Computational Issues for Intelligent Grids

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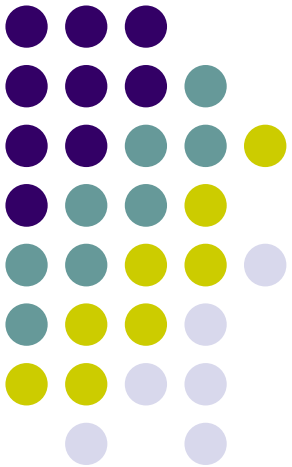
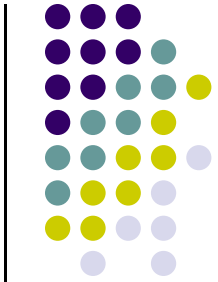


EPRI vision

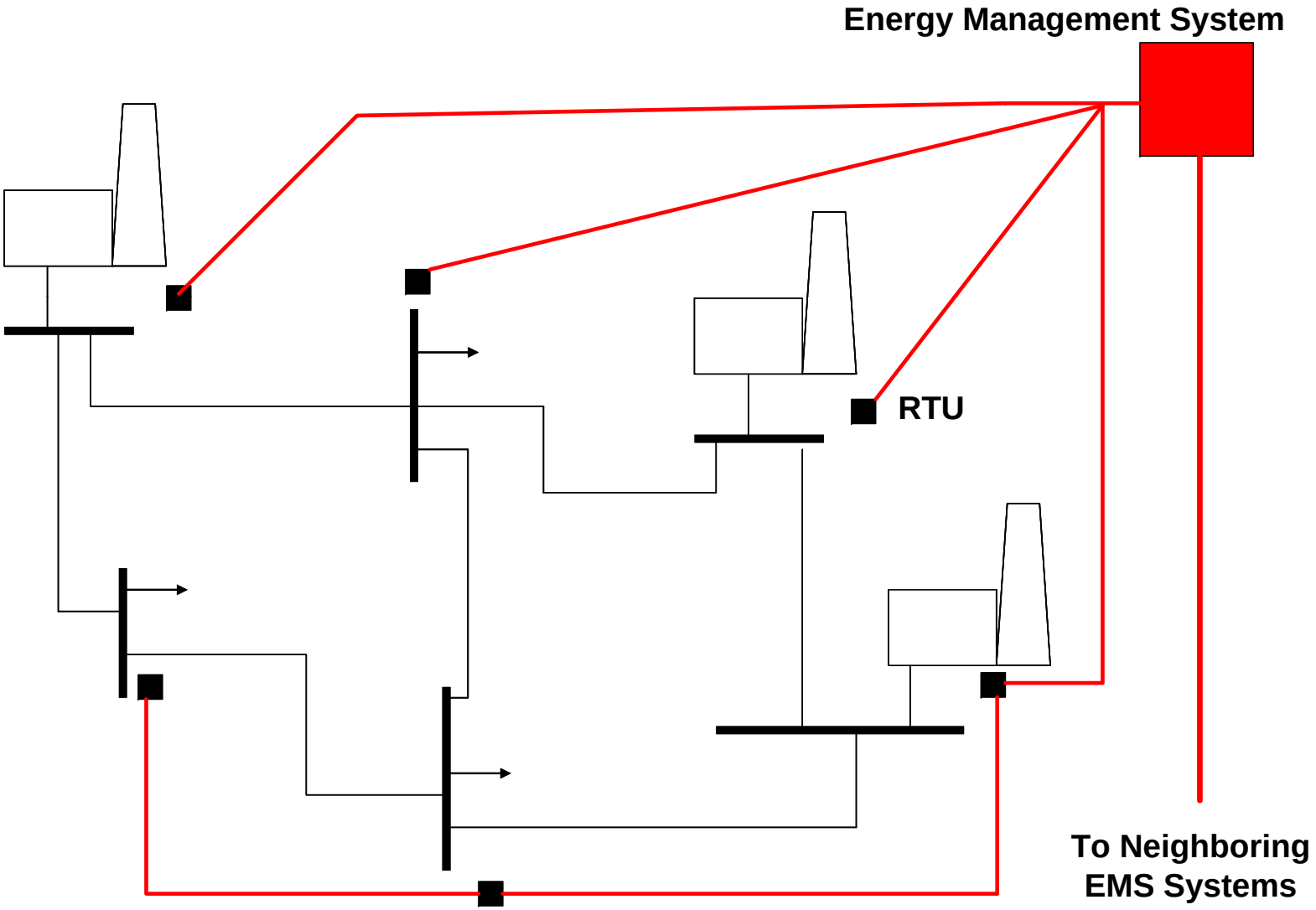


The IntelliGrid Architecture provides guidelines to link communications and electricity into a "smart grid" - an integrated, "self healing," and electronically controlled power system that will offer unprecedented flexibility and functionality, and improve system security. (from IntelliGrid web site)

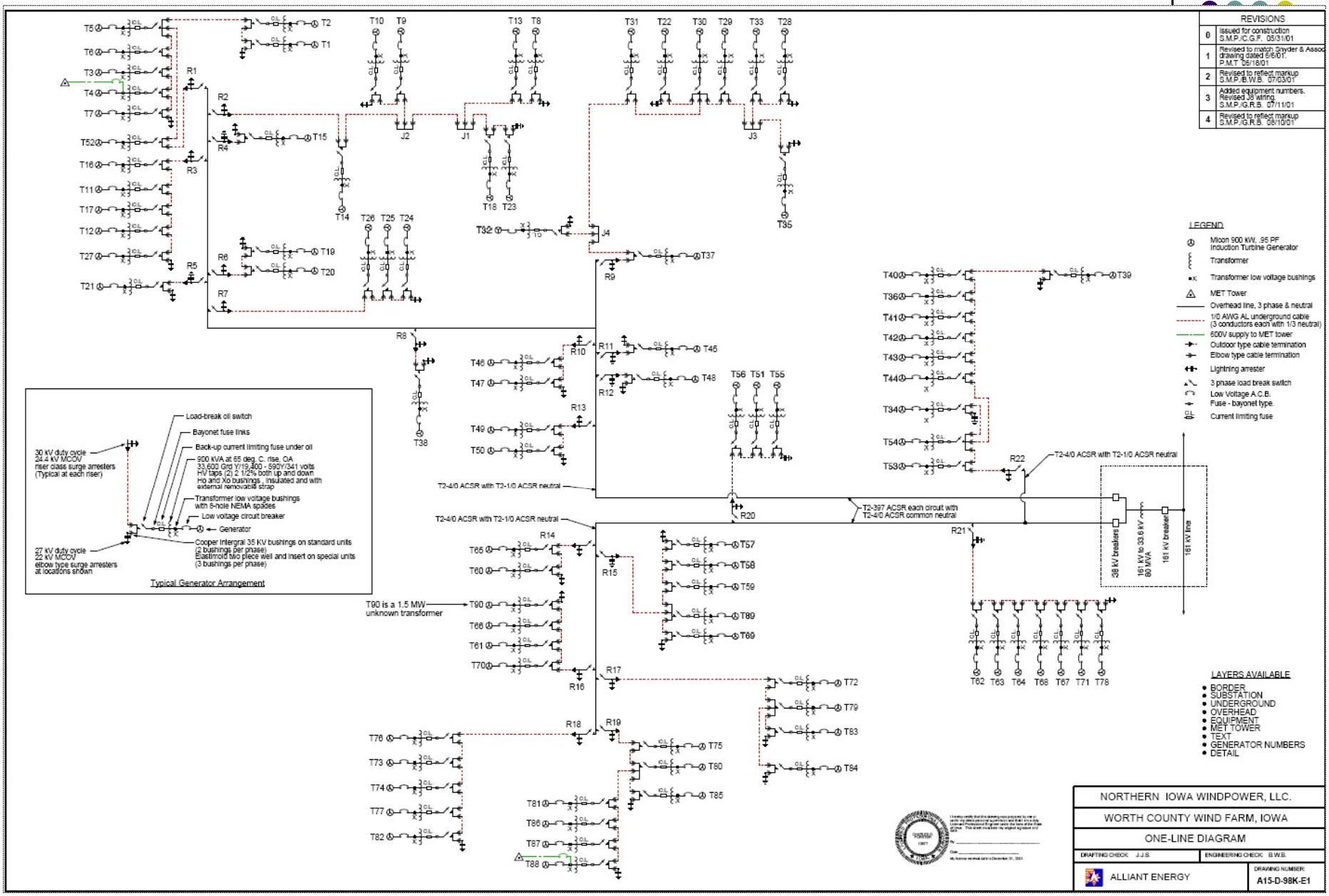
Present scheme for control of a power system

Xcel Energy Control Room Minneapolis

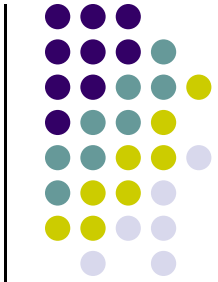
Conventional EMS with concentrated centralized intelligence



Complexity of Power Systems



Intelligence should start at the component level

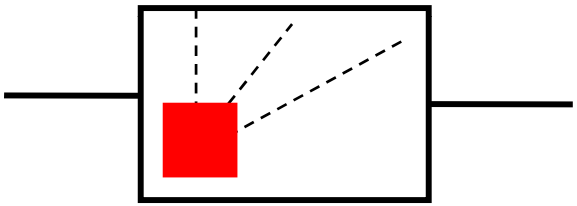


- All substation and power plant components have an embedded processor with ability to connect to fiber communications
- Each high voltage connection has a parallel information connection
- Device processors have permanent information on device parameters, status and analog measurements from the device

“Plug and Play” solution

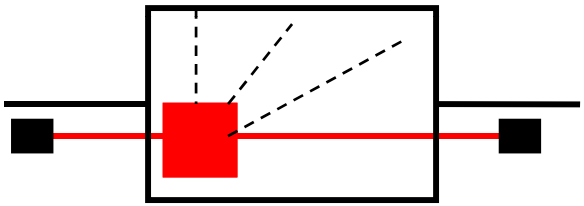
- Typical substation or power plant component

“Plug and Play” solution



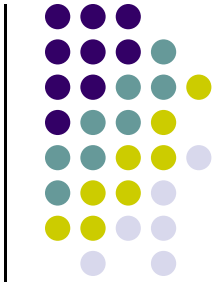
- Internal processor
  - Stores all component parameters
  - Measures component status

