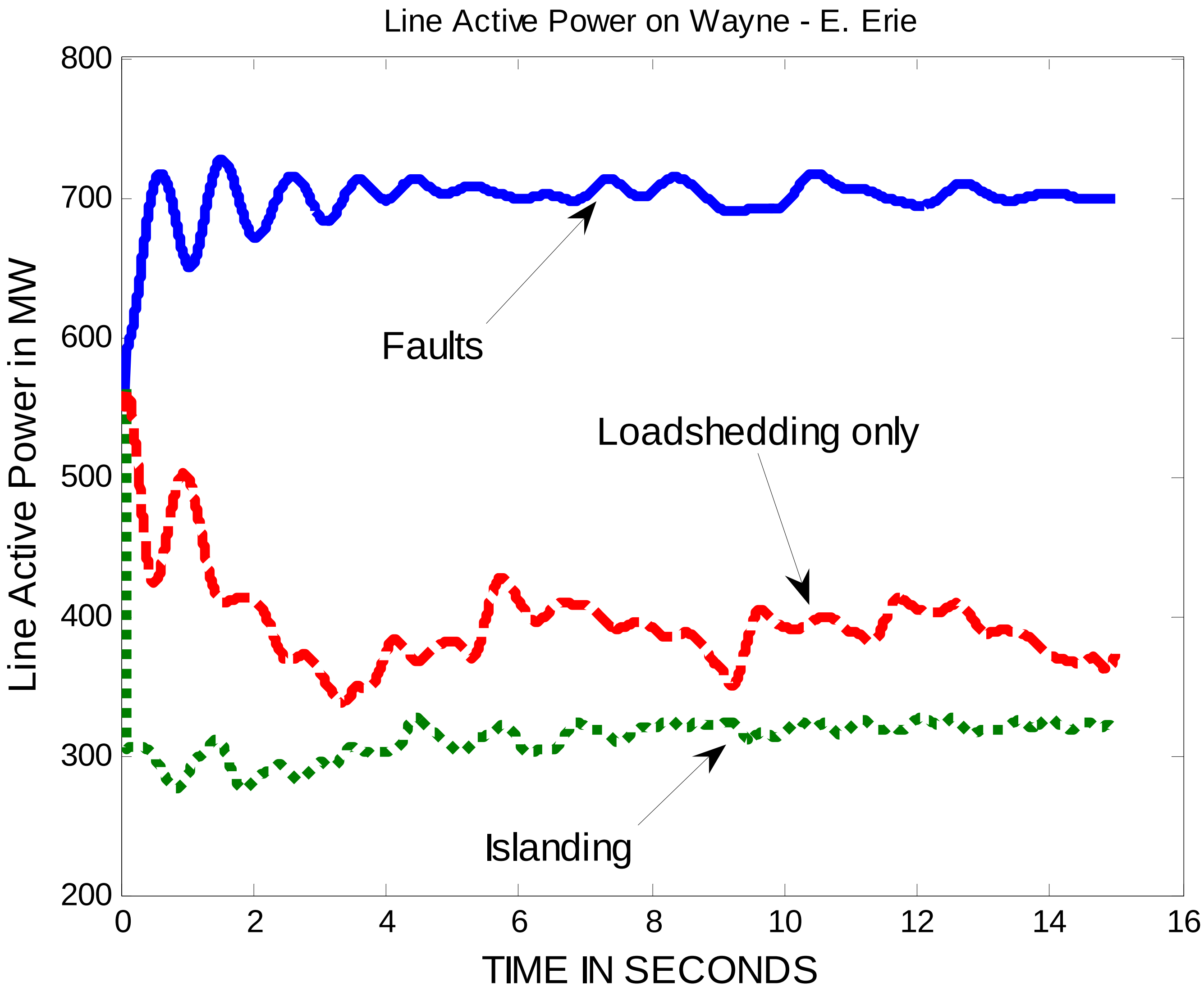

Line Active Power on Sammis-Star
Line Active Power in MW
TIME IN SECONDS
1500
1400
1300
1200
1100
1000
900
800
700
0
2
4
6
8
10
12
14
16
Faults
Loadshedding only
Islanding


Bus Voltage at Star
Bus Voltage in p.u.
TIME IN SECONDS
Loadshedding only
Islanding
Faults
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0
2
4
6
8
10
12
14
16

