Significant Operating Experience Report (SOER) 99-1 "Loss of Grid"

Recommendation Implementation

SOER 99-1 "Loss of Grid"

- SOER issued because of recent events (including US events) associated with loss of grid
- intent of the SOER recommendations is to help ensure barriers that protect nuclear plants from grid loss or degradation are in place

Attachment 3

Evaluation of SOER Implementation

- began in June 2000
- 14 Stations/27 Units evaluated as of mid October
- implementation of recommendations
  - 61.5% satisfactory (complete)
  - 37% satisfactory plans in place for completion
  - 1.5% unsatisfactory

Recommendation 1 - establish appropriate interface with the grid operator

- plant coordination with grid maintenance and testing
  - One station is correcting a weakness they identified in this area.
- plant is made aware of grid status
  - One station is correcting weaknesses they identified in the grid early warning process.

Recommendation 1 - establish appropriate interface with the grid operator

- plant requirements and status are made known to the grid operator
  - Some design inputs are being inserted into grid interface documents at 3 stations.
- grid operator is made aware that the plant is an important customer
  - Grid operator procedures require nuclear plants be given priority (for example: power restoration and load shedding).

Recommendation 1 - establish appropriate interface with the grid operator

- responsibilities for grid/switchyard equipment maintenance are clearly defined
  - Because of recent corporate restructuring/unbundling, three stations are revising agreements on grid/switchyard equipment responsibilities.

Recommendation 1 - establish appropriate interface with the grid operator

- One plant was found to have unsatisfactorily implemented this recommendation.
  - Coordination of grid and station work was not controlled by a process (done informally).
  - Not all station voltage requirements were formally provided to the grid operator.
  - Guidance on communicating important information was not thorough.

Recommendation 2 – verify procedure adequacy for loss or degraded grid

- Generally plants were found to have appropriate procedures in place. Three stations found weaknesses in procedures for actions in response to degraded grid conditions. One station's procedures were found to have insufficient cautions for the operators to focus on plant safety and stability, and to ensure grid stability before restoring off-site power. Two station were revising abnormal procedures to specifically include degraded grid conditions.

Recommendation 3

verify high voltage grid distribution equipment under plant responsibility is in the plant PM program

- Three plants are revising PM programs because of new corporate structures (mergers and deregulation).

Recommendation 4

- **confirm grid reliability and stability design assumptions remain valid**
  - A station is discussing LOOP recovery times with the grid operator to confirm original design assumptions.
- **review trip setpoints** – (Degraded grid voltage may result in unanticipated component trips prior to emergency power source automatic actuation.)
  - One station is in the process of modifying switchyard protective schemes because of station changes. Another station is verifying assumed voltage relay setpoint drift.

Recommendation 5 – operator training

train on degraded grid voltage, post loss of grid, and manual electrical bus alignments

- About 64% of the stations evaluated are developing and implementing training on degraded grid voltage and/or recovery from LOOP with a subsequent LOOP. Simulator modeling and training schedules are the main hurdles in this effort. A significant amount of LOOP and Partial LOOP training was done in preparation for potential Y2K problems.

SOER 99-1 Implementation

- Conclusions Based on Evaluations to Date
  - **Stations are actively addressing the SOER recommendations.**
  - **With one exception, the stations evaluated have completed implementation of the SOER recommendations or have satisfactory plans and schedules for completion.**
  - **Barriers that protect the stations from grid disturbances are in place. However, a few weaknesses in these barriers have been identified and are being strengthened.**

Helping to Maintain Grid Reliability at Nuclear Power Plants

US Nuclear Regulatory Commission

Frank Rahn and Stephen Lee

EPRI

(October 27, 2000)

EPRI

Topics Covered

- LOOP Experience at Nuclear Power Plants
- Power Deliver Reliability Initiative
- North American PRA Study
- Combined Generation and Transmission Reliability
- Integration with Configuration Risk Management Programs
- Conclusion

Attachment 4

Integrated EPRI / Industry Involvement

- A major goal in EPRI's ***Technology Roadmap*** is Resolving Power Delivery Vulnerability in years 1999-2003
  - ongoing LOOP studies, sustained through the EPRI Base Program, are the basis of Baysian updating of PRA data bases and other vulnerability studies
  - EPRI Power Delivery Initiative, a $5M+ separately supported program, has the goal of reducing the North American Grid vulnerability to disruption in service, particularly in the near term
  - Integration with nuclear plant CRMP programs supported by $800K joint DOE/EPRI funds, with NEI support, under NEPO project *Potential Nuclear Plant Vulnerabilities Arising from Grid Voltage Inadequacies*

List of Acronyms

- **API** = Application Program Interface
- **ATC** = Available Transfer Capacity
- **CIM** = Common Information Model
- **CRMP** = Configuration Risk Management Program
- **EFOR** = Equivalent Forced Outage Rate
- **EOOS** = Equipment Out Of Service (Computer Code)
- **FG** = Flow Gate
- **GADS** = Generator Availability Data System
- **ICCP** = Inter-Control Center Protocol
- **IDC** = Interchange Distribution Calculator
- **LOOP** = Loss of Off-Site Power
- **NEPO** = DOE's Nuclear Energy Performance Optimization program
- **OTDF** = Outage Transfer Distribution Factor
- **P&ID** = Piping and Instrumentation Diagram
- **R&R UG** = EPRI's Risk and Reliability Users Group
- **R&R WS** = EPRI's Risk and Reliability Work Station
- **RSDD** = Real-time Security Data Display
- **SCIS** = Security Coordinator Information System
- **TLR** = Transmission Loading Relief
- **V&R** = name of a company

Losses Of Off-Site Power at Nuclear Units Through 1999

US Nuclear Regulatory Commission

Frank Rahn
EPRI

October 27, 2000

Nuclear Power Division

EPRI

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LOOP Events

- EPRI does a biennial study on LOOP events
  - Through 1999 EPRI Report 1000158
  - Through 1997 EPRI Report TR-110398
  - --
  - Through 1985 EPRI Report NSAC-103
- Database includes *all* LOOP events and all but relatively minor *partial* LOOP events
- Results based on in-depth collection and *evaluation* in contract to LOOP estimates created by mathematically merging failure experience of many individual lines buses, breakers, transformers, cables, etc.
- Examines the length of time off-site power was truly unavailable

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Results of LOOP Events Through 1999

- Recent experience: loss of *all* off-site power
  - in 1998 – [illegible] events
  - in 1999 – 2 events
  - [illegible] losses per generating unit year
- Recent experience consistent with, but somewhat lower, than prior years
  - LOOP probability ~0.034 losses per generating unit year
  - > 1 hour ~0.020 losses per generating unit year
  - median duration of LOOP events is ~1.5 hours

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Significant LOOP events 1998-1999

- Davis Besse 6/24/98
- Indian Point 2 8/31/99
- Braidwood 1 9/6/98
- Clinton 1/6/99
- Fort Calhoun 5/20/98
  - [illegible] that weather can cause extensive widespread damage that cannot be quickly repaired
  - almost all LOOP events lasting longer than [illegible] are weather related

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Selected Partial LOOP events 1998-1999

- 9 partial LOOP events were evaluated in detail
- Callaway 8/12/99
  - did not involve a full or even partial LOOP
  - precursor in nature in that approached tech spec limits
  - below the minimum operability limit there may not be sufficient voltage margin to start large pumps and other loads needed under worse case accident conditions
  - when a unit trips off, local grid voltage will drop by some amount due to the lost generation
  - unfortunately, grid voltage that is needed to ensure adequate grid voltage during an accident cannot be verified through direct reading of plant switchyard or safety bus values
  - the required grid voltage must be determined through analysis of grid and plant conditions

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EPRI Power Delivery Reliability Initiative

(Transmission Program)

Presentation to the NRC

Stephen Lee

October 27, 2000

Power Delivery Reliability Initiative EPRI

Scope of Reliability Initiative

- Power Delivery Reliability Issues The Challenge
  - Final Report. January 2000
- [illegible] abilistic Risk Assessment for the [illegible] SERC
  - Final Report. January 2000
- T-1 - Probabilistic Risk Assessment - Methodology [illegible]
  - Completed. March 2000
- T-2 - Workshop: Summer 2000 Operation Strategies
  - Atlanta. April 11. 2000
- T-3 - Probabilistic Risk Assessment for the AEP System (8 15 00)
- T-4 - Probabilistic Risk Assessment for the North American Grid (4 1 01)
- T-5 1 - Summer 2000 - Operating Tools
  - Real Time Security Data Display. delivered - June 15. 2000
  - Tag Dump. Completed - June 15. 2000

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EPRI Power Delivery Reliability Initiative - Dual Objectives

- Perform Probabilistic Risk Assessment (PRA) Study for three Interconnections. Complementary to NERC activities (e.g.. working with the Reliability Assessment Subcommittee on developing and applying Probabilistic Approach)
- Develop Near Term Tools for Enhancing Reliability

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Real-time Security Data Display (RSDD)

- Purpose - to provide a bird's eye view of the grid reliability over a wide area (up to entire N. America)
- Data Displayed
  - Flowgate flows and TLR status
  - Voltages at up to 300 buses
- Color code (Red, Yellow and Blue)
  - TLR 3 and above is Red, TLR 1/2 is Yellow
  - Voltage below low limit is Red
    Marginal is Yellow

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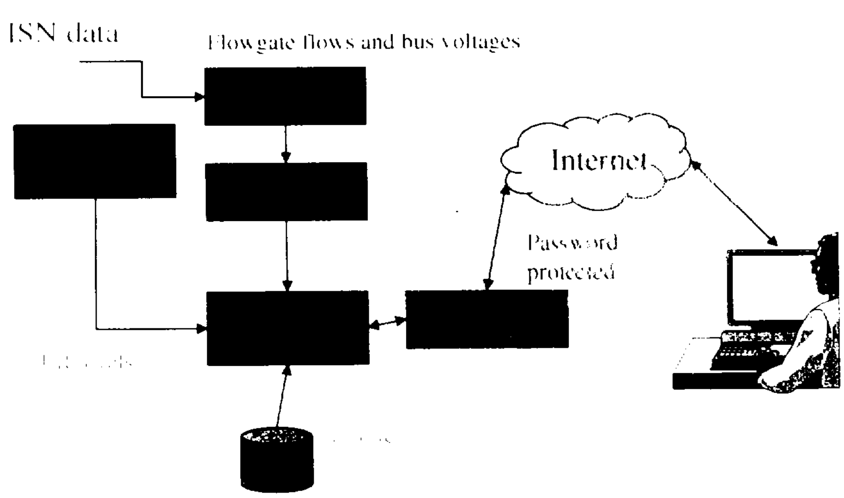
RSDD - System Architecture



