2010 EDF Workshop: Energy Systems Simulation and Modeling

Artificial Intelligence Applications in Power System Control

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Iowa State, US NSF, US DoD

Artificial Intelligence Applications to Power Systems

- Rule-based systems
- Expert systems/Knowledge-based systems
- Artificial neural networks
- Fuzzy logic
- Evolutionary algorithms
- Multi-agent systems
- Other AI techniques
- Lessons learned

Feeder Service Restoration

- **One of the most important function of Distribution Management Systems**
- **Problem has combinatorial nature**
  - Deals with on/off status of the switches
- **KEPRI service restoration system**
  - Considers multiple criteria

Restoration Strategy

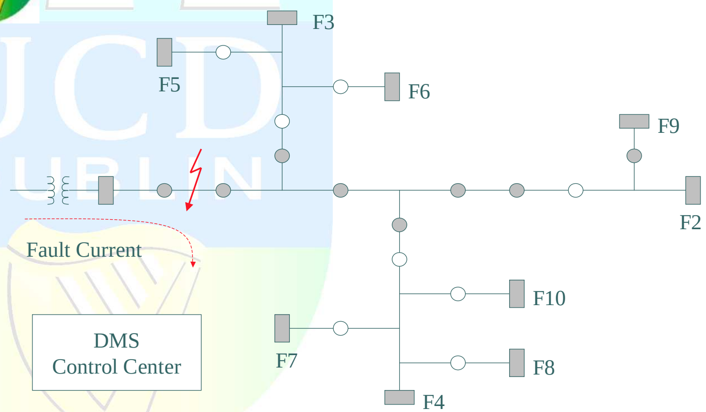
- **Phase I : Generate candidate set**
  - Constructs set of feasible plans
  - Applies six basic schemes
  - Constraints: line current, voltage drop
- **Phase II : Select most preferable plan**
  - Considers multiple criteria

PHASE II

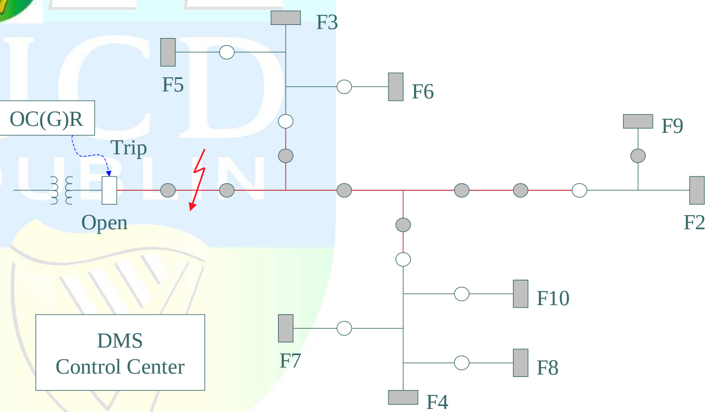
Select most preferable plan

- **Evaluation method**
  - Fuzzy decision making
- **Criteria**
  - Number of switching actions
  - Load balancing
  - Amount of live load transfer
  - Contingency preparedness

Example – Service Restoration
Fault occurs on the feeder

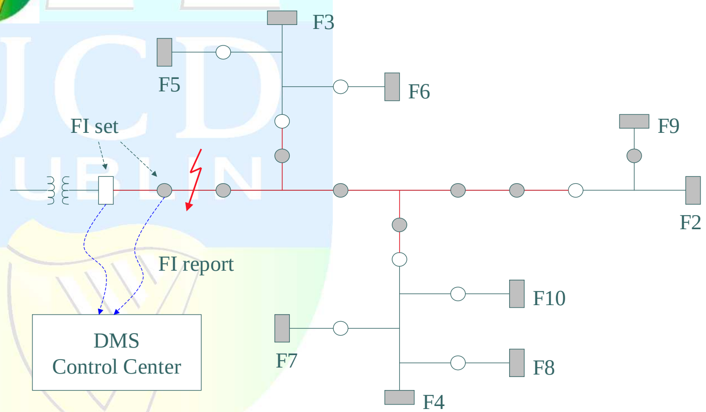


Example – Service Restoration
Protective relay opens CB



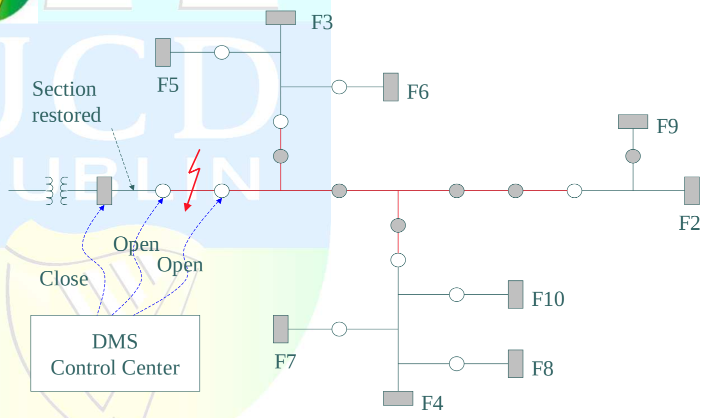
KEPRI – Korea Electric Power Research Cooperation