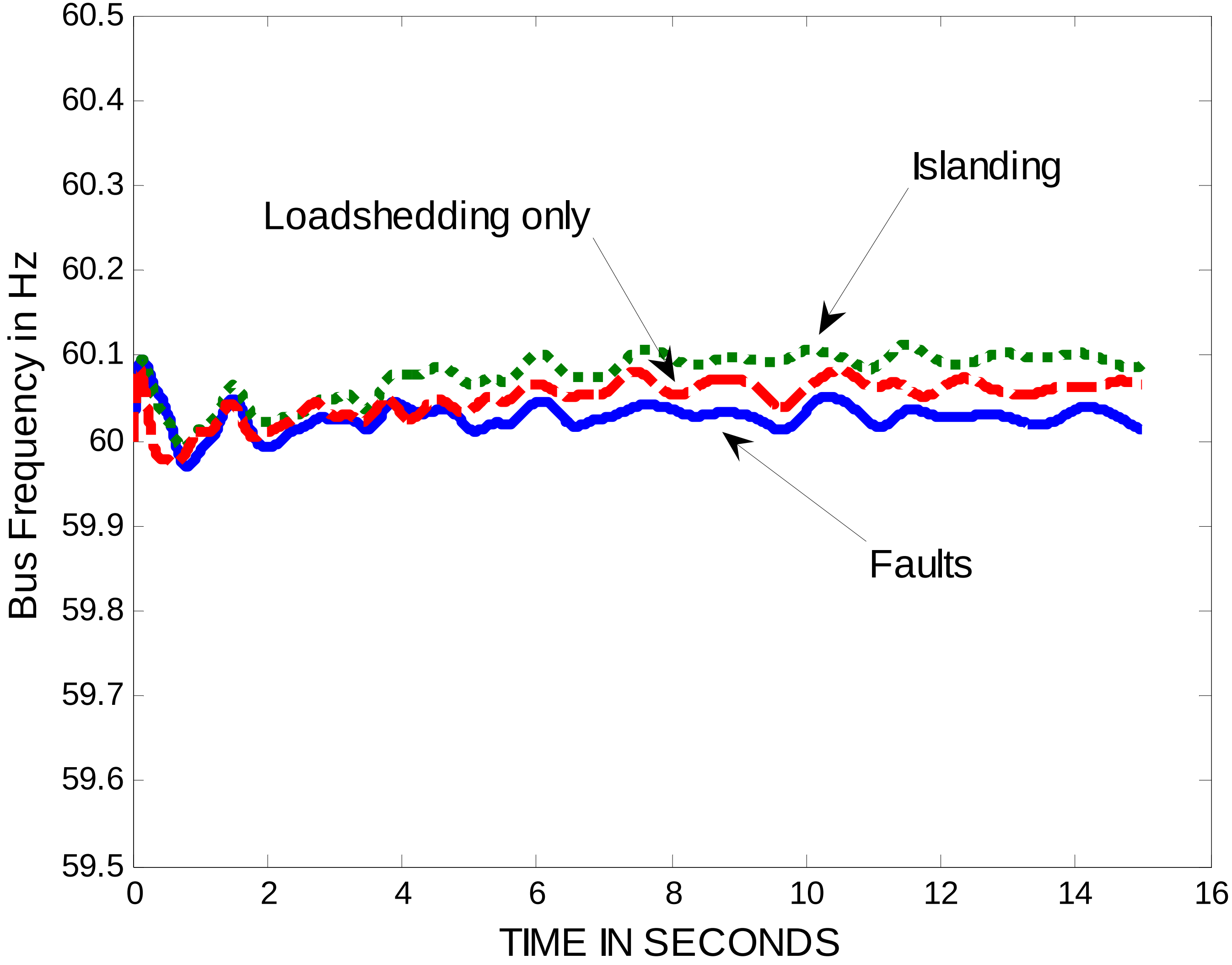


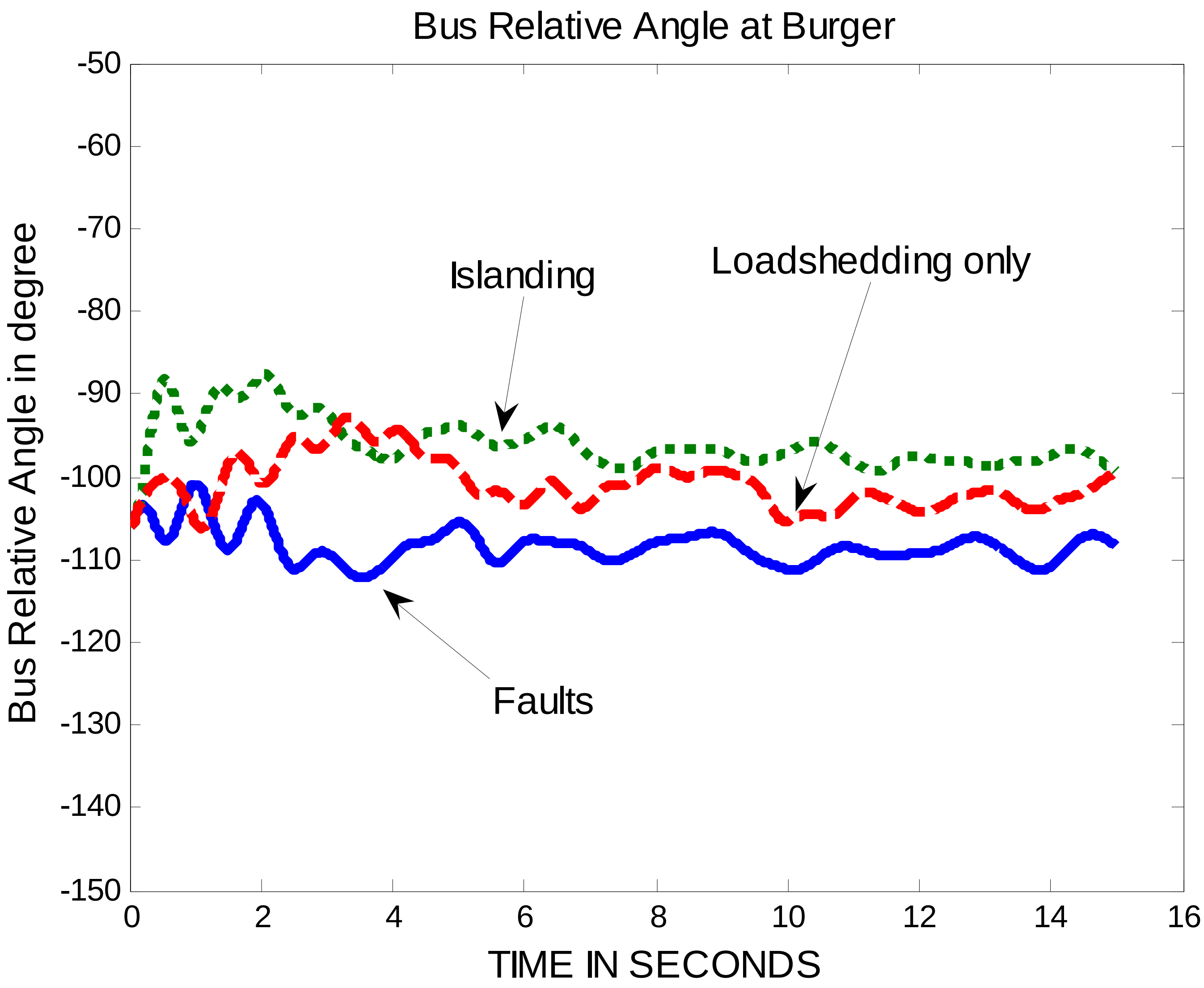
Bus Voltage at Sammis
1.06
1.04
1.02
1
0.98
0.96
0.94
0
2
4
6
8
10
12
14
16
Bus Voltage in p.u.
TIME IN SECONDS
Loadshedding only
Faults
Islanding


Bus Frequency at Edgewater
Bus Frequency in Hz
62
61.5
61
60.5
60
59.5
59
58.5
58
57.5
57
0
2
4
6
8
10
12
14
16
TIME IN SECONDS
Loadshedding only
Islanding
Faults


Line Active Power on Wayne - E. Erie
800
700
600
500
400
300
200
0
2
4
6
8
10
12
14
16
Line Active Power in MW
TIME IN SECONDS
Faults
Loadshedding only
Islanding

Bus Frequency at New Castle




Bus Relative Angle at Burger
Bus Relative Angle in degree
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
0
2
4
6
8
10
12
14
16
TIME IN SECONDS
Islanding
Loadshedding only
Faults