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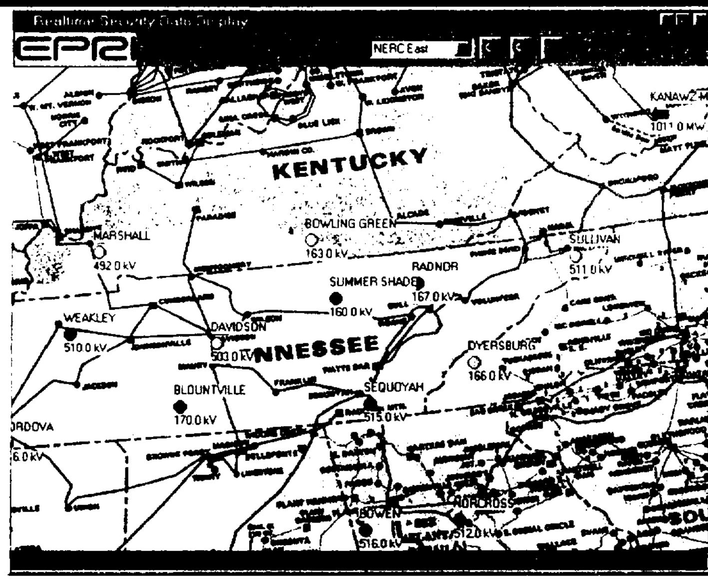
Sample Screen of RSDD



15

Tag Dump Program

- Purpose - to aggregate the near real-time historical and prospective E-tags into inter-regional (control area to control area, or security coordinator to security coordinator) total interchange schedules
- **Applications** -
  - To perform operational planning studies (e.g., for the next hour)
  - To compute ATC for next hour or next day
  - To develop scenarios of severe transfer patterns

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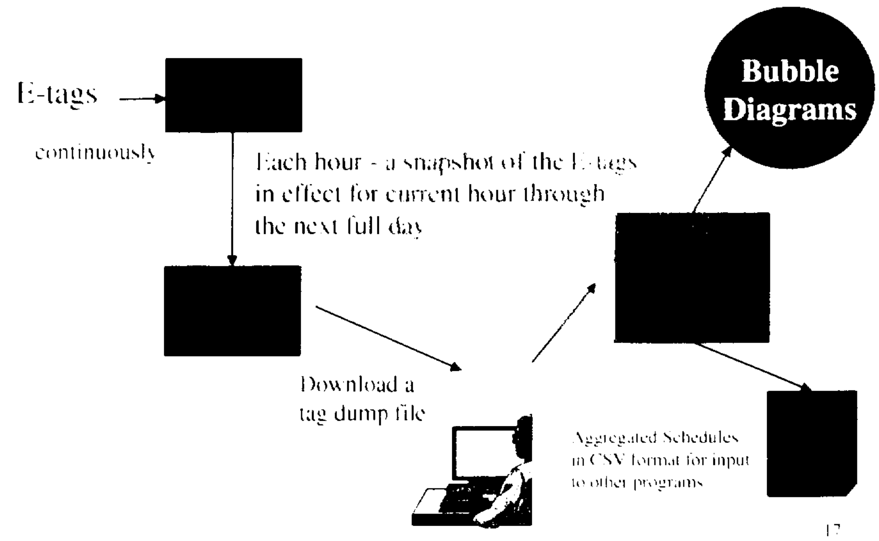
Tag Dump Input and Output



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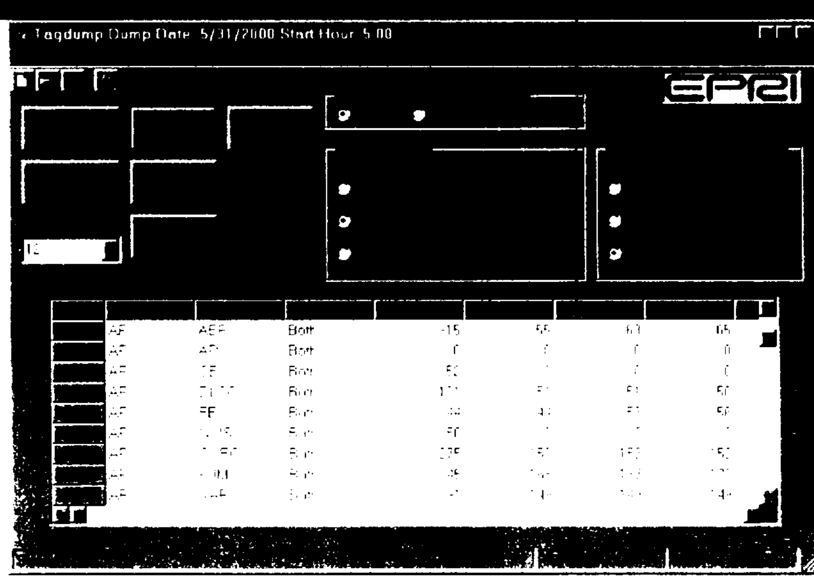
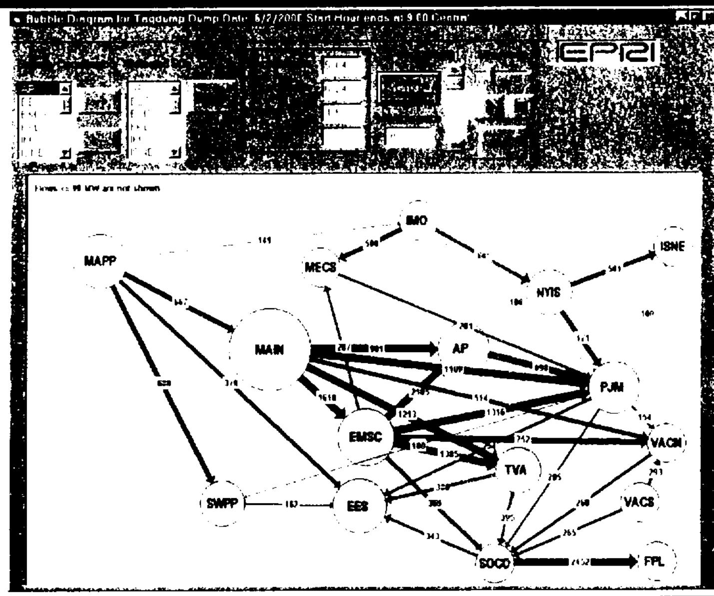
Tag Dump - Main Screen



18

Tag Dump - Bubble Diagram



19

Tag Dump Program Status and Future Plan

- Released on June 15, 2000 and available to signatories of the NERC Confidentiality Agreement
- Potential Enhancements or Applications -
  - Include Distribution Factors to compute impacts on Flowgates, useful for Flow-based Assessment of Transaction Schedules
  - EPRI to analyze historical flow patterns for Reliability Initiative and as data service to Security Coordinators

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Plan for N. American PRA Study

Transmission Program

Stephen Lee
October 27, 2000

Power Delivery Reliability Initiative EPRI

Data Requirements for Each Interconnection

- One interconnection-wide power flow base case for summer 2000
- Enough severe transfer patterns that stress the interconnection to reveal bottlenecks
  - Obtain historical flow patterns (e.g., Tagdump)
  - Postulate as-yet unobserved flow patterns
- Outage probability data
  - Generator EFOR from GADDS
  - Line and transformer outage from statistical relationship

Line and Transformer Outage Probabilities

- Funders to provide statistical data for their own systems, if available. If not, provide line miles.
- In the rest of the interconnection, use formulas based on best sources that relate outage rate to line-miles and voltage class, e.g.,
  - 345 kV line outage/yr = 0.3 + 0.003 * L,
    repair time = 8 h
  - 345/138 Xfr: outage/yr = 0.05,
    repair time = 720 h
- To estimate line miles, use average impedance per mile for different voltage classes

Assumptions - Zone

- Take all Reliability, OTDF and Contingency FGs (about 700 in the EI)
  - For each FG, define the center of a FG Zone as the set of terminal buses of all the monitored elements of the FG
- Between each pair of FG Zones, define the distance as the minimum number of lines/transformers that will connect the two centers (or sum of impedances)
- Reduce the number of FG Zones to a manageable number by merging adjacent Zones with distance < N

Assumptions - Zone

- Re-define the "center" of each Zone by the combined set of buses representing the center of each original FG Zone
- Define the Zone membership of each bus in the Interconnection as follows:
  - Determine the shortest distance of each bus to the "center" of each Zone, measured by the smallest number of lines/transformers separating the bus to "center" buses
  - Each bus belongs to the Zone to which its distance is shortest

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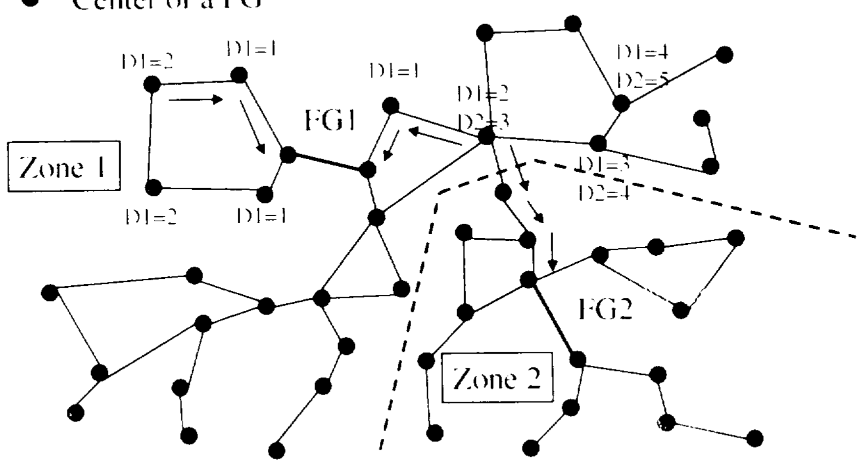
Concept of Zone