“Plug and Play” solution



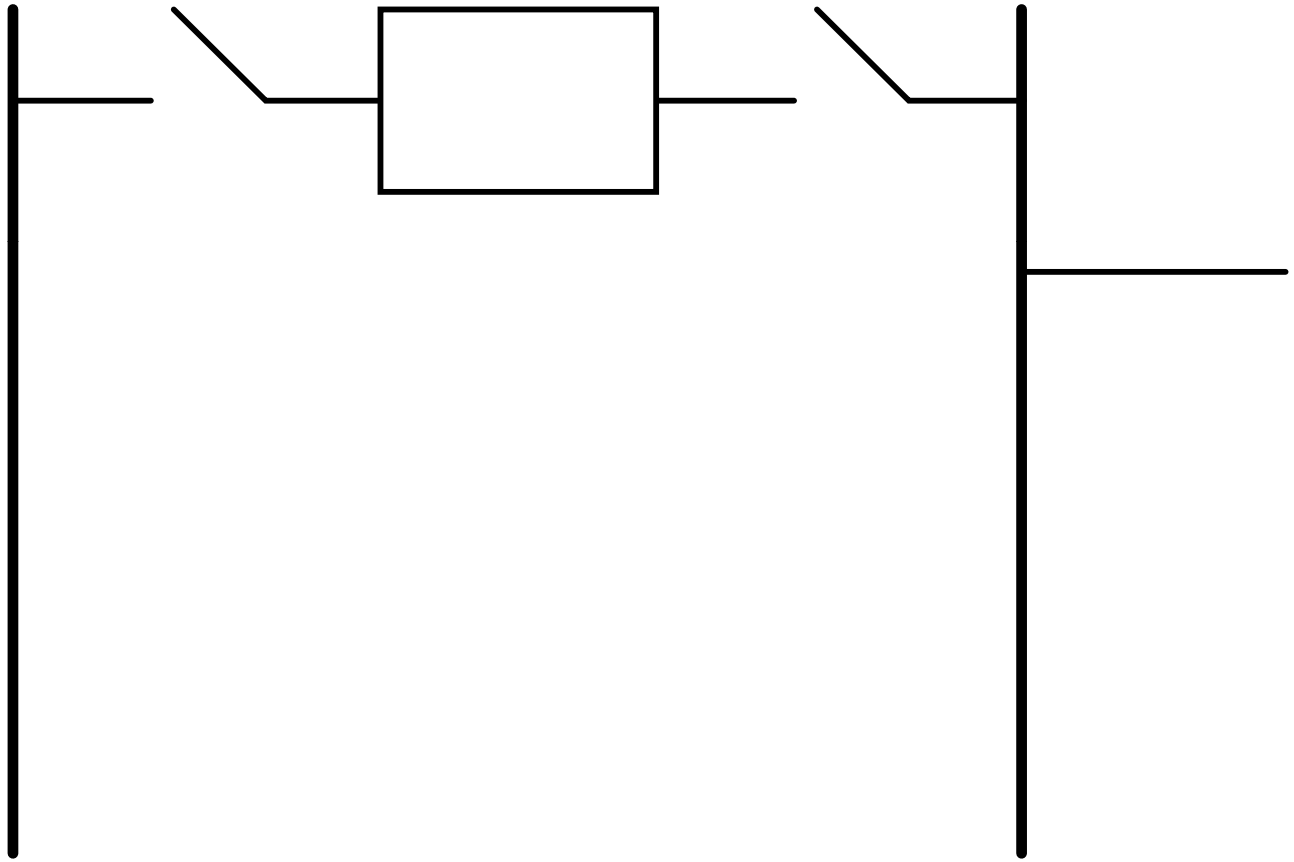
- Processor communicates with other components it is connected with

Keeping a central computing database up to date

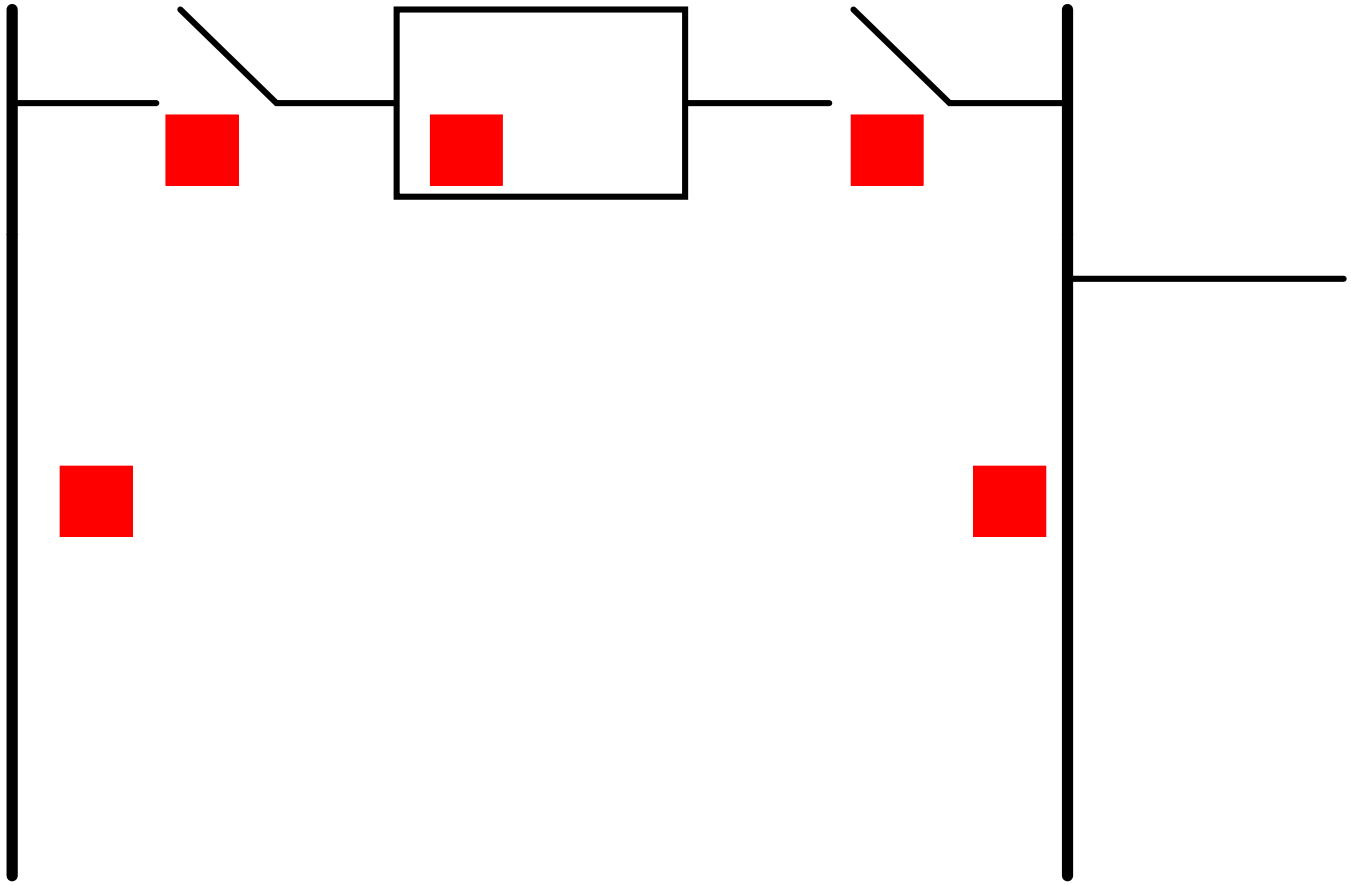


- Problem:
  - New equipment is installed in a substation
  - Its connection to other equipment must be recorded alond with all parameters describin the new equipment
  - The central computer's database must be updated and the substation one line diagrams updated for system operators
- This often takes too much time and errors can be made

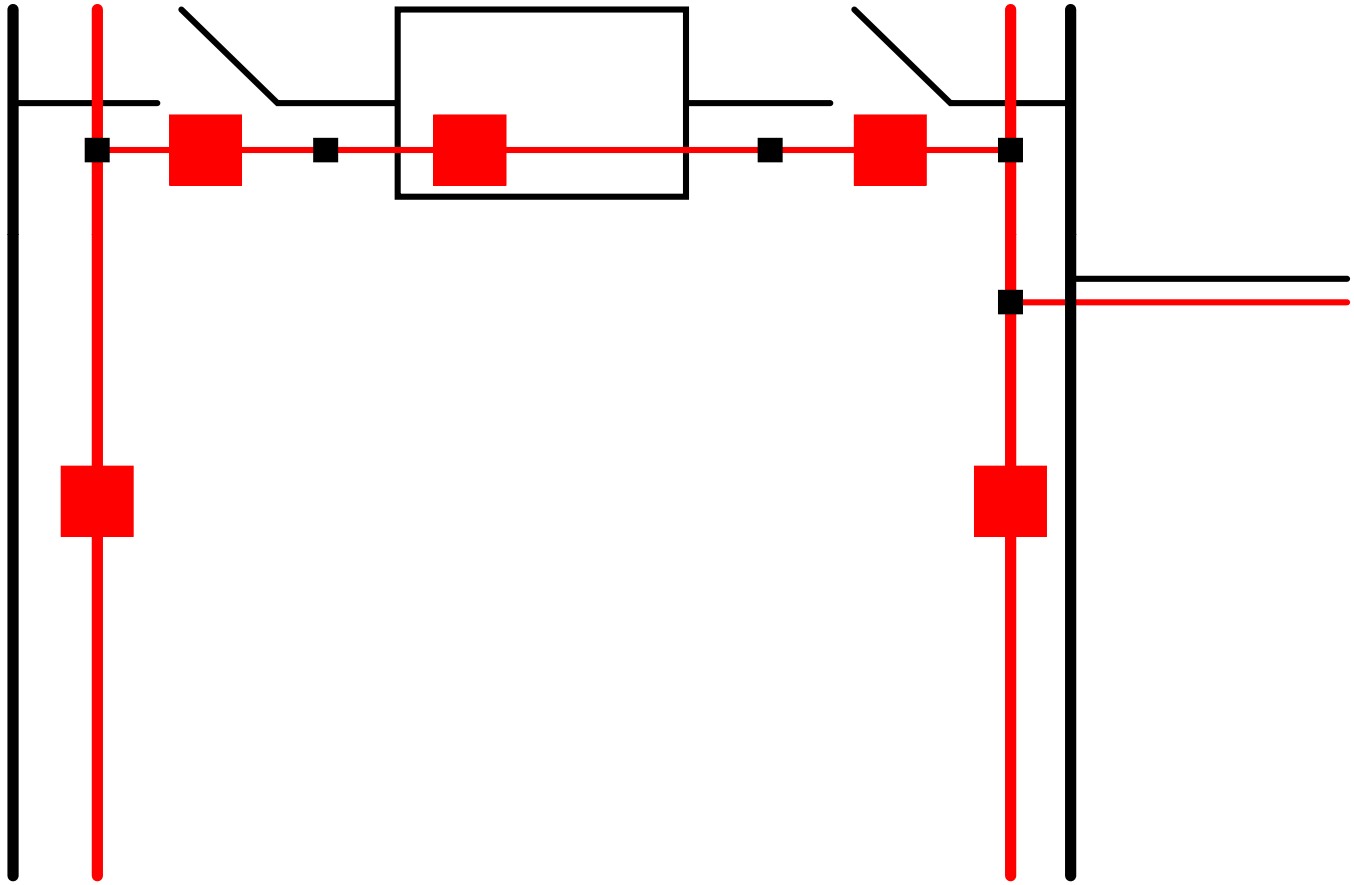
Substation buses connected by breakers and disconnects