Example – Service Restoration
Faulted section identification



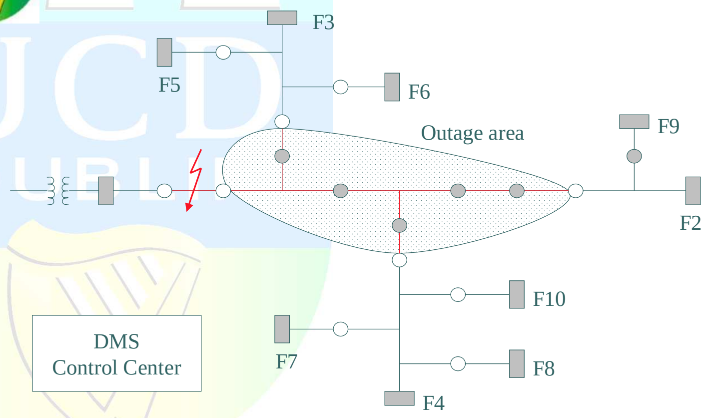
KEPRI – Korea Electric Power Research Cooperation

Example – Service Restoration
Faulted section isolation



KEPRI – Korea Electric Power Research Cooperation

Example – Service Restoration
Outage area to be transferred



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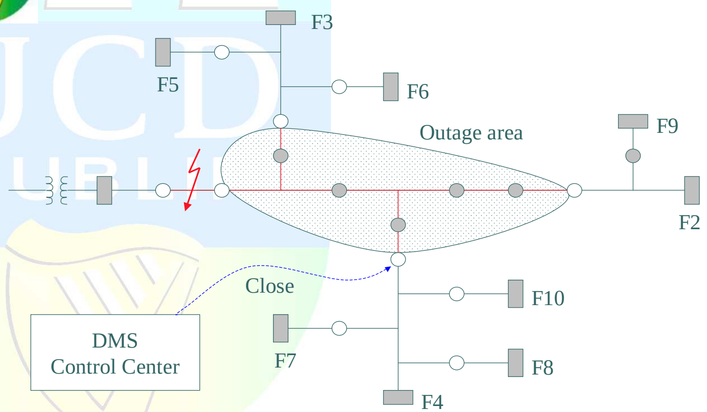
Example – Service Restoration
Execute restoration plan



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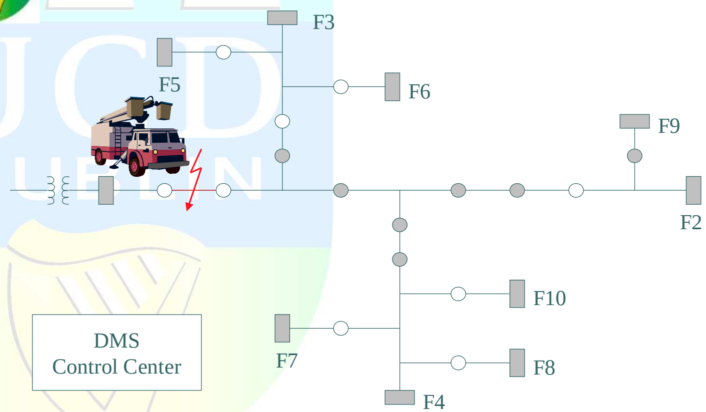
Example – Service Restoration
Field crew



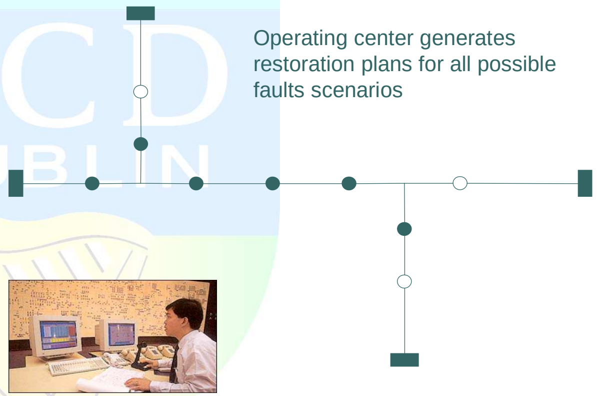
KEPRI – Korea Electric Power Research Cooperation

Benefits

- Labor savings due to reduced patrol and manual switching time (typically small $ benefit)
- Reduction in unserved energy due to power being restored more quickly for some customers (typically small $ benefit)
- Minimum operation time (a few minutes)
  - Automatic reclosing time
  - Communication time
  - Operator decision making time
- SAIDI and CAIDI should be reduced significantly

Restoration Plan Generation

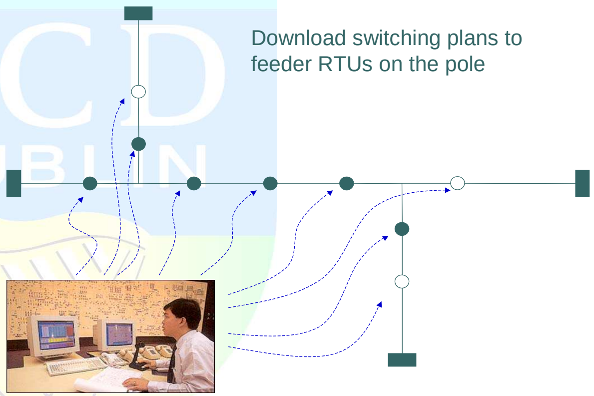
Operating center generates restoration plans for all possible faults scenarios