- Center of a FG

Distance between FG1 and FG2 = 5



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Advantages of FG Zone Definition

- Based on known physical elements with potential reliability concern
- Not based on organizational boundaries -- likely to span adjacent entities as well
- Each Zone is a physical (electrically connected) area for summarizing the reliability behavior (thermal overloads and voltage limits) of the elements inside the area
- The constrained and constraining elements within the Zone is not limited only to the elements defining the FG itself

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Assumptions - Contingency

- Contingency Criteria should be the same within the Interconnection:
  - N-1L: All lines and transformers at a certain voltage and above. What is that voltage? (100 kV)
  - N-1G: All generators above a certain MW size. What is that size? (100 MW)
  - N-2LL: Any two of N-1L within the same Zone
  - N-2LG: Any 1 of N-1L plus 1 of N-1G within the same Zone

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Combined Generation and Transmission Reliability

Concepts of Probabilistic Reliability Index
and Relationship with
Deterministic Contingency Criteria

Stephen Lee
EPRI
October 27, 2000

Risk and Reliability Indices

Risk / Real Time Operation	Reliability / Planning
Computed over a time interval [*0, T*]	Computed for a random time during planning period
Model Failures and Repairs	*Model Availability*
Consider Transition of Disturbances (events)	Consider Post-Transient State
Focus on High Impact Rare Events	Describe an Average Behavior
Result Pertain to Real-Time Operation	Result Pertain to a System Structure

Definition of Risk / Reliability Index

- Risk/Reliability Index = Probability x Impact
- Probability is the probability of experiencing the Impact, that is, the probability of the contingencies that cause the Impact
- Impact is measured by severity
  - Thermal overload (MW)
  - Voltage violation (% V deviation from limit)
  - Voltage stability
  - Dynamic stability

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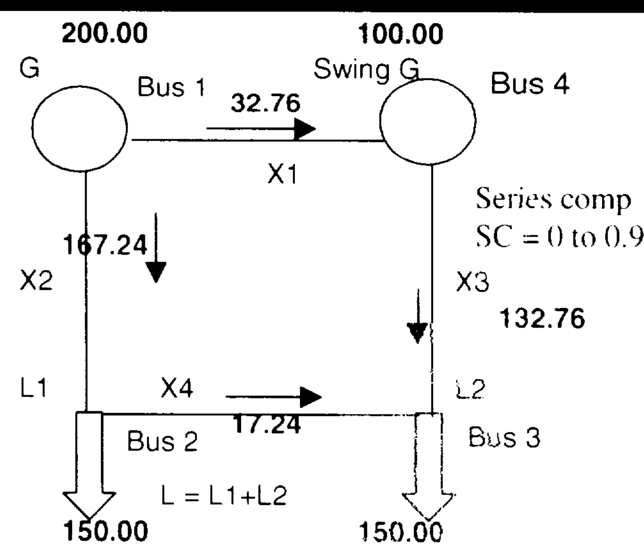
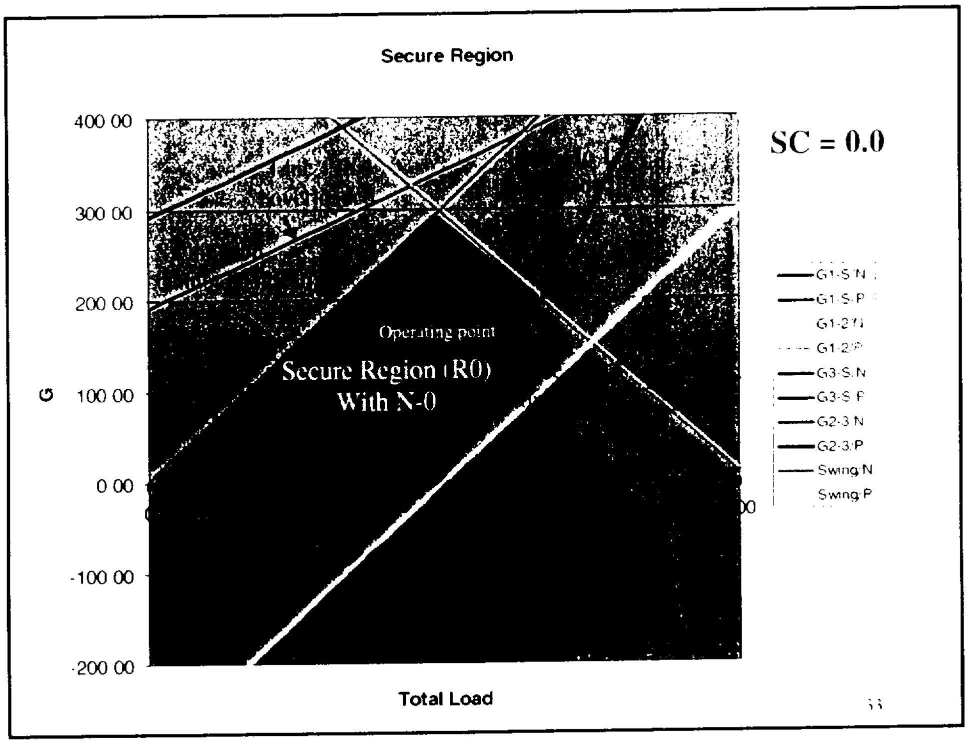
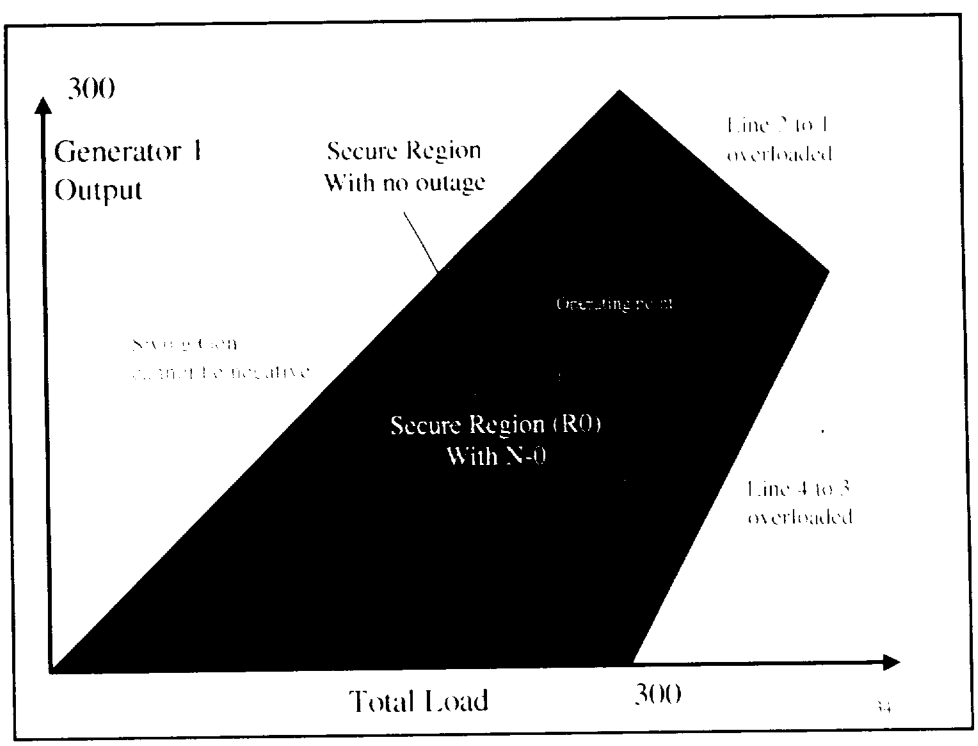
Network for Illustrating Secure Region




Secure Region
400 00
300 00
200 00
100 00
0 00
-100 00
-200 00
G
SC = 0.0
G1-S N
G1-S P
G1-2 N
G1-2 P
G3-S N
G3-S P
G2-3 N
G2-3 P
Swing N
Swing P
Operating point
Secure Region (R0)
With N-0
Total Load


300
Generator 1
Output
Secure Region
With no outage
Line 2 to 1
overloaded
Secure Region (R0)
With N-0
Line 4 to 3
overloaded
Total Load
300

How Do Line Outages Affect Secure Region

- Look at No Outage Case
- Look at Line 1 - 2 ckt 1 out (assuming two circuits with identical rating)
- Look at Line 1 - 4 ckt 1 out (assuming two circuits with identical rating)
- Look at both lines out

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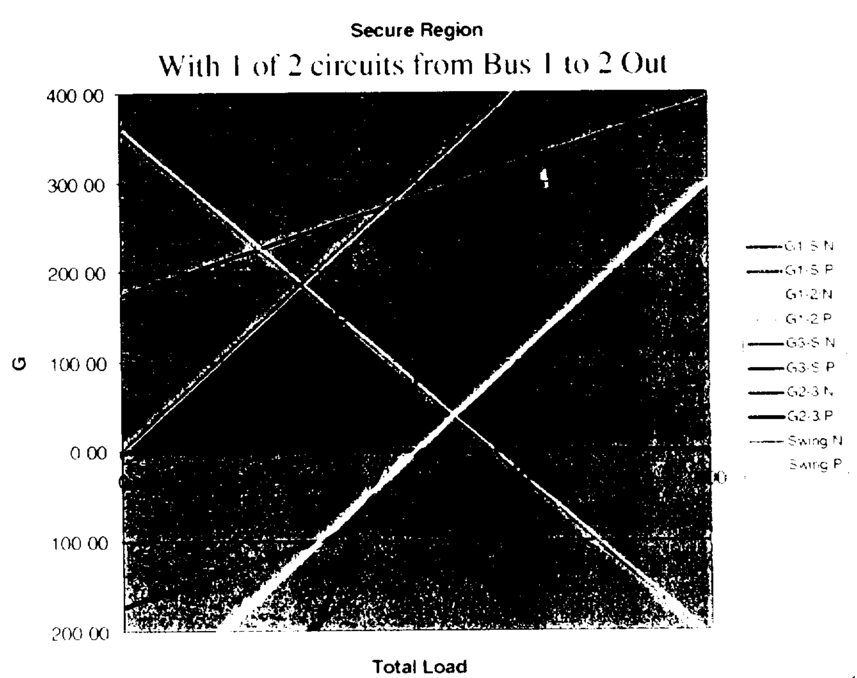