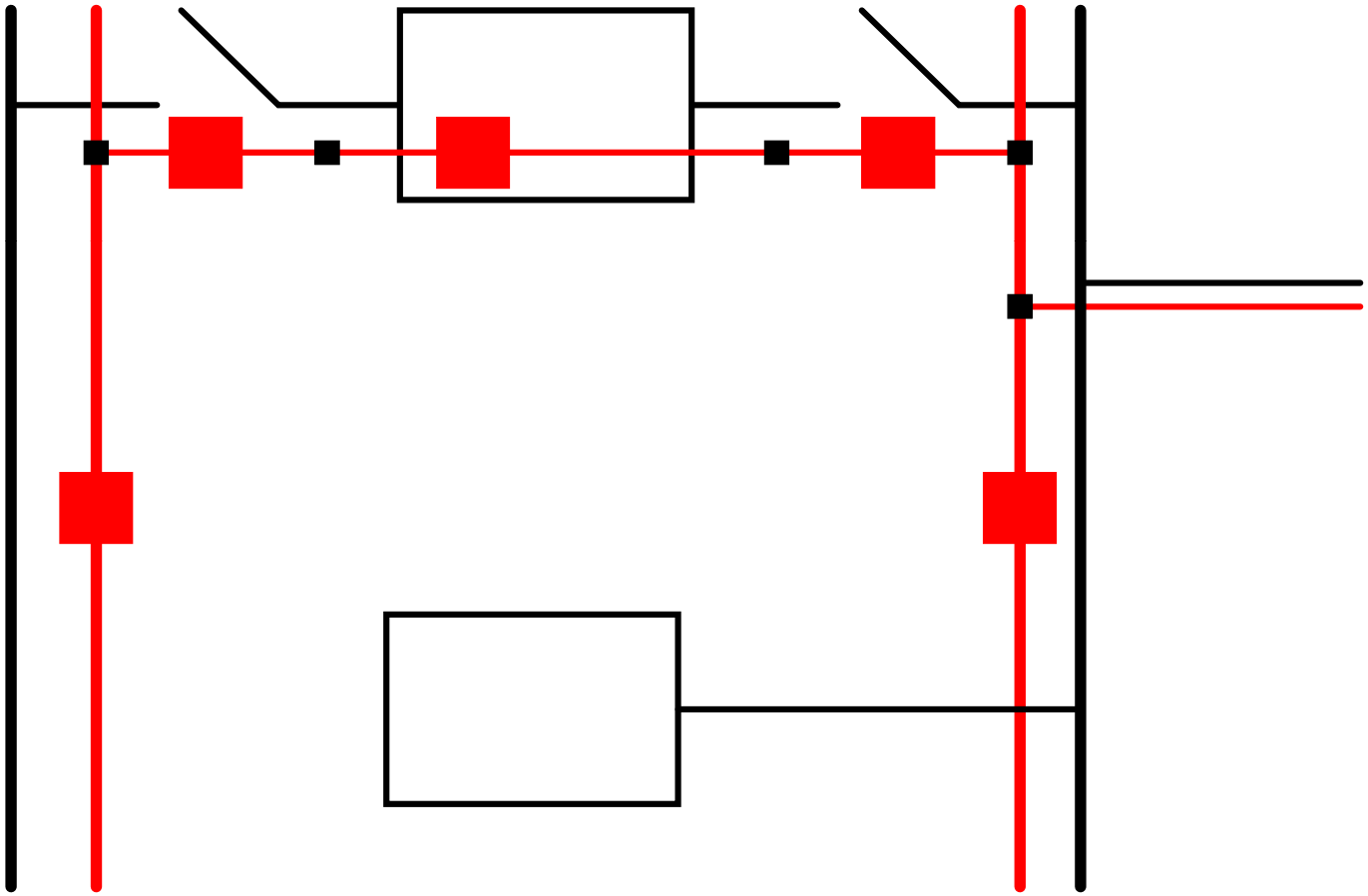
Each device has its own processor



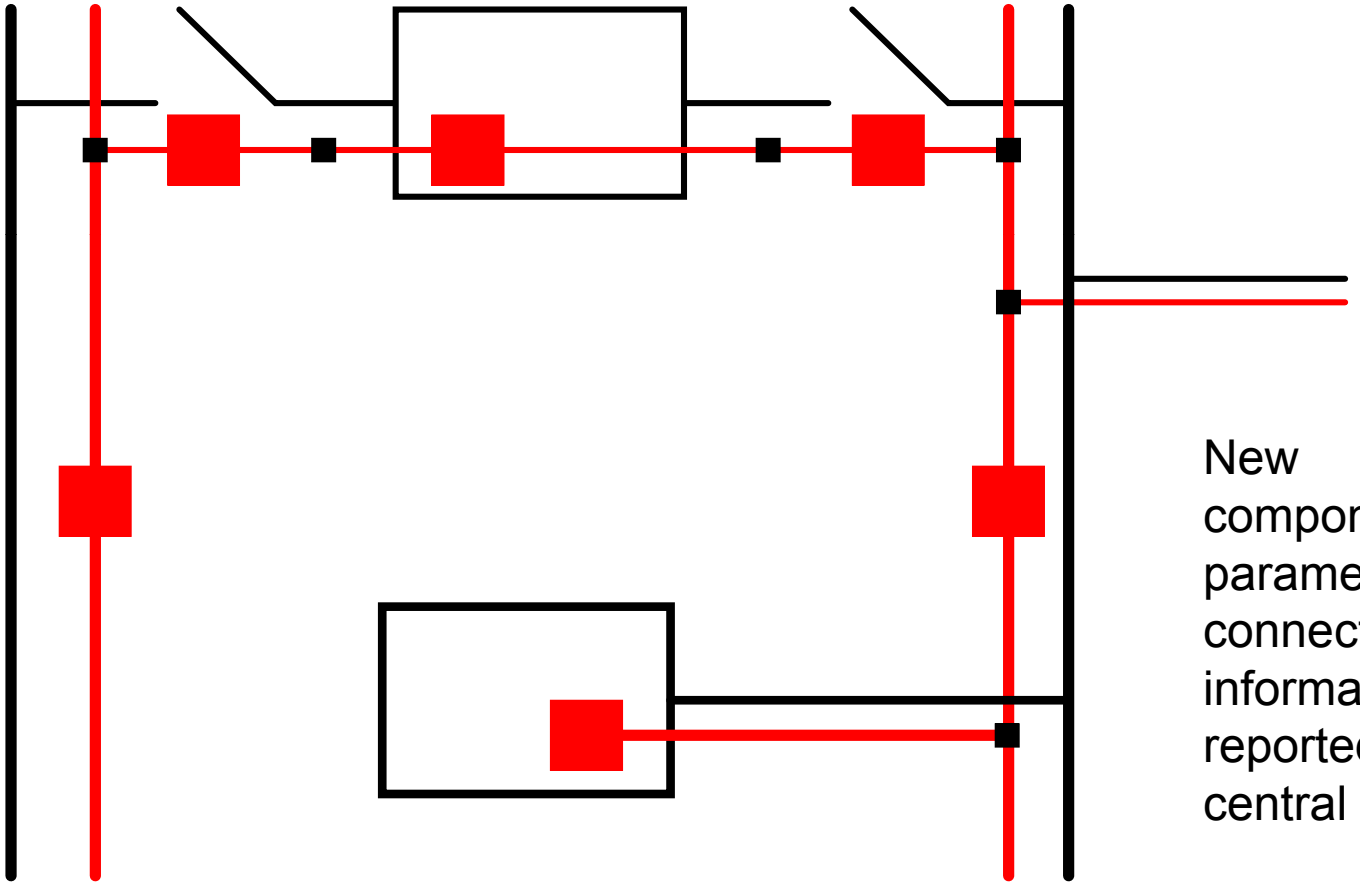
Processors are connected by fiber links



Addition of new component

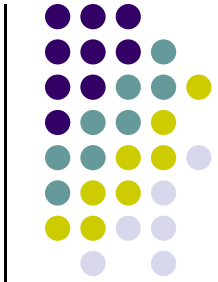


New component is also connected to information layer



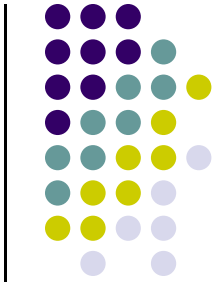
New component's parameters and connection information reported to central database

All components are smart



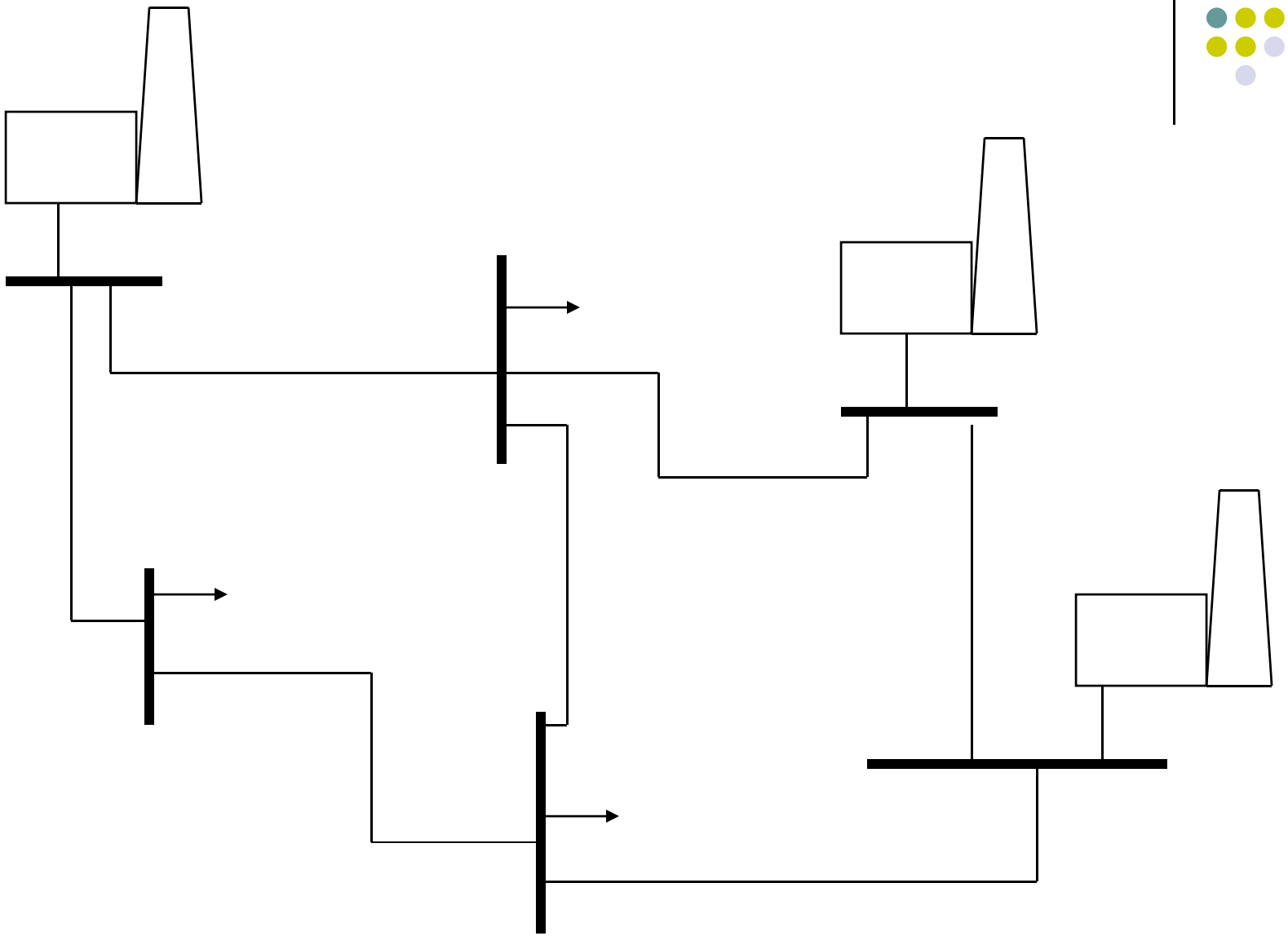
- When a new component is added to a substation – it automatically reports to the system control center
  - All component parameters are uploaded
  - All component interconnections are uploaded
  - The substation data model is self built
  - The substation one line diagrams can show the new component immediately
- Components can form agent networks through the fiber channels and act much faster than normal