Korean patent (pending): NPTC Center, "Distributed Control Based Service Restoration", Oct 2005

Download Switching Plan

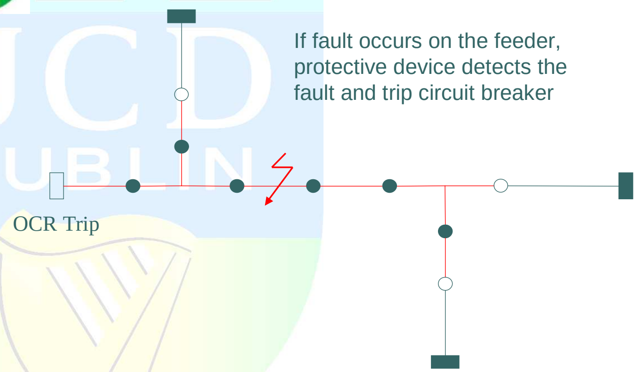
Download switching plans to feeder RTUs on the pole



Korean patent (pending): NPTC Center, "Distributed Control Based Service Restoration"

Fault Detection

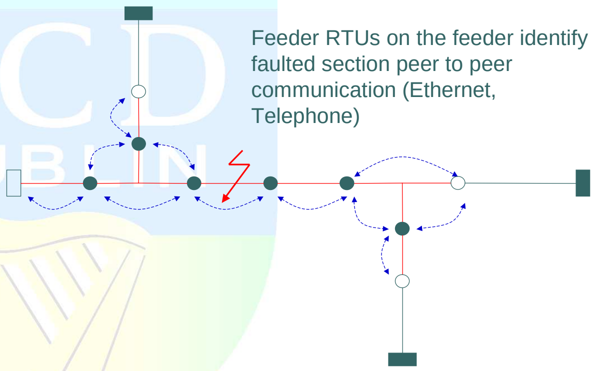
If fault occurs on the feeder, protective device detects the fault and trip circuit breaker



Korean patent (pending): NPTC Center, "Distributed Control Based Service Restoration"

Faulted Section Identification

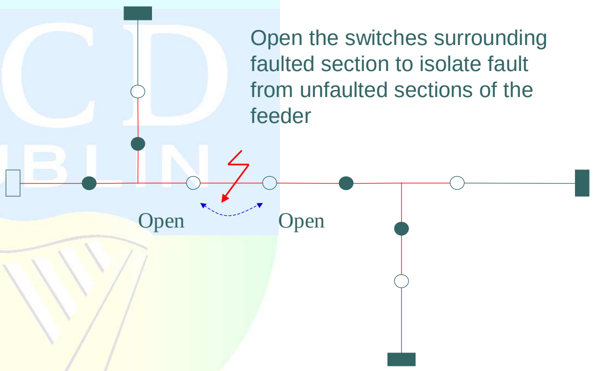
Feeder RTUs on the feeder identify faulted section peer to peer communication (Ethernet, Telephone)



Korean patent (pending): NPTC Center, "Distributed Control Based Service Restoration"

Faulted Section Isolation

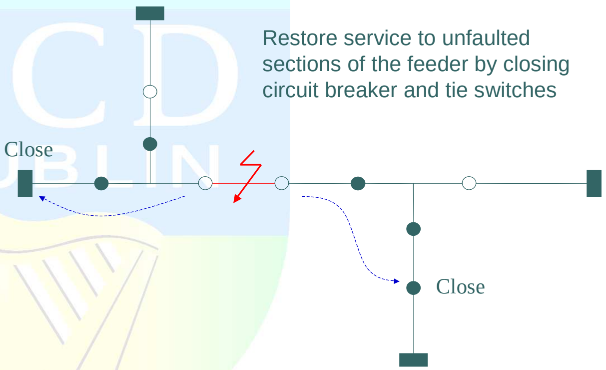
Open the switches surrounding faulted section to isolate fault from unfaulted sections of the feeder



Korean patent (pending): NPTC Center, "Distributed Control Based Service Restoration"

Service Restoration

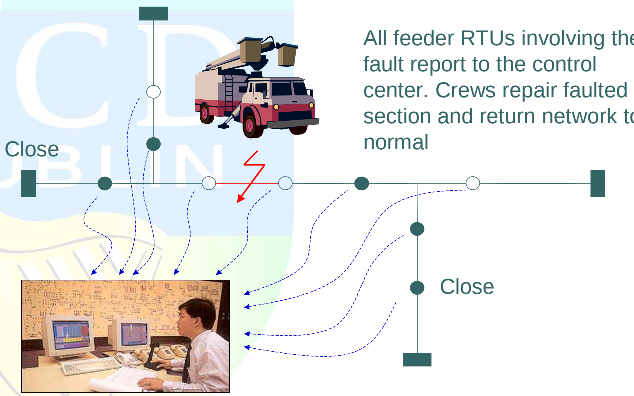
Restore service to unfaulted sections of the feeder by closing circuit breaker and tie switches