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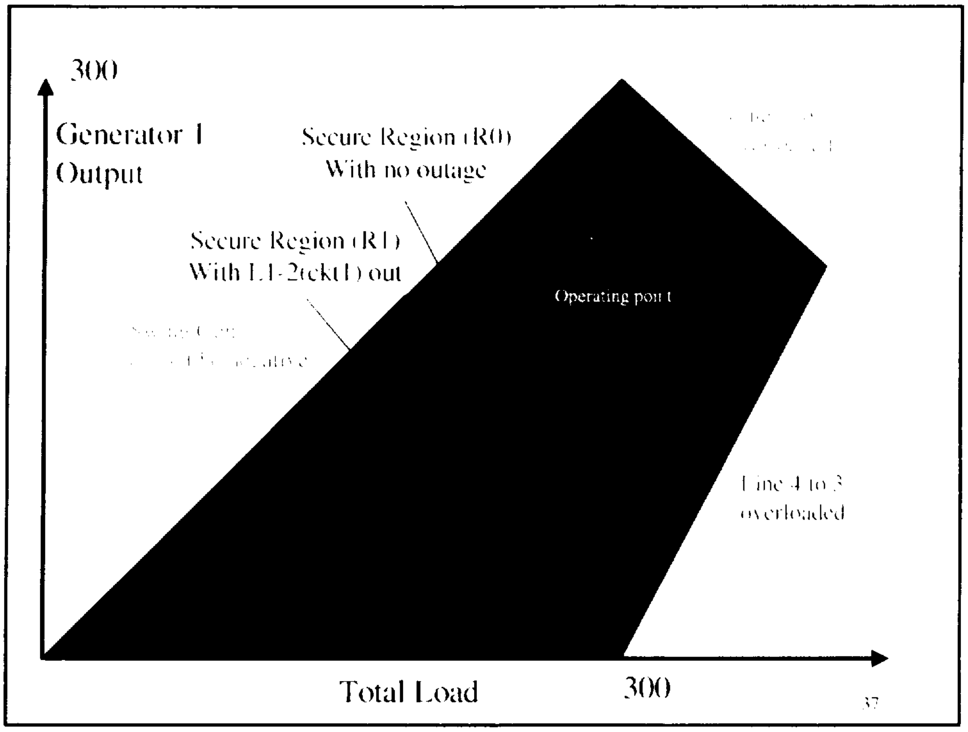
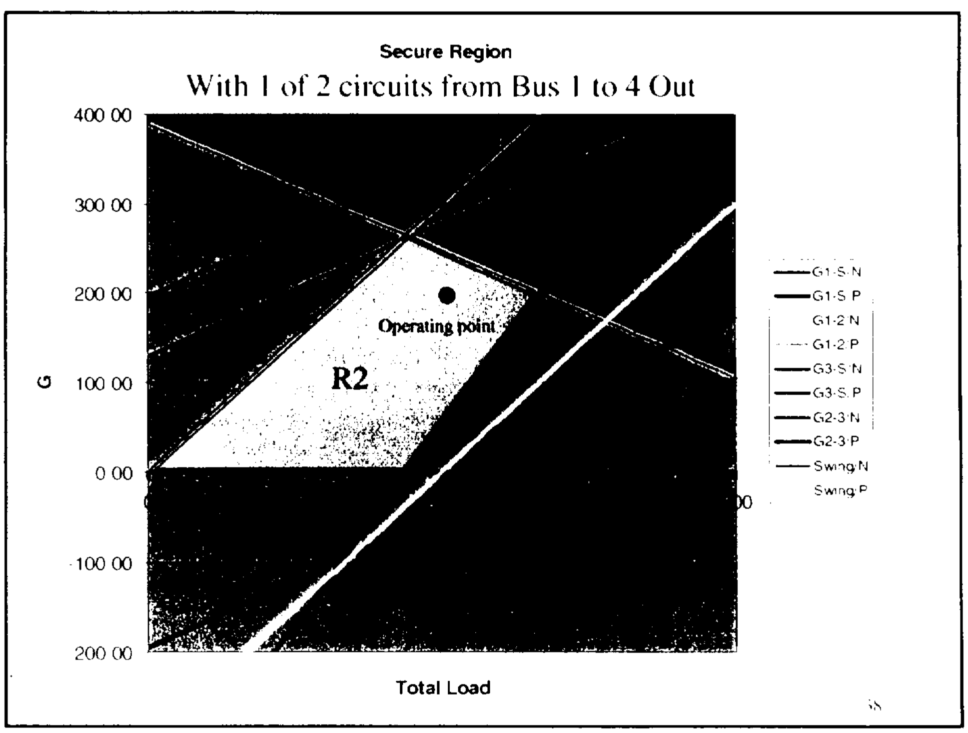
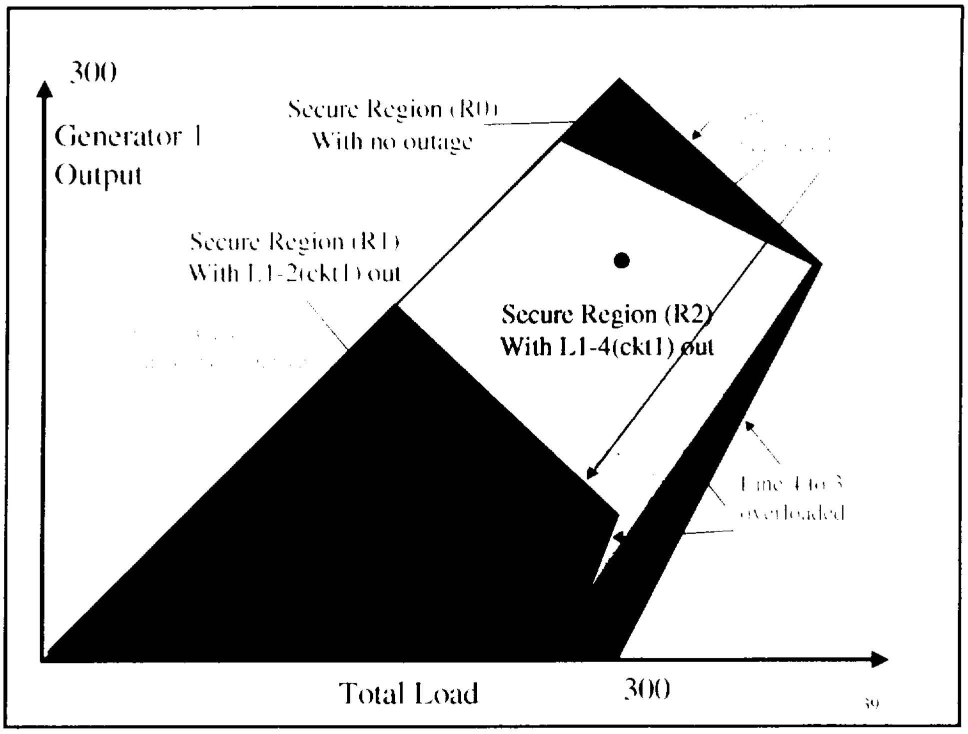
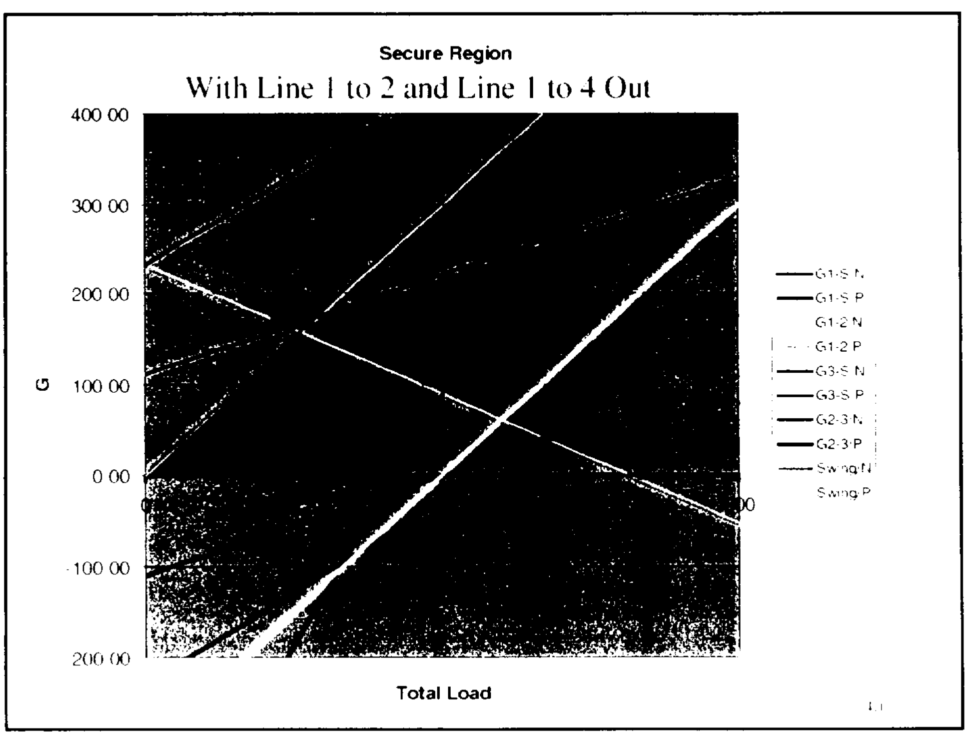
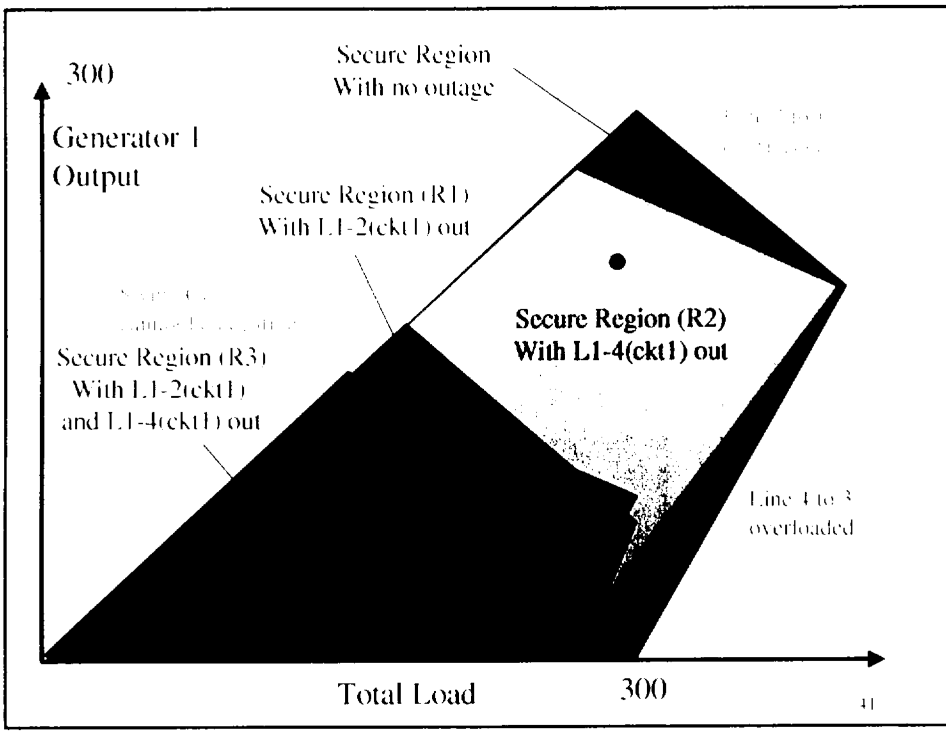