Extending intelligence to the entire power system

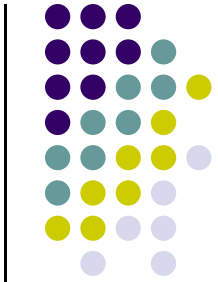


- Act as fast as the protection system
- No central computing site
- Spans the entire power grid

Self Healing Grid example

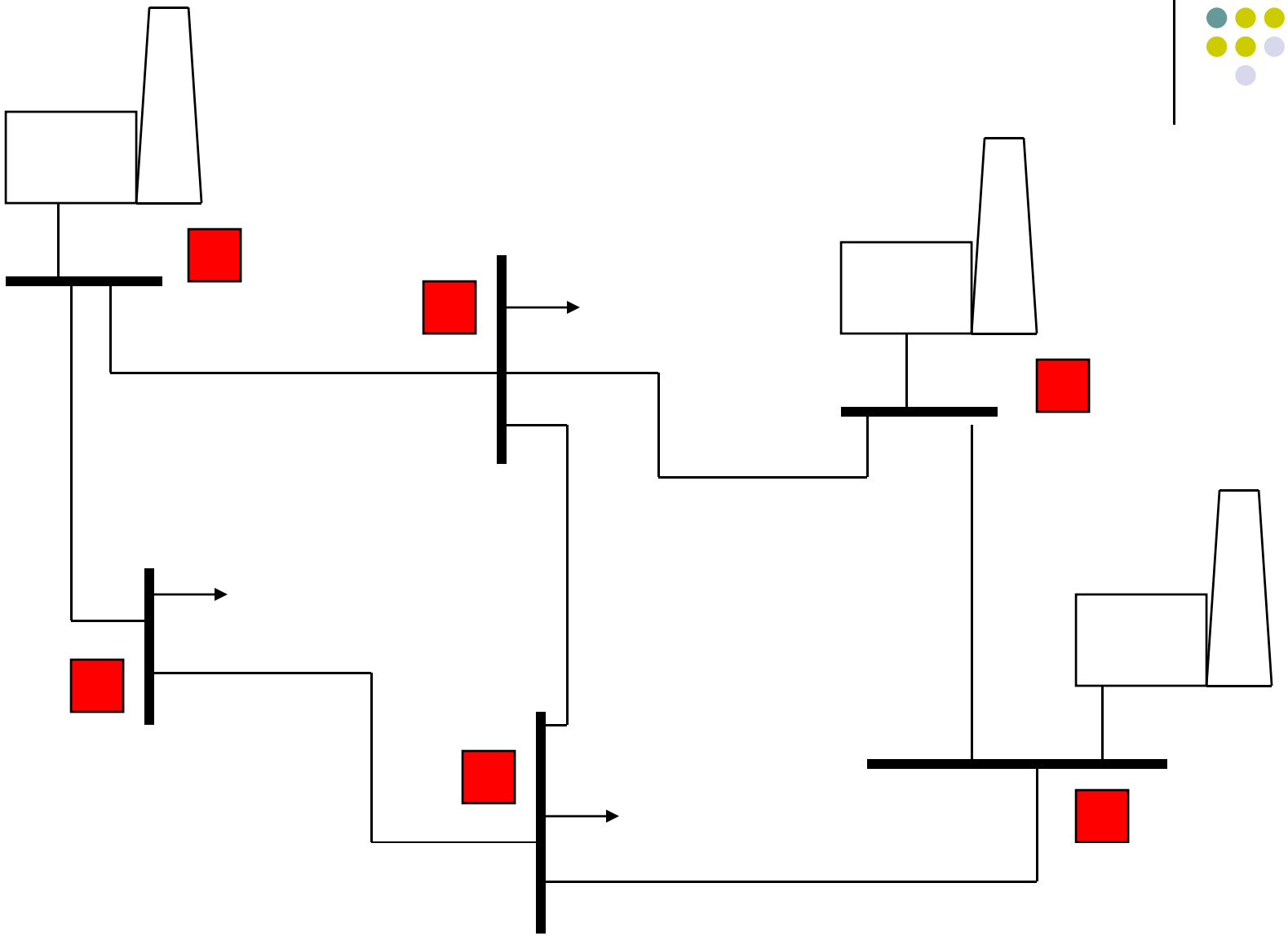


Each substation has an embedded agent

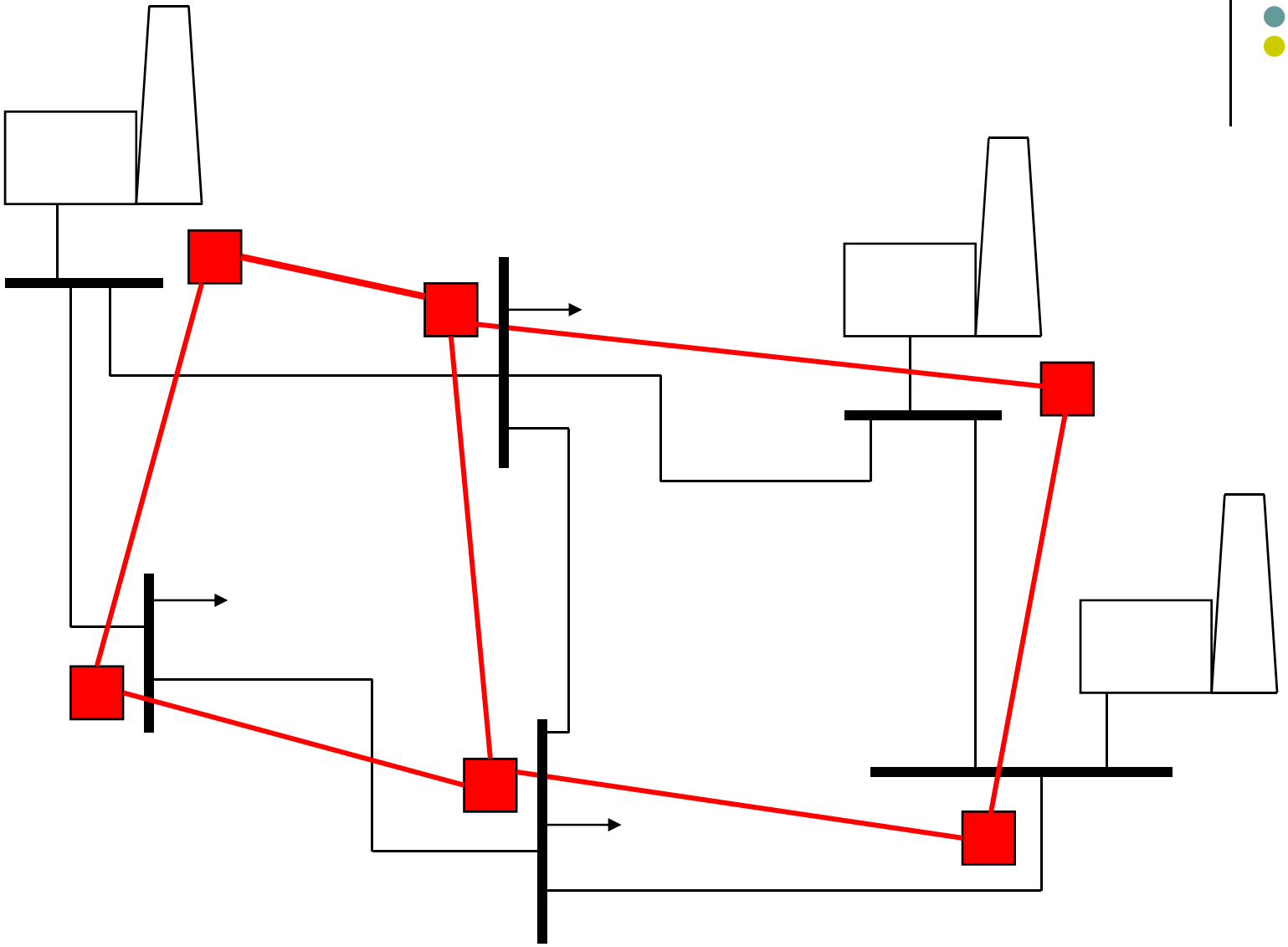


- Each agent communicates with processors within the components
- Each agent communicates with other substations

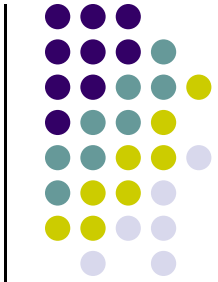
Self Healing Grid example



Self Healing Grid example

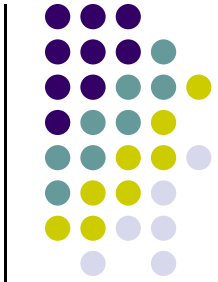


Blackouts



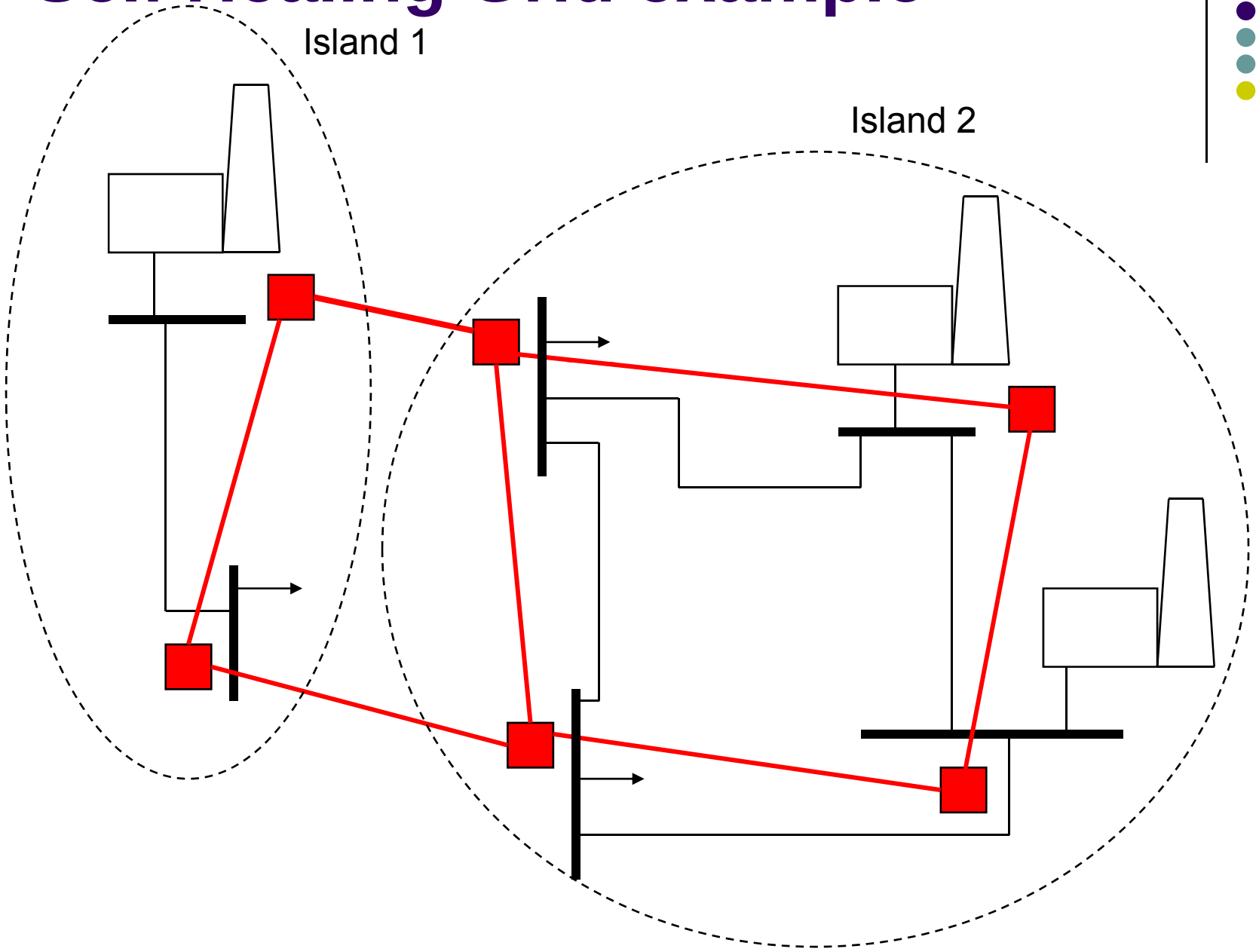
- Usually start in the transmission system
- Result is system breaking into islands
- Generation-load imbalance results in large frequency swing and shut down of generation
- Generation restart time may be many hours, prolonging the blackout