Korean patent (pending): NPTC Center, "Distributed Control Based Service Restoration"

Reporting & Crew Dispatch

All feeder RTUs involving the fault report to the control center. Crews repair faulted section and return network to normal



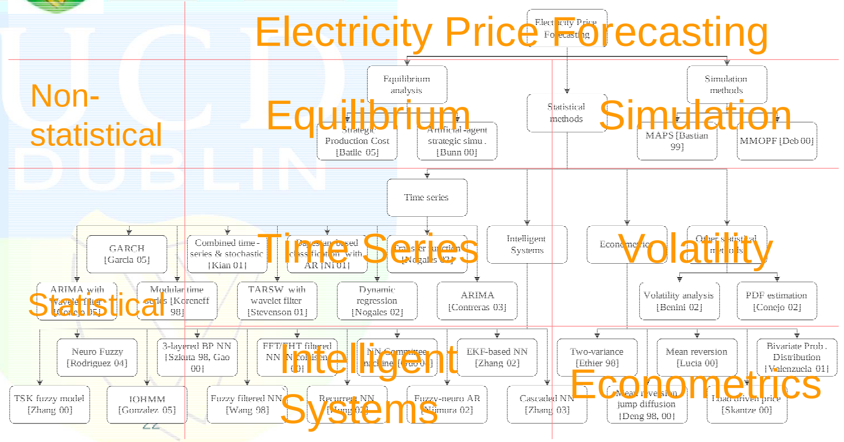
Korean patent (pending): NPTC Center, "Distributed Control Based Service Restoration"

Future Service Restoration

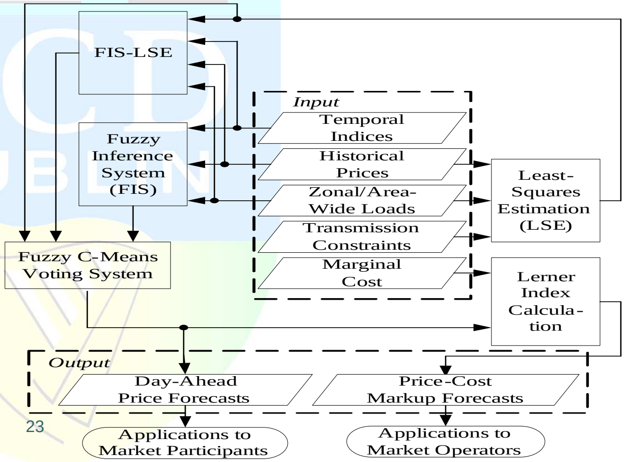
- **Technology**
  - Multi-agent system
  - Ethernet based peer to peer communication
  - Combine protection and restoration
- **Expected benefits**
  - Reduce outage times
  - Operator supervision in restoration planning

Korean patent (pending): NPTC Center, "Distributed Control Based Service Restoration"