300
Generator 1
Output
Secure Region (R0)
With no outage
Secure Region (R1)
With L1-2(ckt1) out
Operating point
Line 4 to 3
overloaded
Total Load
300


Secure Region
With 1 of 2 circuits from Bus 1 to 4 Out
400 00
300 00
200 00
100 00
0 00
-100 00
200 00
G
Operating point
R2
G1-S N
G1-S P
G1-2 N
G1-2 P
G3-S N
G3-S P
G2-3 N
G2-3 P
Swing N
Swing P
Total Load


300
Generator 1
Output
Secure Region (R0)
With no outage
Secure Region (R1)
With L1-2(ckt1) out
Secure Region (R2)
With L1-4(ckt1) out
Total Load
300


Secure Region
With Line 1 to 2 and Line 1 to 4 Out
400 00
300 00
200 00
100 00
0 00
-100 00
-200 00
G
Total Load



Attach Probabilities to Regions

- Assume outage probability for the two circuits as follows:
  - Line A: 1 to 2 0.01
  - Line B: 1 to 4 0.05
- Assume all other elements are perfectly reliable
- P (no outage) = 0.99 x 0.95 = 0.9405
- P (R1: A out, B in) = 0.01 x 0.95 = 0.0095
- P (R2: A in, B out) = 0.99 x 0.05 = 0.0495
- P (R3: A out, B out) = 0.01 x 0.05 = 0.0005
- Total Prob = 0.9405+0.0095+0.0495+0.0005 = 1.0

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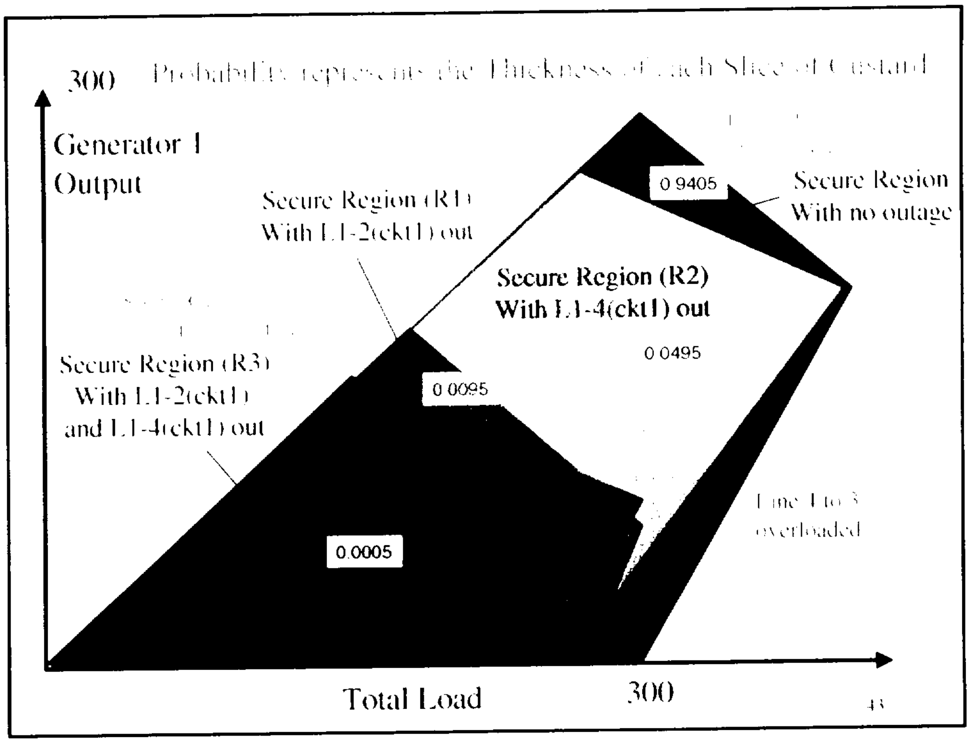
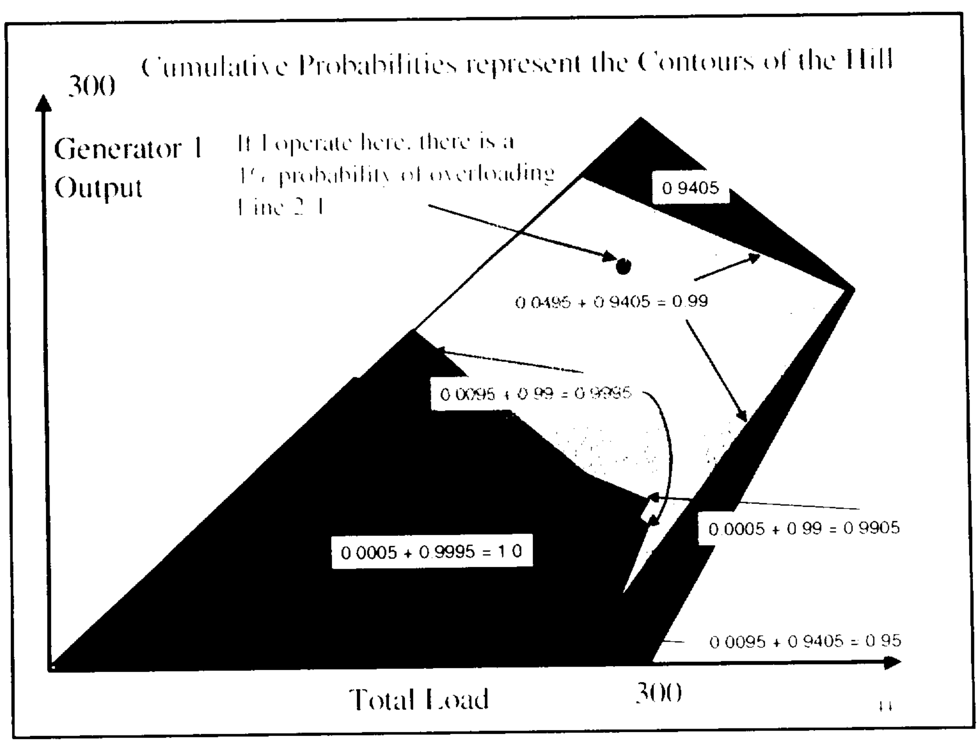
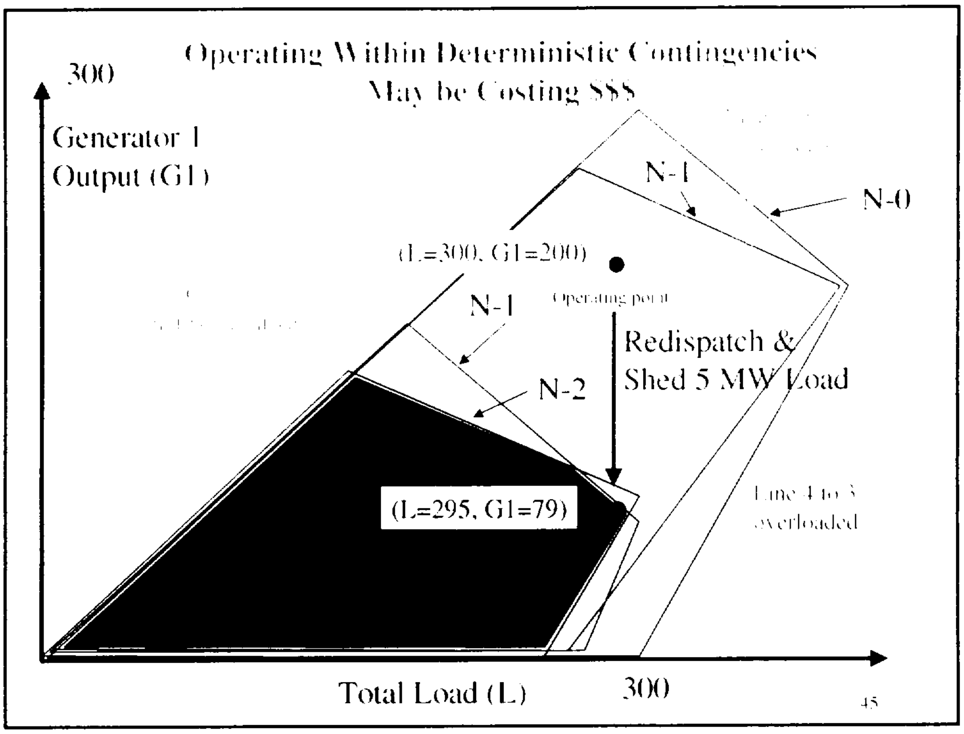
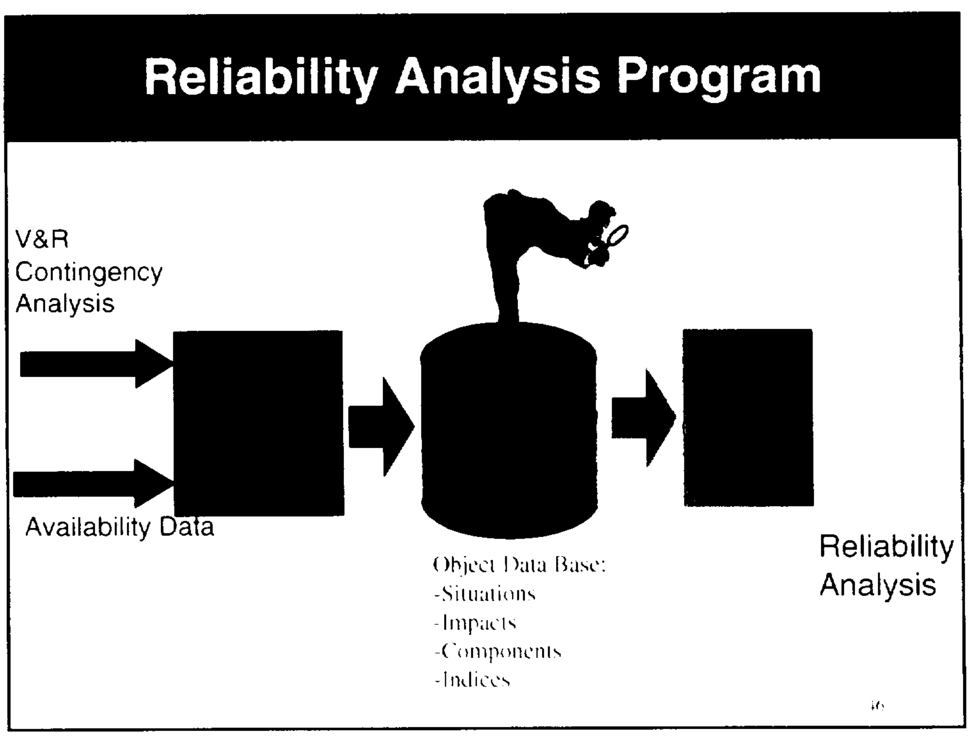
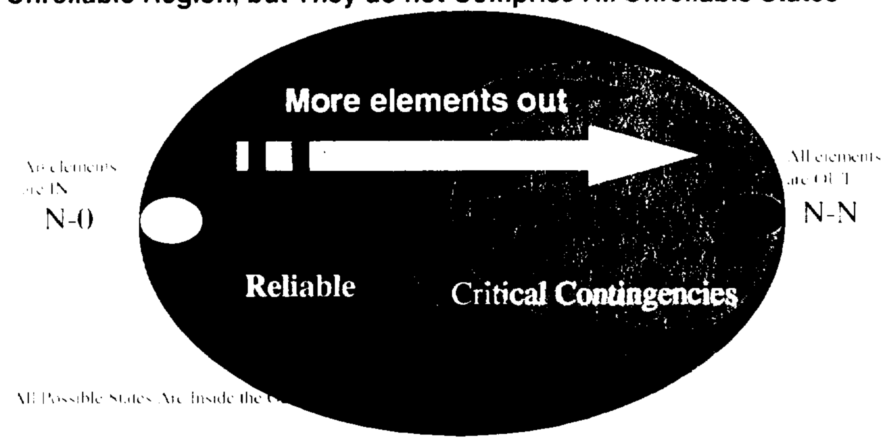