Agent actions at start of power system emergency

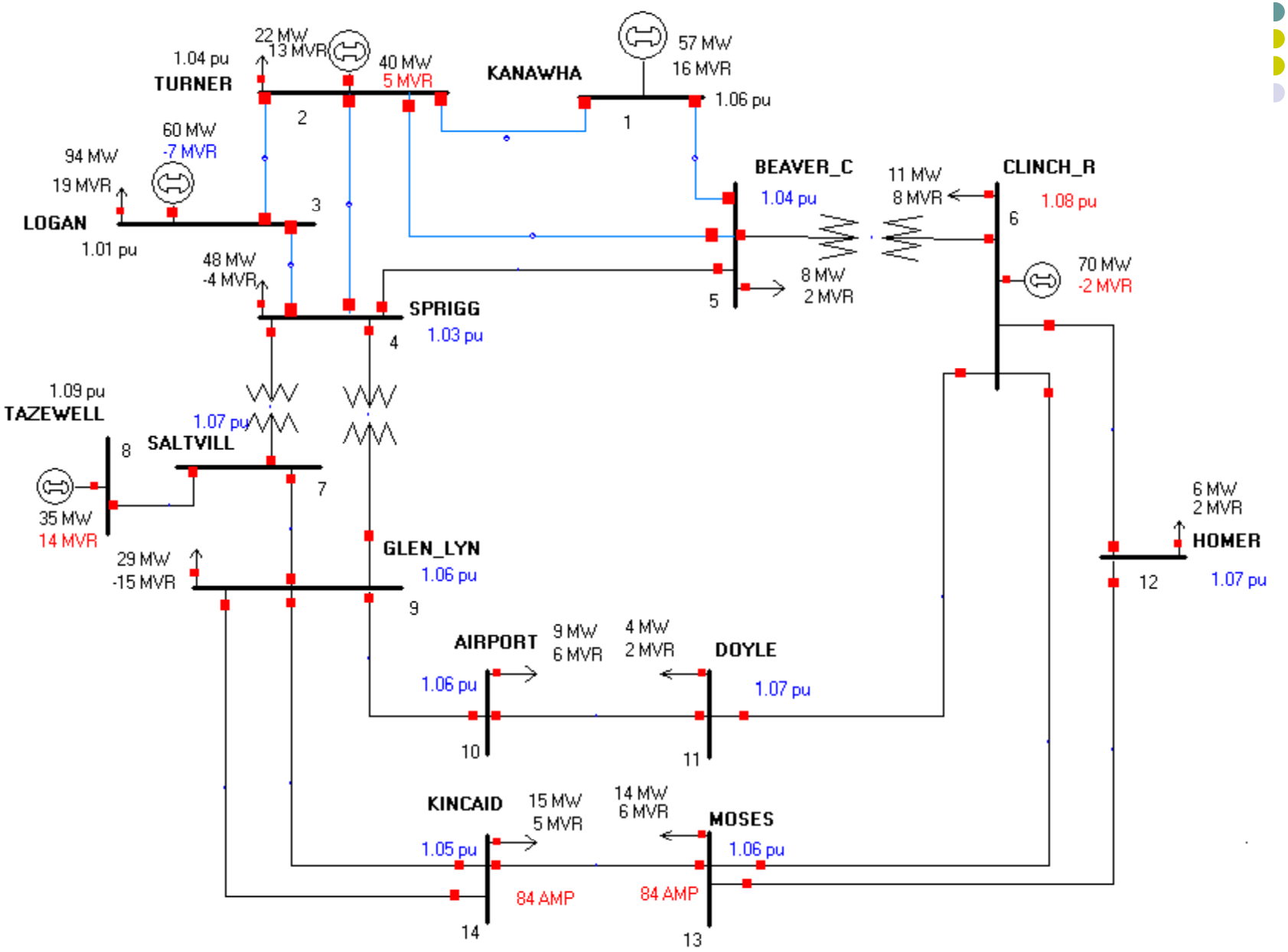


- Become aware of islanding
- Calculate island generation-load balance
- If necessary shed generation or load to maintain balance and stabilize frequency
- This cannot usually be handled by central control systems