Literature Survey on Day Ahead Electricity Price Forecasting

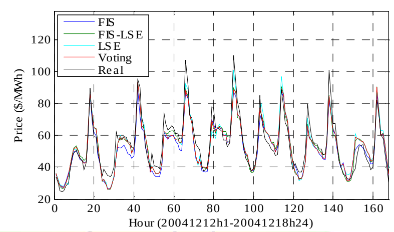


Proposed Integrated System

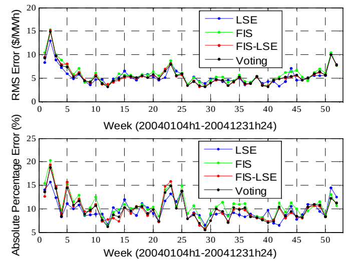


Forecasted PECO Zonal LMPs in 2004

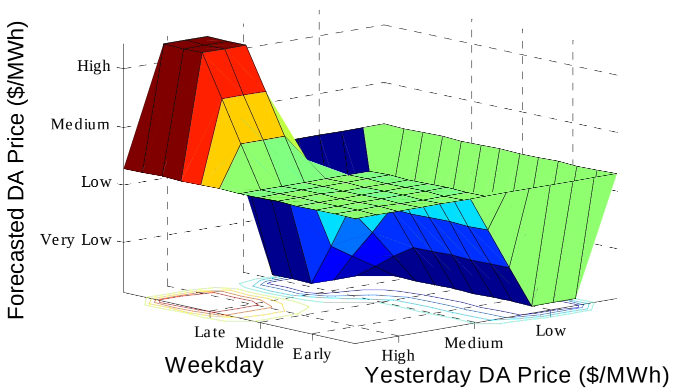
A weekly example



Weekly RMSE and MAPE



An Example of Nonlinear Relation of Variables in the Rule Base

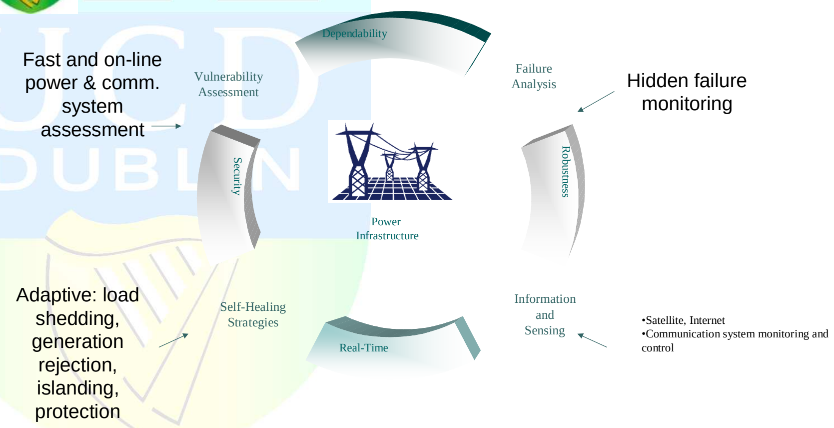


Strategic Power Infrastructure Defense (SPID)

Design self-healing strategies and adaptive reconfiguration schemes

- To achieve autonomous, adaptive, and preventive remedial control actions
- To provide adaptive/intelligent protection
- To minimize the impact of power system vulnerability

Concept of SPID



Multi-Agent System for SPID

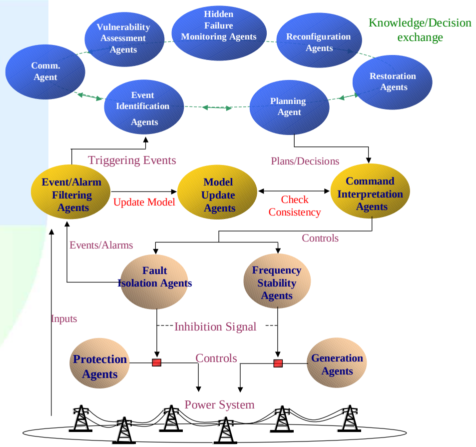
- **Distributed system design**
  - ➢ Problems are too heterogeneous, complex, and distributed
- **Coordination and communication methods for agents knowledge-level interactions**
- **Agent's adaptive capability**
  - ➢ Power systems dynamic and random

Multi-Agent System for SPID

DELIBERATIVE LAYER

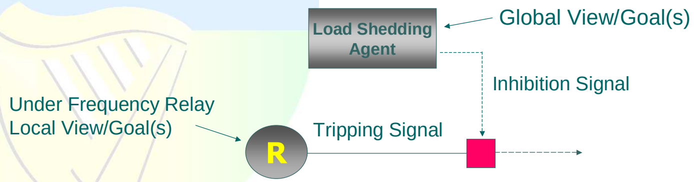
COORDINATION LAYER

REACTIVE LAYER

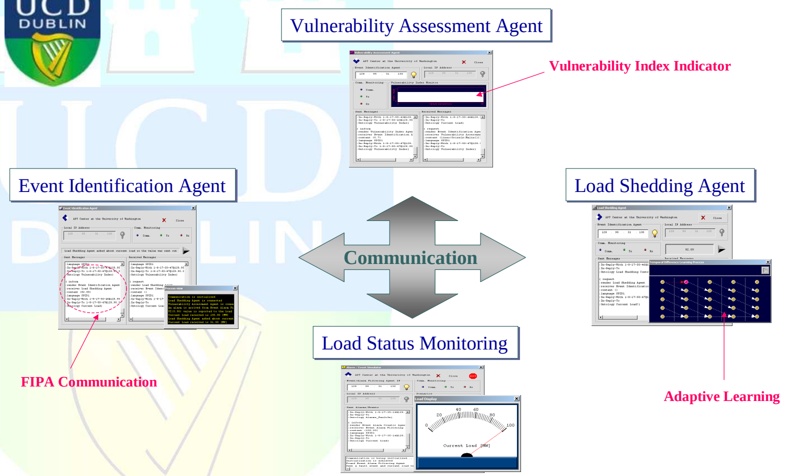


Multi-Agent System for SPID

- Subsumption Architecture (Brooks) for Coordination
- Agents in the higher layer can block the control actions of agents in lower layers

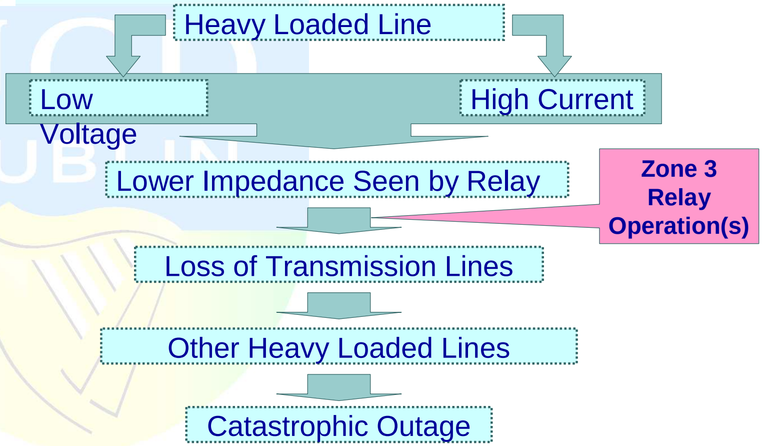


SPID Simulation



Cascaded Zone 3 Operations

Zone 3 Relay Operations Contributed to Causes of Blackouts.