300
Generator 1
Output
0.9405
Secure Region
With no outage
Secure Region (R1)
With L1-2(ckt1) out
Secure Region (R2)
With L1-4(ckt1) out
0.0495
Secure Region (R3)
With L1-2(ckt1)
and L1-4(ckt1) out
0.0095
0.0005
Total Load
300


Cumulative Probabilities represent the Contours of the Hill
300
Generator 1
Output
0.9405
0.0495 + 0.9405 = 0.99
0.0095 + 0.99 = 0.9995
0.0005 + 0.99 = 0.9905
0.0005 + 0.9995 = 1.0
0.0095 + 0.9405 = 0.95
Total Load
300


Operating Within Deterministic Contingencies
May be Costing $$$
300
Generator 1
Output (G1)
N-1
N-0
(L=300, G1=200)
N-1
Operating point
Redispatch &
Shed 5 MW Load
N-2
(L=295, G1=79)
Line 4 to 5
overloaded
Total Load (L)
300
45

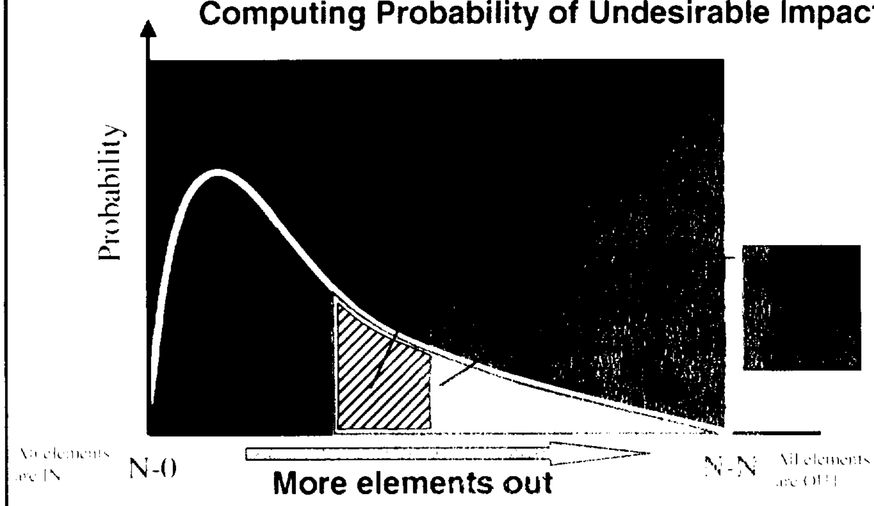

Reliability Analysis Program
V&R
Contingency
Analysis
Availability Data
Object Data Base:
-Situations
-Impacts
-Components
-Indices
Reliability
Analysis
46

Deterministic Critical Contingencies Define a Boundary Between the N-0 and the N-N State to Separate the Reliable Region from the Unreliable Region, but They do not Comprise All Unreliable States