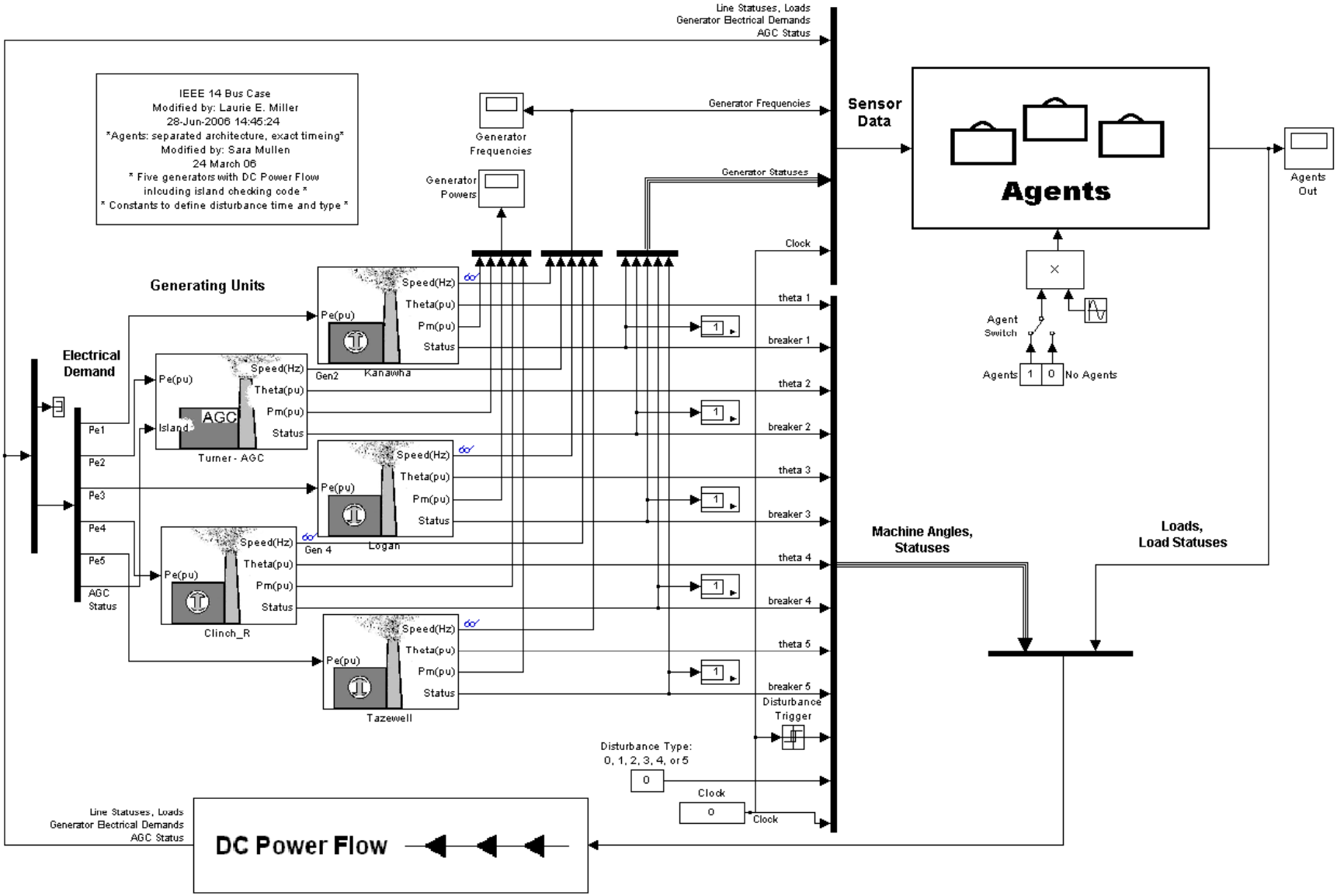
Self Healing Grid example

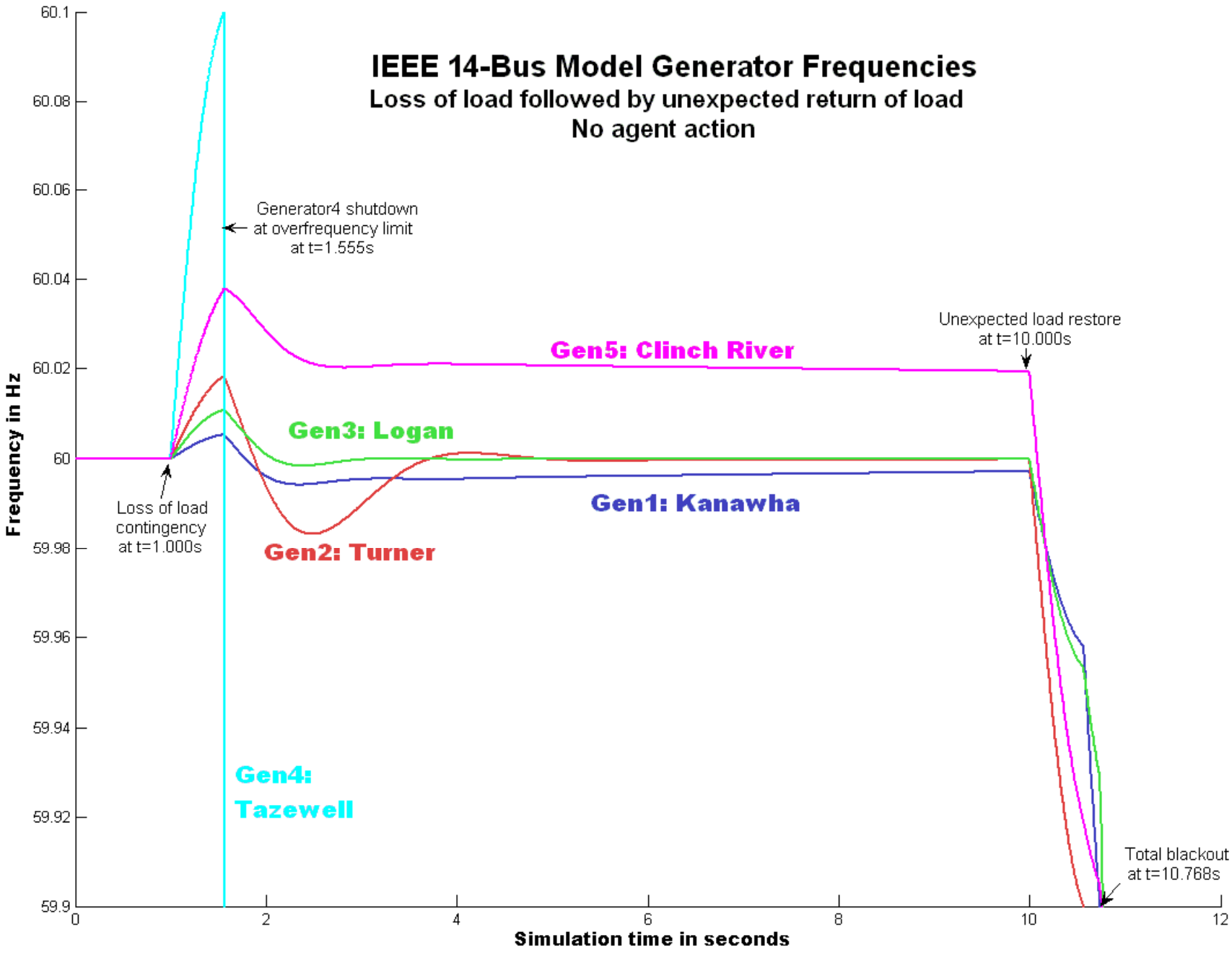


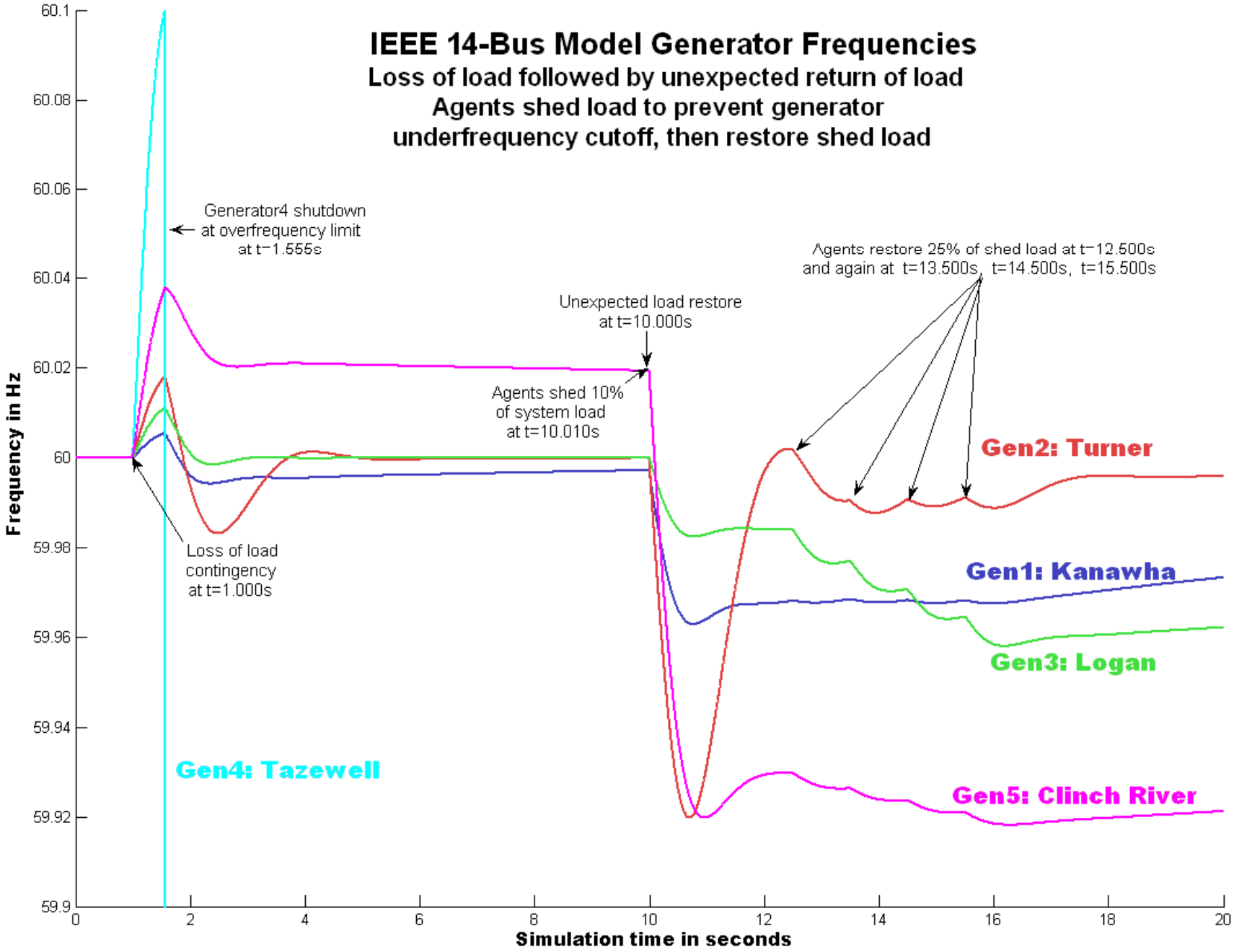
IEEE 14 Bus System



IEEE 14 Bus System With Agents




IEEE 14-Bus Model Generator Frequencies
Loss of load followed by unexpected return of load
No agent action
Generator4 shutdown
at overfrequency limit
at t=1.555s
Unexpected load restore
at t=10.000s
Gen5: Clinch River
Gen3: Logan
Gen1: Kanawha
Gen2: Turner
Gen4:
Tazewell
Loss of load
contingency
at t=1.000s
Total blackout
at t=10.768s
Frequency in Hz
Simulation time in seconds
60.1
60.08
60.06
60.04
60.02
60
59.98
59.96
59.94
59.92
59.9
0
2
4
6
8
10
12


IEEE 14-Bus Model Generator Frequencies
Loss of load followed by unexpected return of load
Agents shed load to prevent generator
underfrequency cutoff, then restore shed load
Generator4 shutdown
at overfrequency limit
at t=1.555s
Agents restore 25% of shed load at t=12.500s
and again at t=13.500s, t=14.500s, t=15.500s
Unexpected load restore
at t=10.000s
Agents shed 10%
of system load
at t=10.010s
Loss of load
contingency
at t=1.000s
Gen2: Turner
Gen1: Kanawha
Gen3: Logan
Gen4: Tazewell
Gen5: Clinch River
Frequency in Hz
Simulation time in seconds
60.1
60.08
60.06
60.04
60.02
60
59.98
59.96
59.94
59.92
59.9
0
2
4
6
8
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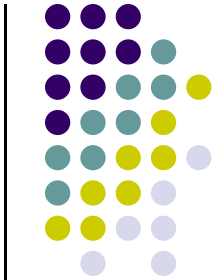
12
14
16
18
20

Problem addressed[1]: accurately simulating automatic emergency load shedding and restoration in a smart grid of the future



(… a smart grid of the future will have network enabled control to prevent power system failures due to under-frequency events)

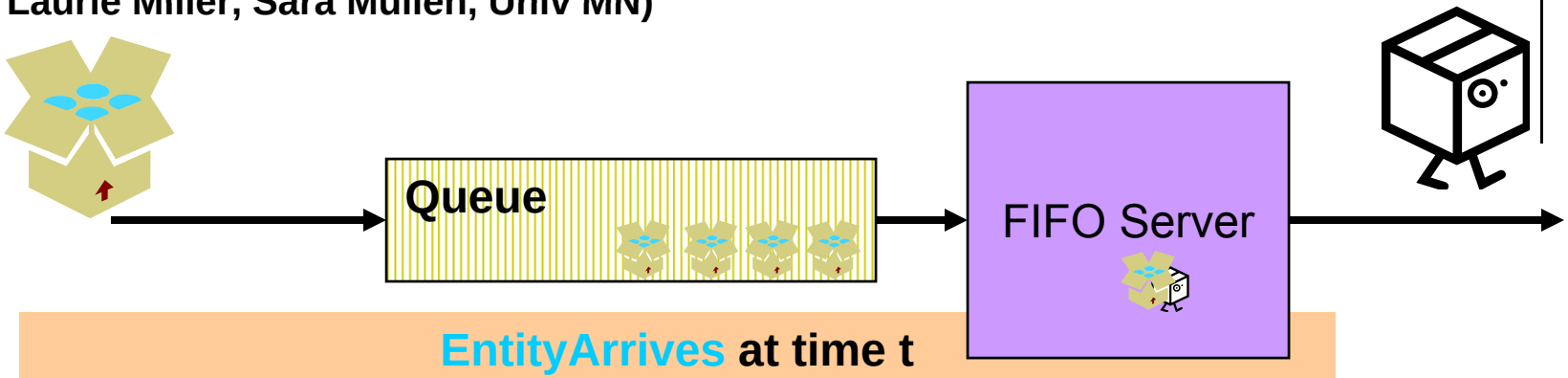
[1]Research conducted in collaboration with the University of Minnesota Center for Electric Energy

Integrated Hybrid Simulation of Electric Power and Communication Systems

IEEE Power Engineering Society, Tampa, June 24-28, 2007;.
James Nutaro, Phani Teja Kuruganti,, Mallikarjun Shankar,ORNL,
Laurie Miller, Sara Mullen, Univ MN

Simple discrete event system

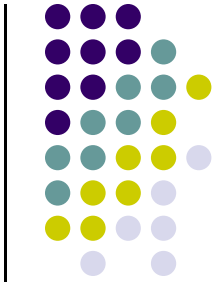
(Source: James Nutaro, Phani Teja Kuruganti,, Mallikarjun Shankar, ORNL
Laurie Miller, Sara Mullen, Univ MN)



EntityArrives at time t
If the server is busy
add the entity to the back of the queue
Else
schedule an EntityServed event time at t + ServiceTime
Endif

EntityServed at time t
Eject the finished entity
If the queue is not empty
remove the first entity in the queue
schedule an EntityServed event at time t + ServiceTime
Endif
End EntityServed