Prediction of Zone 3 Relay Tripping Based on On-Line Steady State Security Assessment

Contingency Evaluation Performed On Line

Post-Contingency Power Flow

Post-Contingency Apparent Impedance

FIS

Corrected Post-Contingency Apparent Impedance

Contingency Evaluation

…

Case	Relay	Status	Contingency Description
1	N/A	Secure	3 phase fault at bus 1
2	Zone 3	Insecure	3 phase fault at bus 2
..		…	
N	N/A	Secure	3 phase fault at bus N

Fuzzy Inference System (FIS) Developed Using ***Off-Line*** Time-Domain Simulations

Automatic Development of Fuzzy Rule Base

Wang & Mendel's algorithm is a "learning" algorithm:

1) One can combine measured information and human linguistic information into a common framework

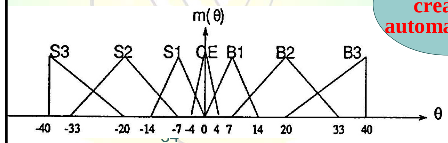
2) **Simple and straightforward one-pass build up procedure**

3) There is flexibility in choosing the membership

Pre-determine number of membership functions N

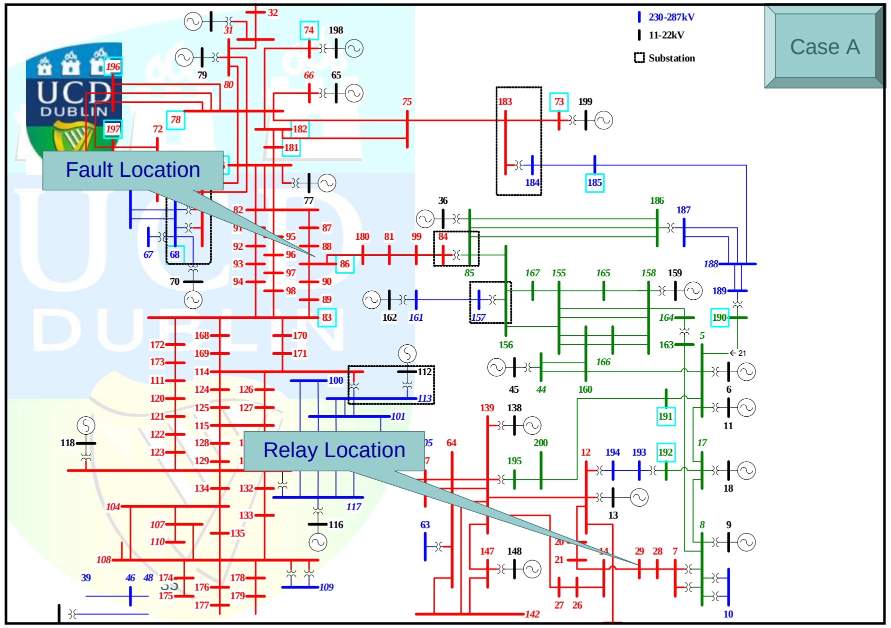
Give input and output data sets

FIS created automatically

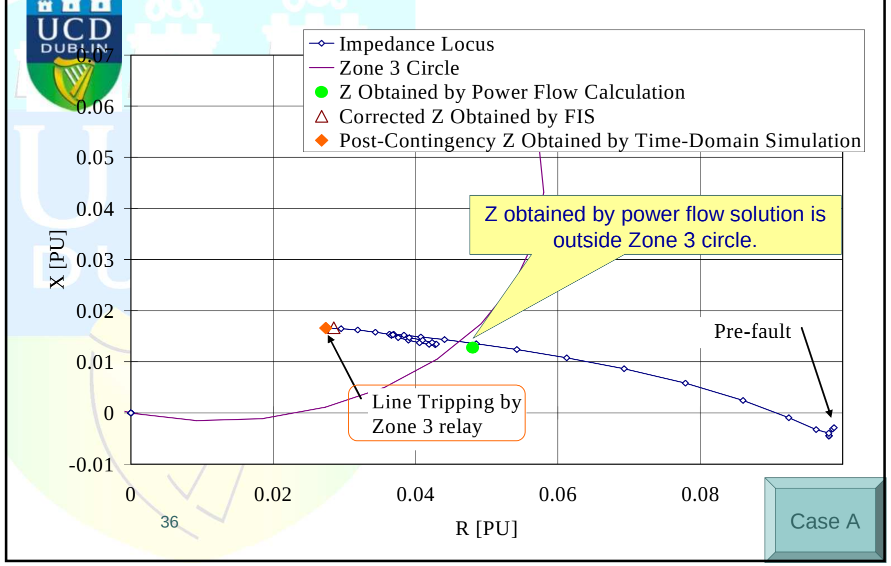


In this example, N is 7

(Inp1, Inp2, Out) = (10, 1, -2)
(Inp1, Inp2, Out) = (8, 3, -1)
(Inp1, Inp2, Out) = (5, 6, -4)
(Inp1, Inp2, Out) = (2, 8, -5)
…



Impedance on R-X (Case A)



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LOAD SHEDDING

- Studies have shown that the August 10th 1996 blackout could have been prevented if just 0.4% of the total system load had been dropped for 30 minutes.
- According to the Final NERC Report on August 14, 2003, Blackout, at least 1,500 to 2,500 MW of load in Cleveland-Akron area had to be shed, prior to the loss of the 345-kV Sammis-Star line, to prevent the blackout.