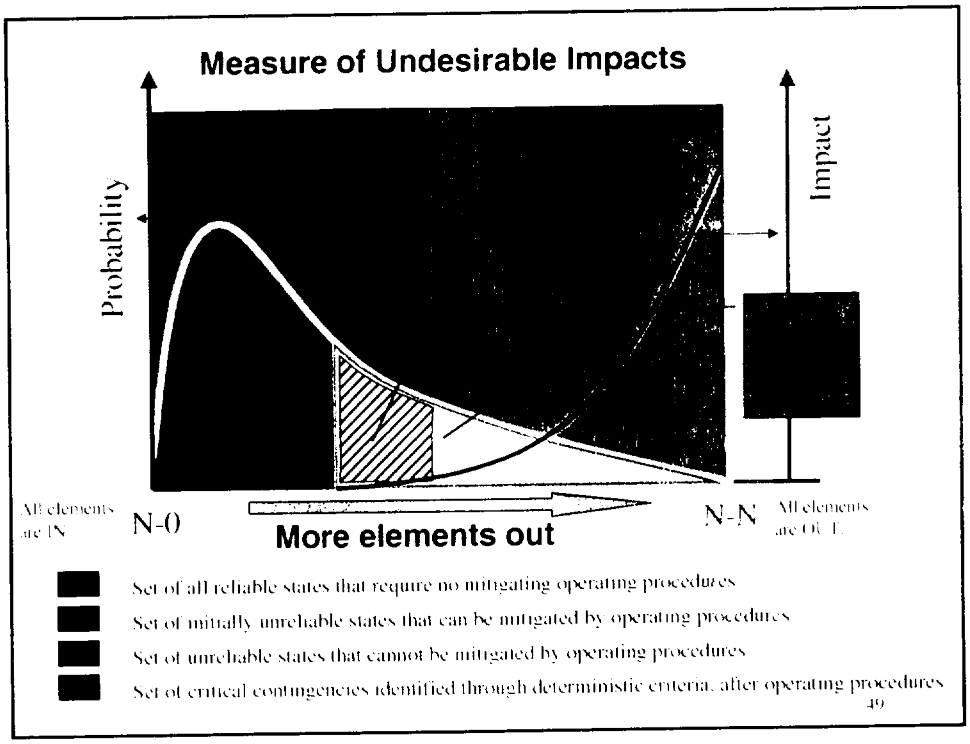


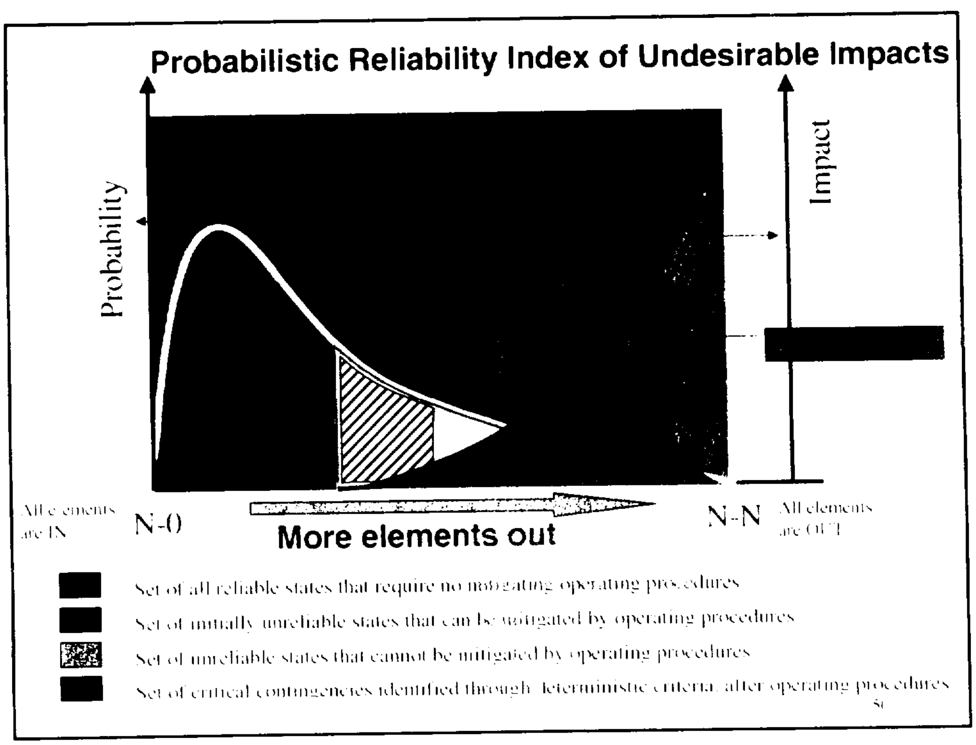
- Set of all reliable states that require no mitigating operating procedures
- Set of initially unreliable states that can be mitigated by operating procedures
- Set of unreliable states that cannot be mitigated by operating procedures
- Set of critical contingencies identified through deterministic criteria, *after* operating procedures

Computing Probability of Undesirable Impacts

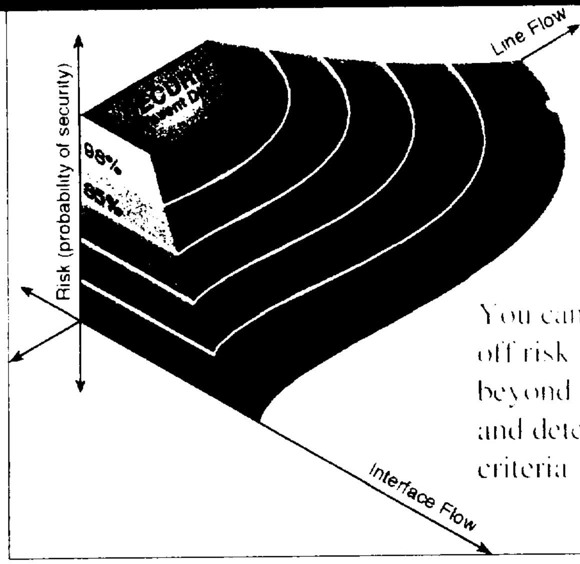


- Set of all reliable states that require no mitigating operating procedures
- Set of initially unreliable states that can be mitigated by operating procedures
- Set of unreliable states that cannot be mitigated by operating procedures
- Set of critical contingencies identified through deterministic criteria, after operating procedures


Measure of Undesirable Impacts
Probability
Impact
All elements are IN
N-0
More elements out
N-N
All elements are OUT
Set of all reliable states that require no mitigating operating procedures
Set of initially unreliable states that can be mitigated by operating procedures
Set of unreliable states that cannot be mitigated by operating procedures
Set of critical contingencies identified through deterministic criteria, after operating procedures
49


Probabilistic Reliability Index of Undesirable Impacts
Probability
Impact
All elements are IN
N-0
More elements out
N-N
All elements are OUT
Set of all reliable states that require no mitigating operating procedures
Set of initially unreliable states that can be mitigated by operating procedures
Set of unreliable states that cannot be mitigated by operating procedures
Set of critical contingencies identified through deterministic criteria, after operating procedures

Idealized Plateau Representing Various Risk Level of Operation



You can consciously trade off risk with $ in operating beyond the conservative and deterministic contingency criteria

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Remarks

- Risk-based Operation provides an objective basis for trading off reliability with market or economics - leads to new Business Practices
- Conversely. Business Practices affect system operation which shows itself in terms of different levels of Reliability
- Transmission Planning (which considers reliability) must take into account the impact of Business Practices on how the Grid is operated. and the subsequent impact of operation on Reliability

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Cooperation with NERC

- NERC Security Committee endorsed the Initiative in March 2000
- NERC Security Coordinators supported the Workshop on Summer 2000 Operating Strategies in April 2000
- NERC Adequacy Committee in July 2000 directed the Reliability Assessment Subcommittee to cooperate with EPRI
- NERC Market Interface Committee in August 2000 endorsed the Initiative

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Integration with Configuration Risk Management Programs

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October 27, 2000

Nuclear Power Division

EPRI

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Bridges to Nuclear Units' Configuration Risk Monitors

- Risk and Reliability Users Group is developing way of integrating grid status information into the R&R Workstation (EOOS)
- Goal is to
  - improve communication between transmission grid and plant operators
  - provide advance intelligence so that contingency and compensatory measures can be put in place when grid is under stress
- Work supported by EPRI, DOE and R&R User Group funding

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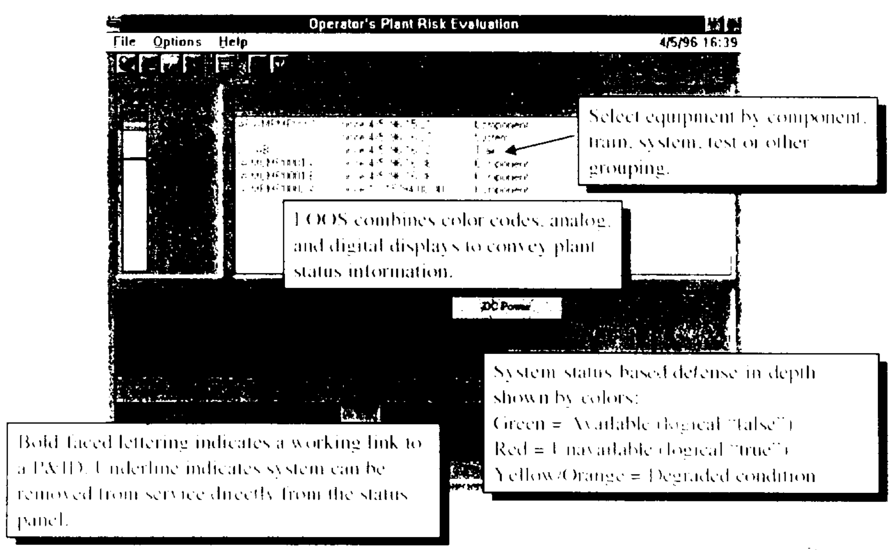
EOOS Operator's Status Panel



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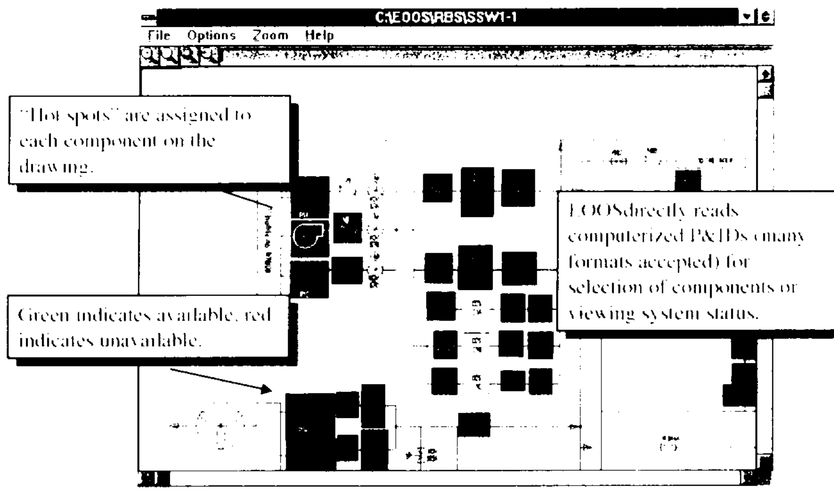
EOOS Drawing Status



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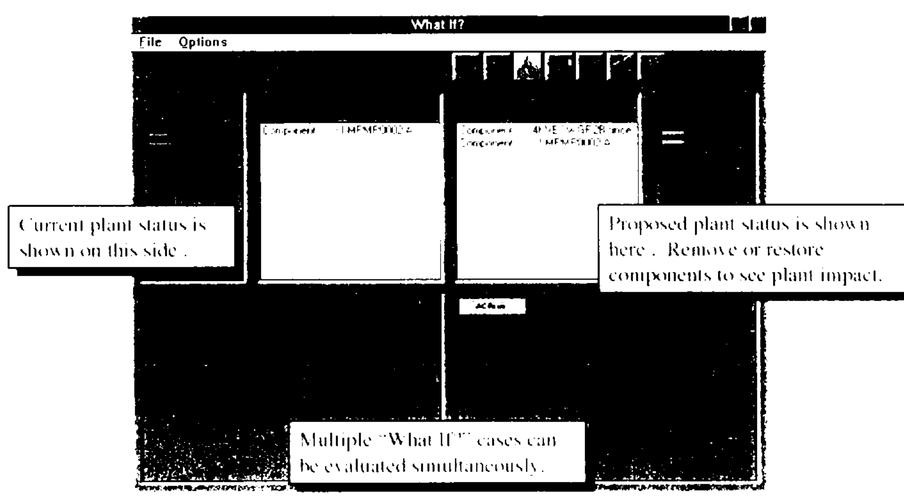
EOOS "What If ?" Evaluation