Three main computational problems



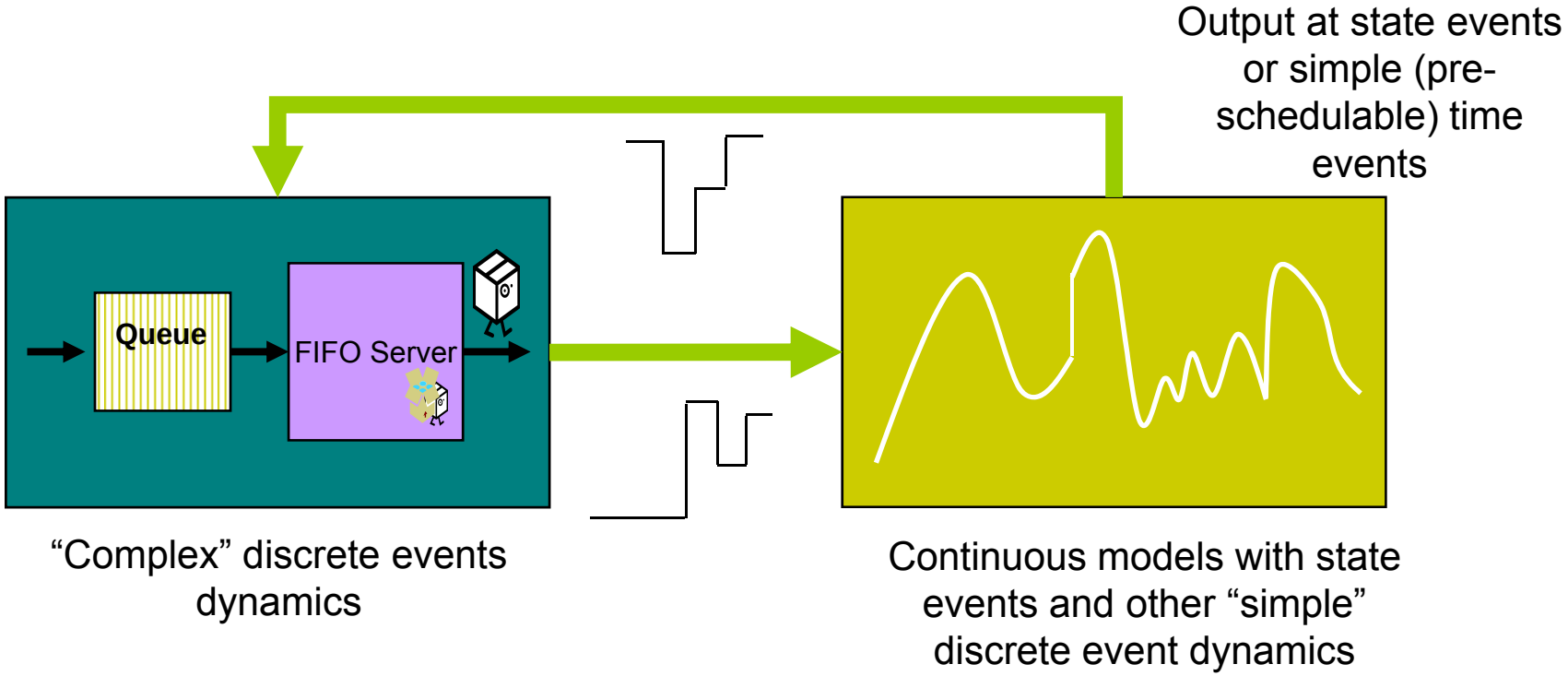
- Precise simulation of discrete events
  - Events that depend on continuous variables (e.g., tripping of the breakers)
  - Events that depend only on time (e.g., pre-scheduled load changes)
  - Events that depend on previous events (e.g., simulating the UDP/IP protocol stack)
- Accurate approximation of the continuous dynamics between events
  - Numerical integration of the ODE set
- Computational efficiency
  - Reasonable performance of the event scheduler
  - Reasonable step-size selections for the numerical integration scheme

(Source: James Nutaro, Phani Teja Kuruganti,, Mallikarjun Shankar, ORNL
Laurie Miller, Sara Mullen, Univ MN)

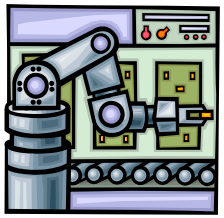
Integrating discrete/continuous models

**(Source: James Nutaro, Phani Teja Kuruganti,, Mallikarjun Shankar, ORNL
Laurie Miller, Sara Mullen, Univ MN)**

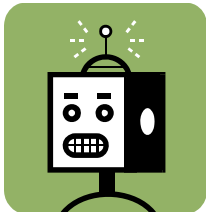
- Overarching simulation is discrete event
- Continuous sub-systems are simulated with embedded numerical algorithms



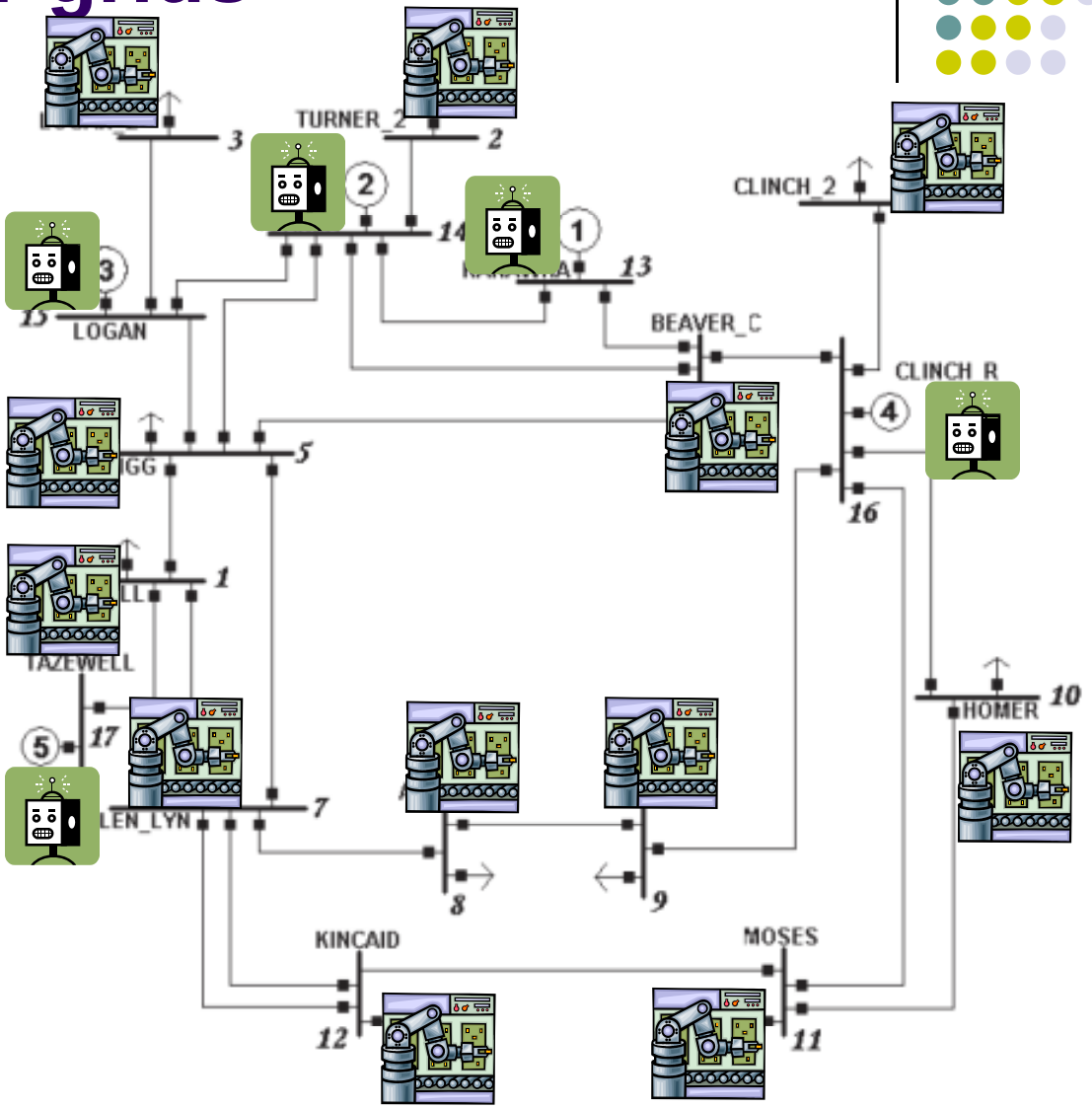
Example: Automatic, coordinated control of wide area power grids



Networked actuators at electrical substations can connect and disconnected loads in fixed increments



Monitor and control software attached to the generators control the actuators through an IP-based, wide area network



State Estimation:

$$Z = h(X) + V$$

where:

Z = The measurement vector

X = The state vector

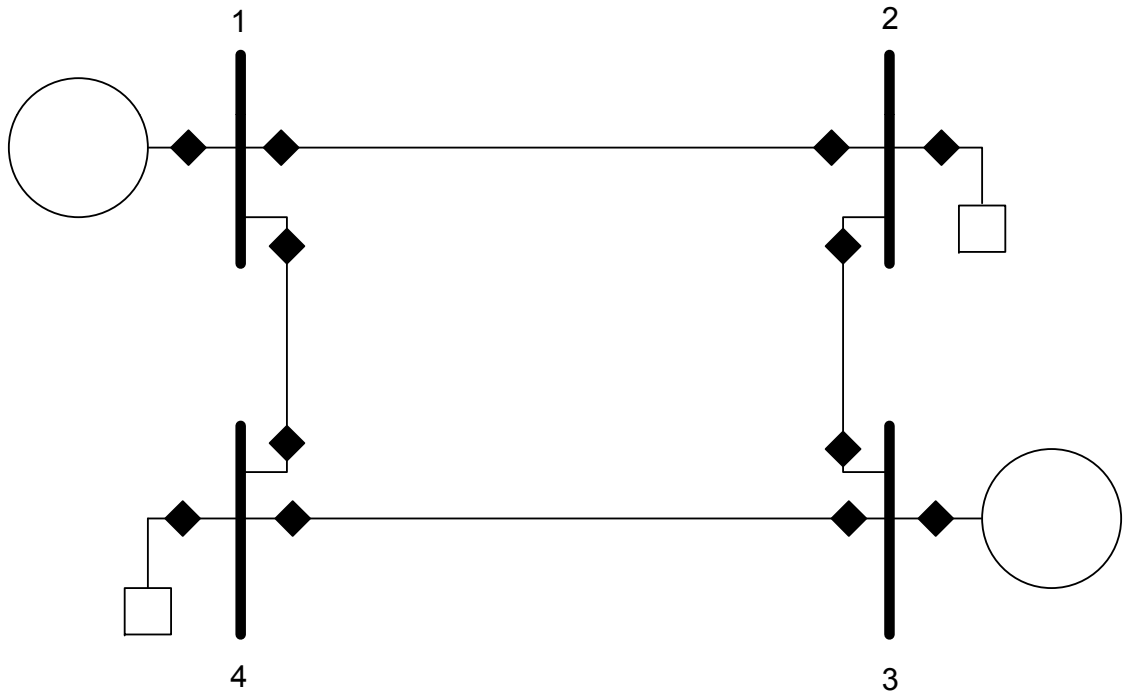
V = The measurement error vector

$h(X)$ = Non-linear observation function, the set of electrical equations relating MW and MVAR values to bus voltages and angles