Load Shedding –Comparison of different levels

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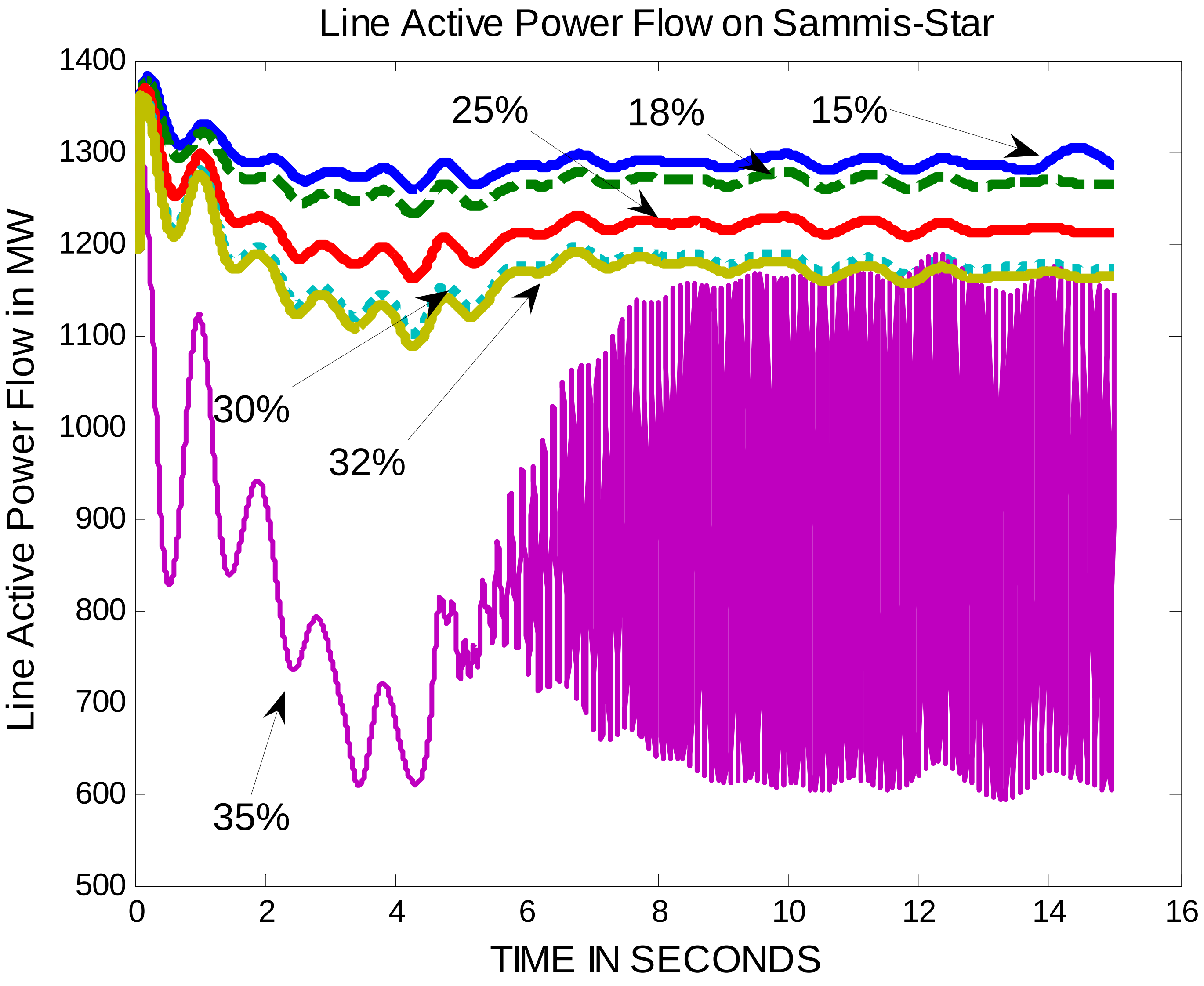

What is the advantage of islanding?