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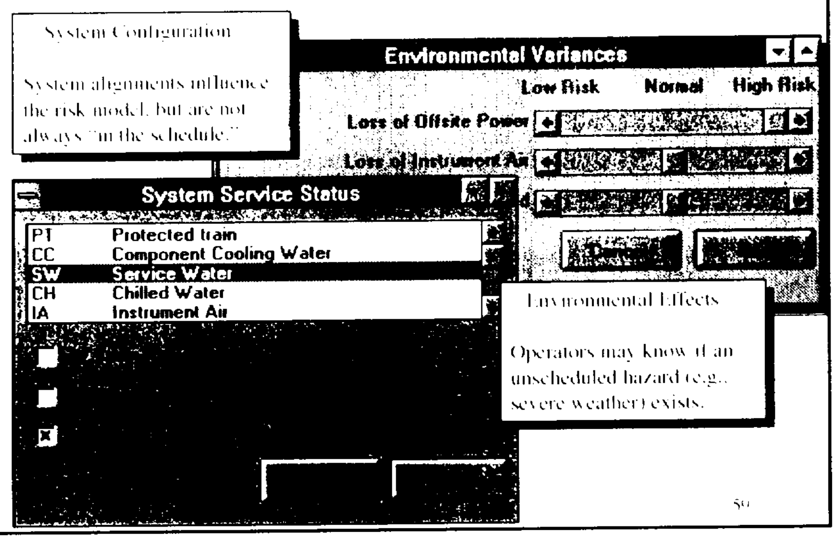
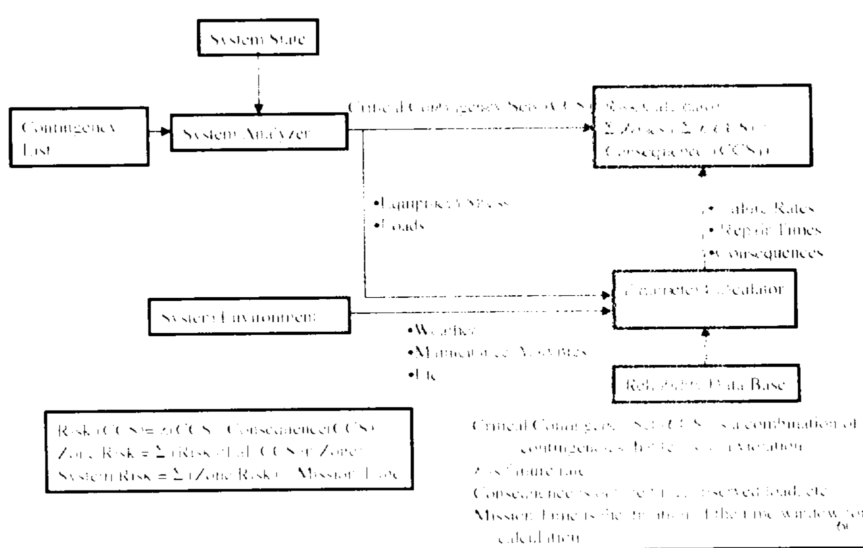
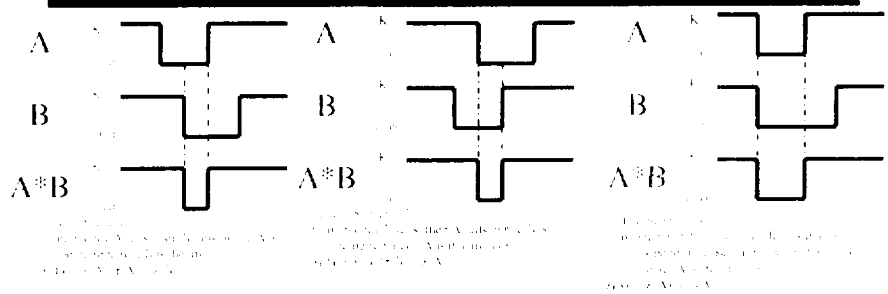
EOOS Risk Monitor
Other Factors Affecting Risk



Calculation of Risk Indices



Critical Contingency Set (AB) λ Calculation



λ of a critical contingency set is the sum of the λs for all applicable failure scenarios; failure scenarios describe how multiple contingencies occur in time

The K&K Workstation Cutset Editor supports all the necessary calculations. (a Cutset is equivalent to Critical Contingency Set)

Definitions:

A,B are contingencies
A B is a critical contingency set that causes a violation
Initiating Event - The event that triggers failure, is a Failure Rate (λ)
Enabling Event - The event(s) that allow failure to occur when the initiator occurs, is a probability (λ * τ or Probability)
λ - Failure Rate
τ - Average Repair Time
P(B|A) - Probability of B failing given A fails

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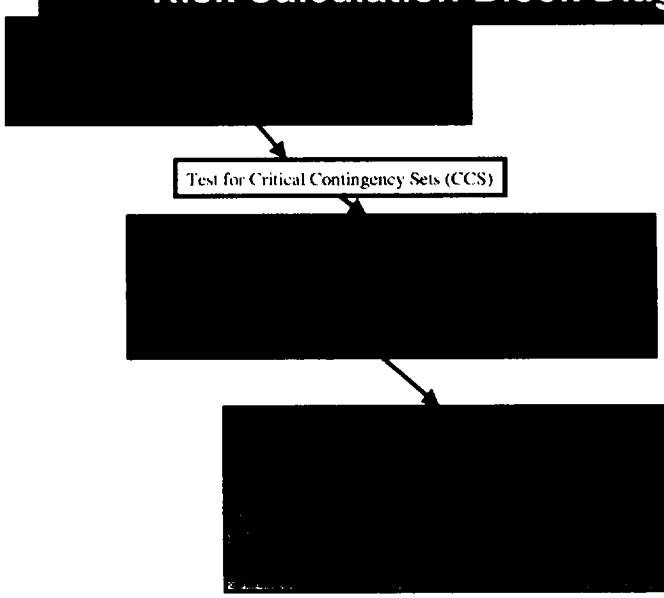
Risk Calculation Block Diagram



Failure Event Importance prioritizes failure prevention.

Enabling Event Importance prioritizes failure prevention, detection, and repair

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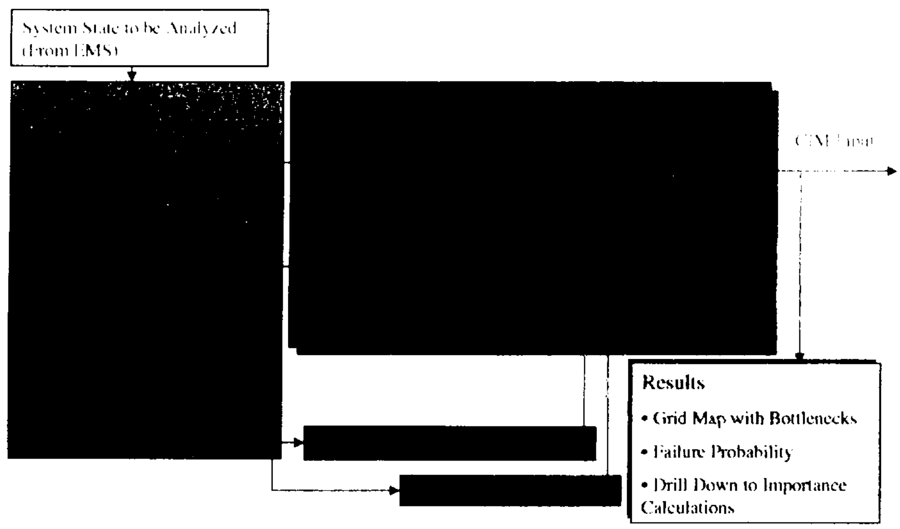
Risk Monitor Architecture



Conclusions

- Short and long-term LOOP experience is stable at very favorable rates
- EPRI (with NERC DOE and User Group support) is:
  - demonstrating a practical PRA methodology for Planning
  - collecting outage statistics on transmission lines and transformers (as with GADDS)
  - adopting PRA as a reliability standard for Transmission Planning
  - developing CRMP Tools that interface with existing risk monitors to allow plants to put into effect contingency and compensatory measures

DRAFT 10/27/2000

Workshop Title:	Grid Reliability at Nuclear Power Plants
Workshop Subtitle:	Managing Nuclear Plants and Transmission Systems to Improve Overall System Stability and Safety
Sponsors:	Nuclear Energy Institute and Institute of Nuclear Power Operations
Location:	(TBD)
Dates:	April, 2001
Focus:	

Time	Topic	Presenter
11:00-1:00	*Registration*	
1:00-3:00	*Plenary: Grid Reliability Perspectives*	
	Welcome	NEI/INPO
	Keynote	TBD
	Electricity Market Overview *(Past, Present, Future)*	NEI
	Challenges Presented by Electricity Market Changes	NERC
	Recent Station Blackout Experience	EPRI
	The Grid Reliability - Nuclear Safety Connection	INPO
3:00-3:20	*BREAK*	
3:20-5:00	*Panel Session: Nuclear Plant Experience*	INPO, EPRI, Sites, Transmission Providers
5:30-7:30	Reception	

8:00-9:30	*Plenary: Grid Reliability Issues*	
	Grid Reliability (NPP Issues, Events, Concerns)	NEI
	Regulatory Perspectives on NPP Offsite Power Reliability	NRC
	Nuclear Power Industry Recommendations	INPO
9:30-9:50	*Break*	
9:50-10:50	*Plenary: Design Analysis and Modifications*	INPO, Sites, EPRI, Other
10:50-11:45	*Plenary: Preventive Maintenance and Equipment Configuration Control*	INPO, Sites, EPRI, Other
11:45-1:00	*LUNCH*	
1:00-2:00	*Plenary: Plant Procedures and Training*	INPO, Sites, Other
2:00-3:00	*Plenary: Transmission Provider-Site Interface*	INPO, Sites, Transmission Providers, Other
3:00-3:15	*BREAK*	
3:00-5:00	*Breakout: Transmission Provider - Site Interface*	

8:00-10:00	*Plenary: Response of Industry Organizations to Grid Voltage Reliability Issues*	
	Report on Regional Breakouts	
	EPRI Power Delivery Reliability Initiative	EPRI
	Other	TBD
9:45-10:00	Break	
10:00-11:00	*Closing Session*	