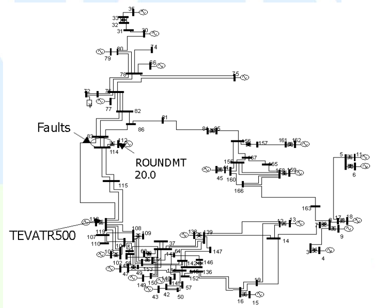
Adaptive Self-healing: Load Shedding Agent

- **A control action might fail**
- **Unsupervised adaptive learning method should be deployed**
- **Reinforcement Learning**
  - Autonomous learning method based on interactions with the agent's environment
  - If an action is followed by a satisfactory state, the tendency to produce the action is strengthened

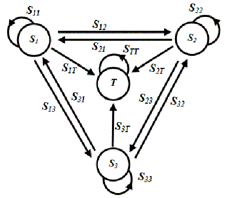
Adaptive Self-healing: Load Shedding Agent

- The 179 bus system resembling the WSCC system
- ETMSP simulation
- Remote load shedding scheme based on frequency decline + frequency decline rate
- Temporal Difference (TD) method is used for adaptation: *Need to find the learning factor for convergence*

Adaptive Load Shedding Agent

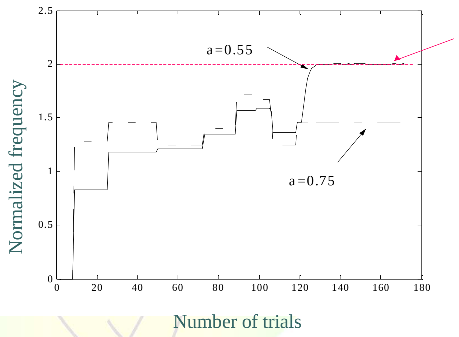


179 bus system



State 1	State 2	State 3
Freq := 59.5 Dec.rate > threshold value	Freq := 58.8 Dec.rate > threshold value	Freq := 58.6 Dec.rate > threshold value

Adaptive
Load Shedding Agent



Expected normalized system frequency that makes the system stable

"The load shedding agent is able to find the proper control action in an adaptive manner based on responses from the power system"

Intelligence, Agents and Smart Grids: The Electric Power System of the Near Future?

Professor Stephen McArthur

U. Strathclyde

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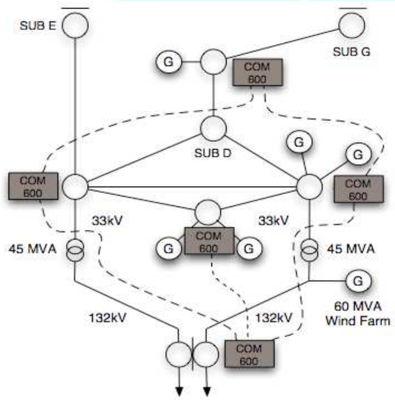
INSTITUTE FOR ENERGY AND ENVIRONMENT

AuRA-NMS:
Autonomous
Regional **A**ctive
Network **M**anagement
System

Multi-agent System Technology plays a key role in the **AuRA-NMS** Architecture

Scope of Automation & Control:

- Restoration - reduce customer minutes lost (CML)
- Reconfiguration - reduce customer interruptions (CI)
- Voltage Control
- Management of Constrained Connections
- Proactive Network Optimisation - e.g. reduction of losses
- Explanation of Control Actions*



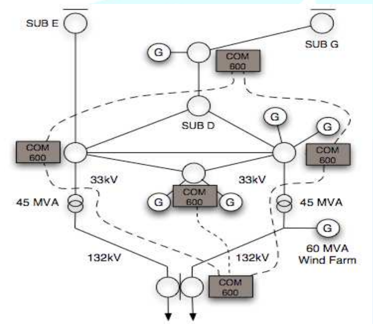
Using:

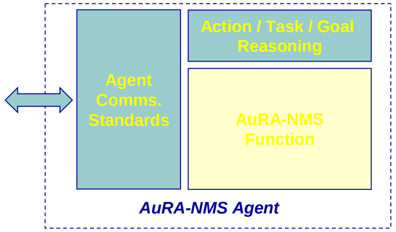
- Distributed hardware
  (ABB COM600 Industrial PC)
- Distributed, agent based, control software

Aim to provide:

- Plug and play functionality
- Flexibility and extensibility
- Enhanced network control
- An AURA controller is not a single device
- AURA software exploits hardware redundancy
- Initial functions:
  - Thermal Management
  - Voltage Control
  - Reconfiguration