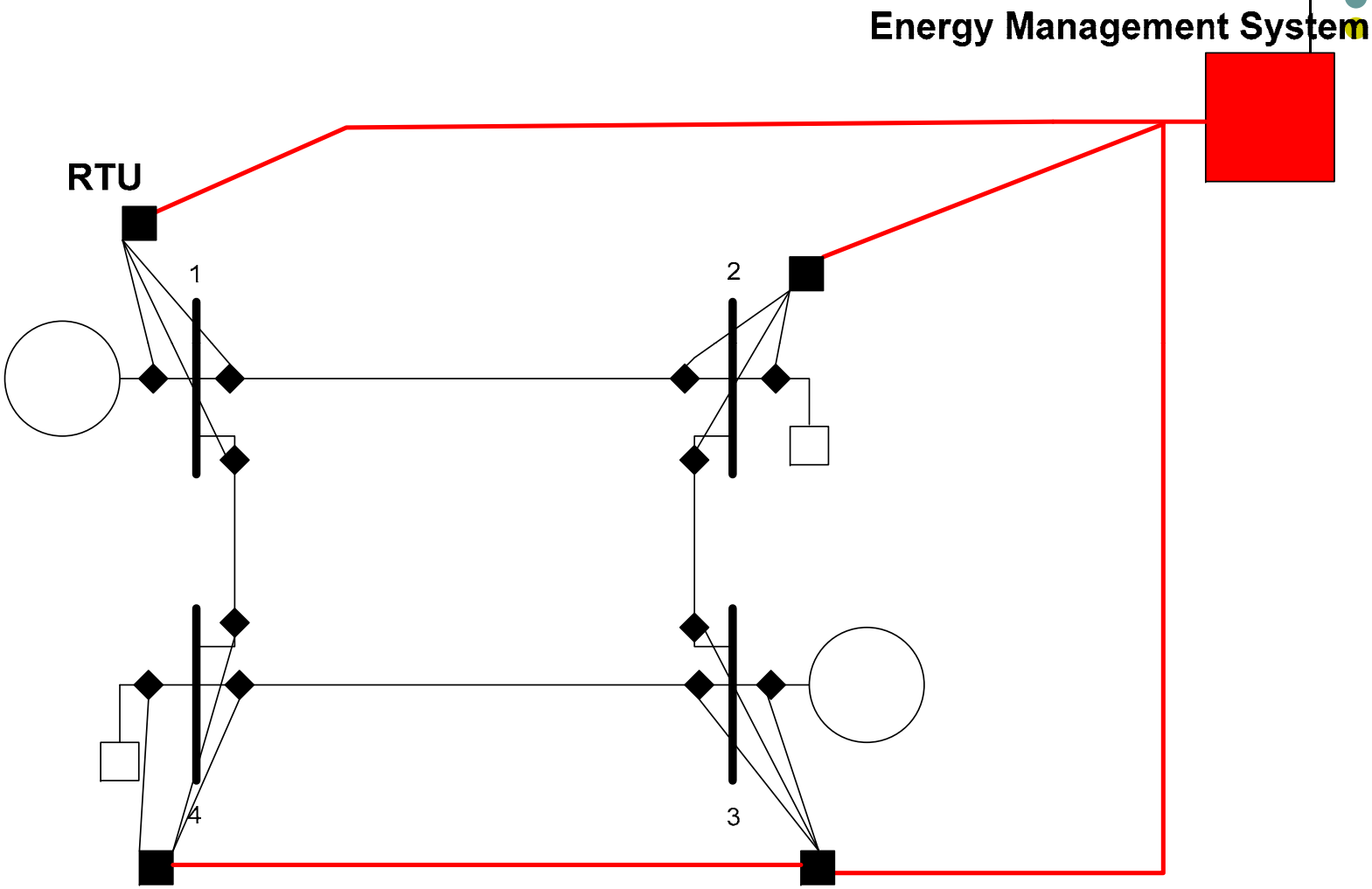
$$Min.\ J(X) = [\ Z - h(X)\ ]^T\ R^{-1}\ [\ Z - h(X)\ ]$$

R = The measurement error covariance matrix

State Estimation Example

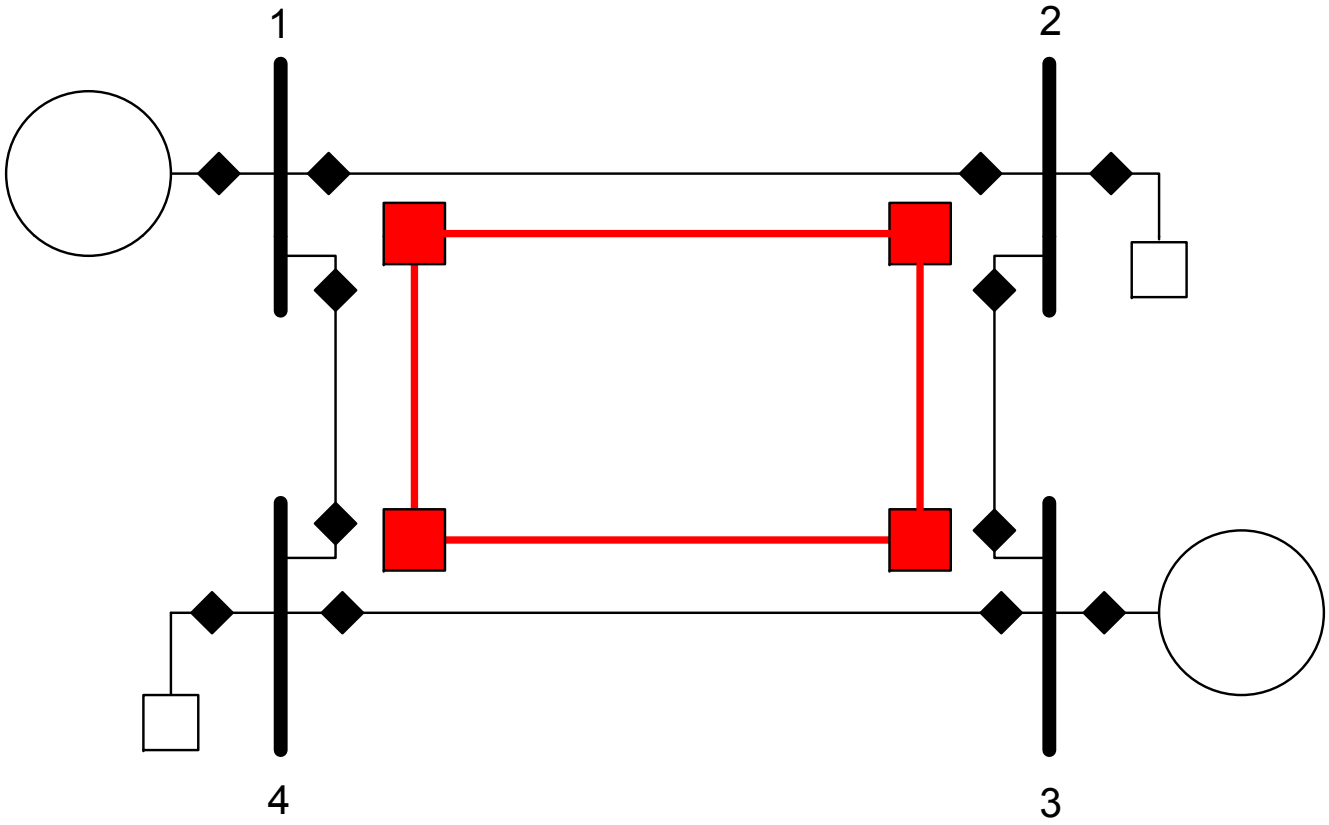


Central State Estimation

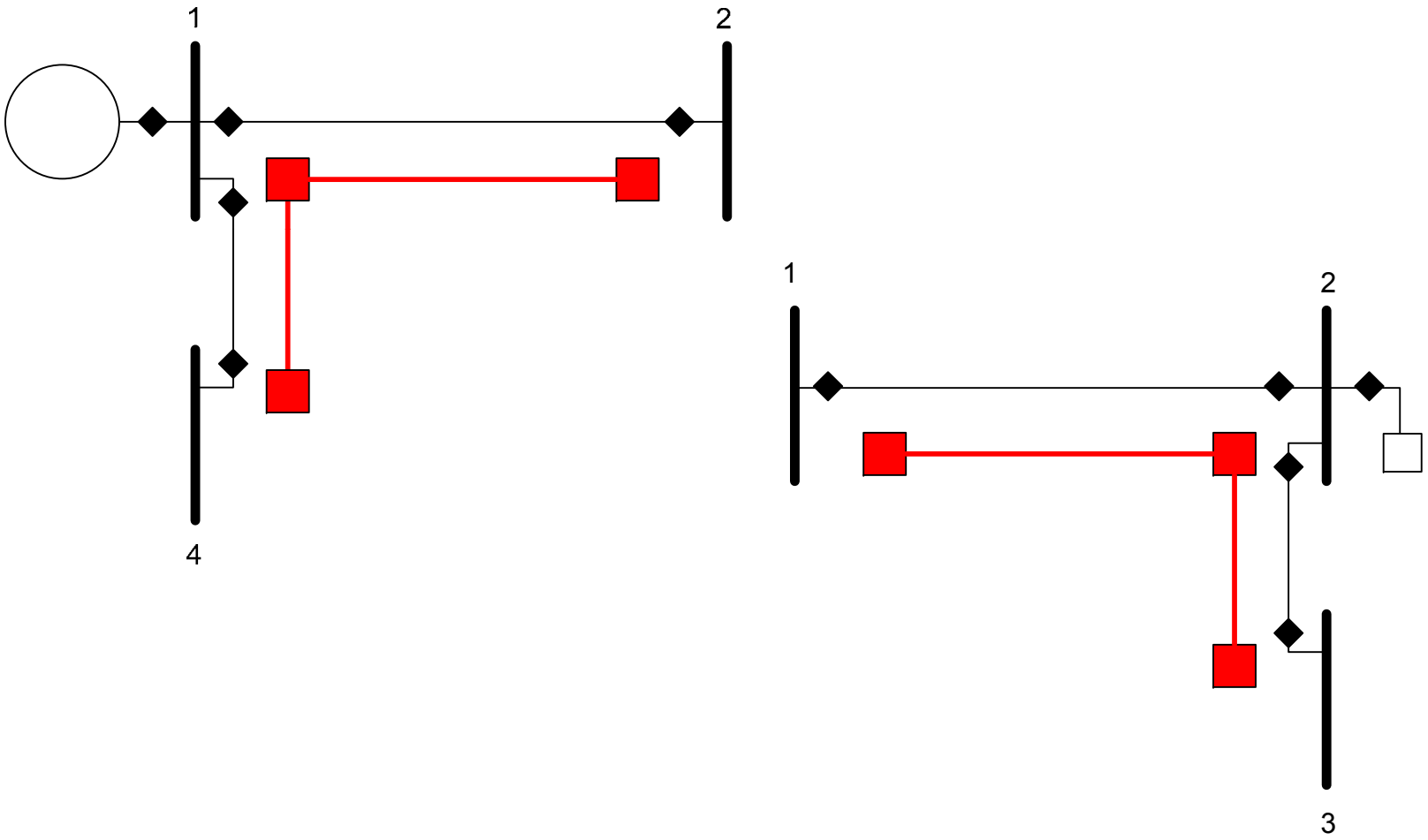


Central State Estimation
2 gen measurements
2 loads measurements
8 line measeasurements

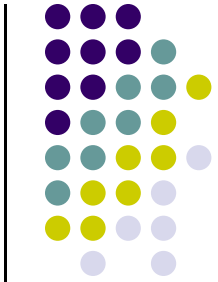
State Estimation using intelligent agents



State Estimation now done on a bus by bus basis

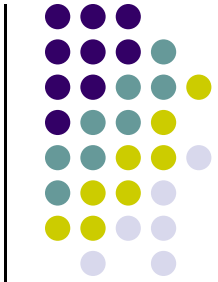


Research Priorities



- Redefining existing power system concepts in terms of intelligent agents
- Redesigning algorithms to work with agents instead of central EMS
  - State Estimation
  - Power Flow
  - Contingency Analysis
- How to simulate agents in parallel with power system simulation

Applications in the future



- As renewable generation is added, owners may wish to disconnect from the grid and reconnect later
- Reconnection means resynchronization which may be easier with a local intelligent agent
- Management of small energy storage should be easier with local intelligent agents
- Distributed intelligent agents become a supercomputer
  - Risk assessment
  - Accurate allocation of use of transmission

Acknowledgements

Professor Massoud Amin of the University of Minnesota

James Nutaro, Phani Teja Kuruganti,, Mallikarjun Shankar, Oak Ridge National Laboratory

Laurie Miller, Sara Mullen, University of Minnesota graduate students

QUESTIONS?

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