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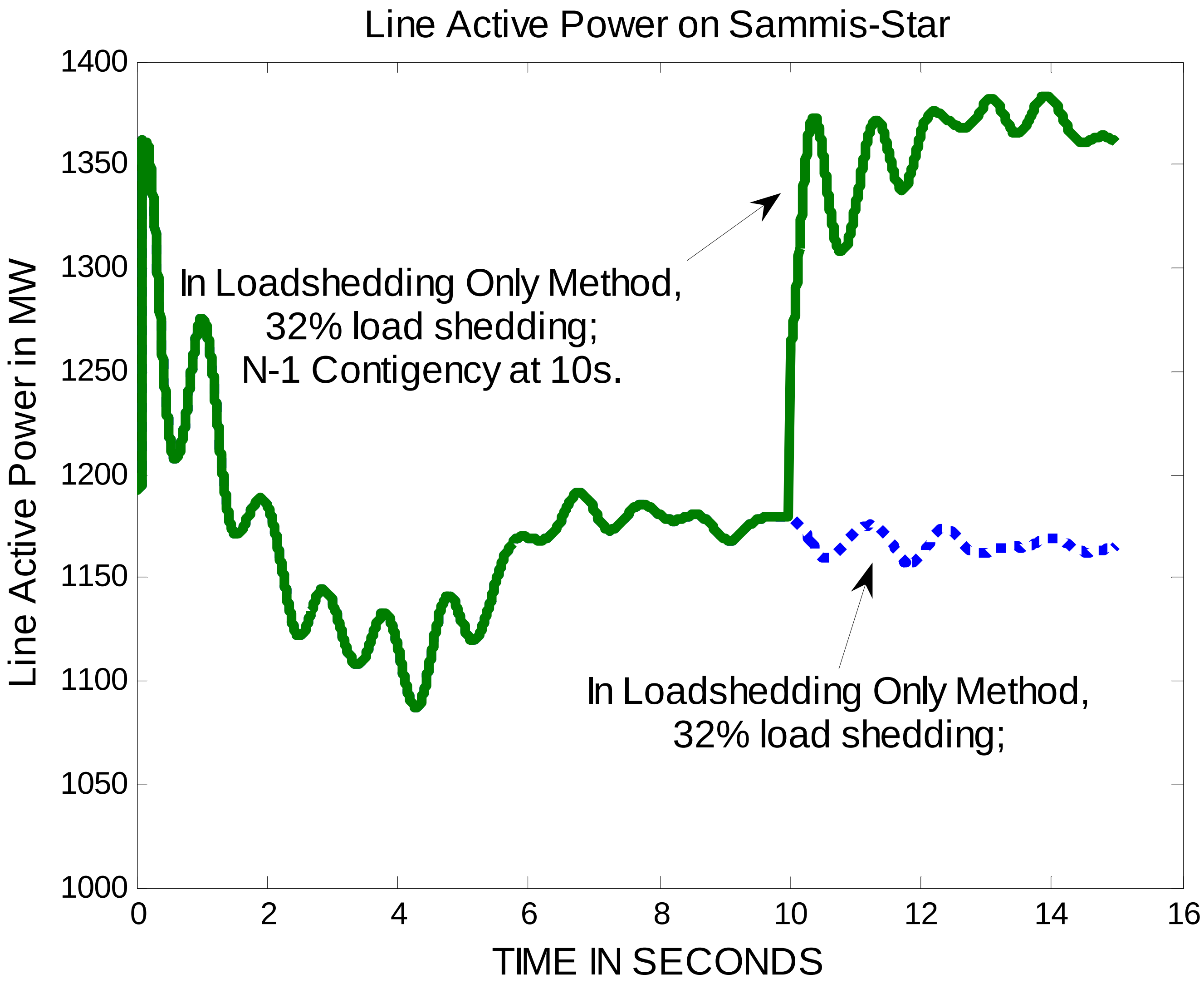
- One could ask the question why island?
- Could one only do load shedding?
- The system in this case is severely stressed.
- Without islanding the impact of any subsequent disturbance on the rest of the system could be severe.
- We drop the Perry generator within the island – In the islanding case this will not cause any impact outside the island. More load would have to be shed within the island.

N-1 Security in Load Shedding only case



Conclusions

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- The results clearly show that concept of slow coherency based islanding works effectively in constraining the effect of the disturbance to the island created and prevents the effect of the disturbance from spreading to the rest of the system.
- The qualitative result in the August 14th, 2003 blackout case clearly demonstrates the efficacy of the approach.
- The controlled islanding scenario was also compared with the load shedding only case and showed that it is highly effective in containing the effect of any subsequent disturbance within the island created.