MAS technology: Autonomy & System Integration





Autonomous behaviour:

- Automatically planning and executing network management functions
- Automatically reacting to control decisions from other AuRA-NMS functions
- Negotiation and arbitration to determine correct actions to take

System integration:

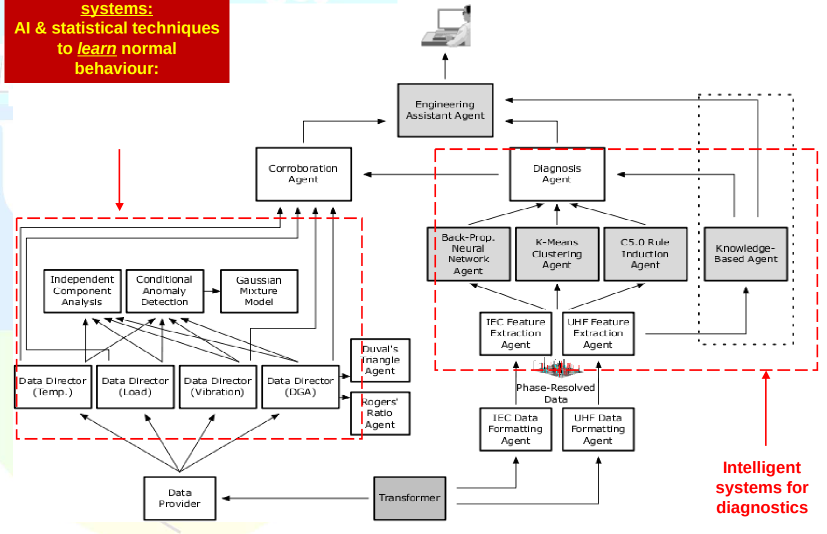
- New agents automatically integrate with existing control functions
- Agent communications standards (FIPA)
- Ontologies and content languages for interoperability
- Harmonisation with CIM and IEC 61850

EPSRC Supergen 5 Demonstrator Using MAS and Intelligent Systems for National Grid

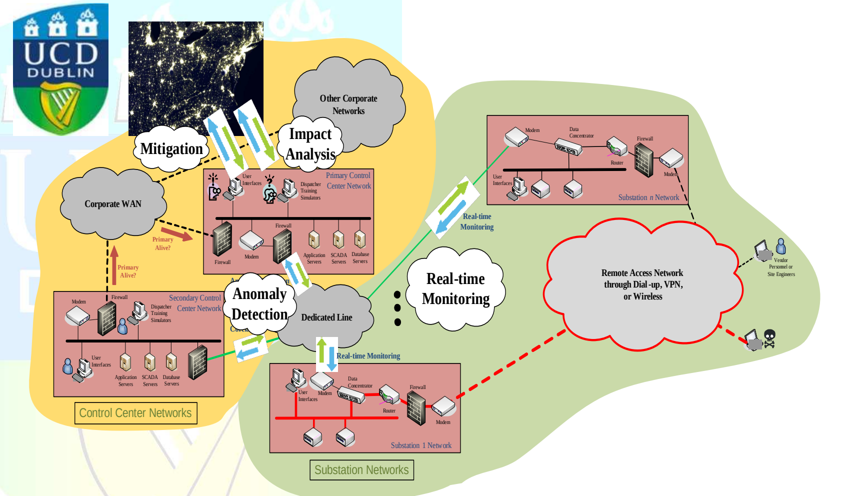
- Two sister transformers
- Manufacturer: GEC Witton
- 275/132kV, 180MVA
- One fine, one in poorer health
- Transfix on-line dissolved gas monitoring
- Over 30 sensors added to oil cooling circuit, main tank, pumps and fans.

Self-learning monitoring systems:
AI & statistical techniques to *learn* normal behaviour:

Monitoring Architecture

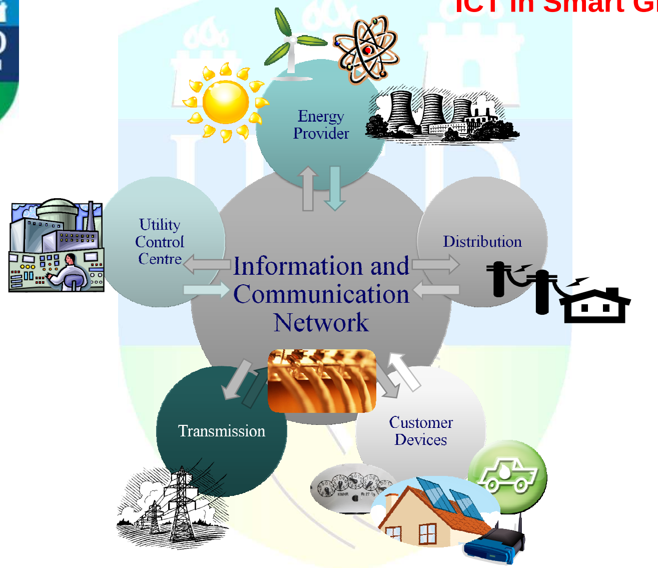


Intelligent systems for diagnostics



Cyber Security Monitoring and Mitigation

ICT in Smart Grid



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