Power Flow Addition to the Transmission Planning White Paper

Interactive Simulations

Prepared for the National Association of Regulatory Utility Commissioners, Inc (NARUC)

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http://www.powerworld.com

Overview

- This tutorial features a fictitious power system the size of a medium-sized city
- The simulations explore several facets of power system planning and operations
  - Addition or removal of transmission facilities
  - Addition, de-rating, or removal of generating resources
  - Demand response and use of customer-owned generation, such as rooftop solar
  - Physical or cyber attack on a substation

The Power System

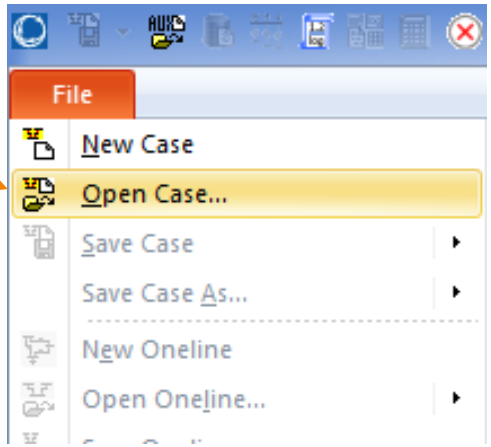
- Fictitious “Stellar Light and Power” System
- Load: 754 MW (similar to summer peak load of City Utilities of Springfield, Missouri; service-area population of 229,000)
- Generation: 1187 MW Capacity
  - 1 coal unit (400 MW), 1 combined-cycle natural gas unit (230 MW), 4 simple-cycle gas turbines (267 MW), 1 hydroelectric unit (150 MW), 1 wind farm (140 MW), distributed rooftop solar (future development)
- Transmission
  - 345 kV, 138 kV, and 69 kV lines and transformers
  - Load aggregated across various 69 kV and 138 kV buses

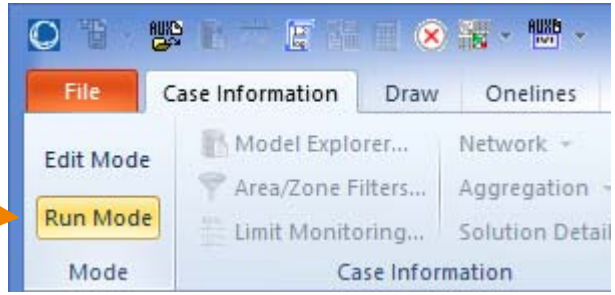
Power System Model

- Download the tutorial files from http://www.powerworld.com/knowledge-base/interactive-tutorial
- Place all of the power system model files in the same directory
  - InteractiveSimulations.pwb
  - InteractiveSimulations.pwd
  - Actions.pwd
  - InteractiveSimulations.aux
- If needed, download PowerWorld Simulator (version 18 or newer) at http://www.powerworld.com/gloversarmaoverbye
- Run the installation executable
- Open PowerWorld Simulator

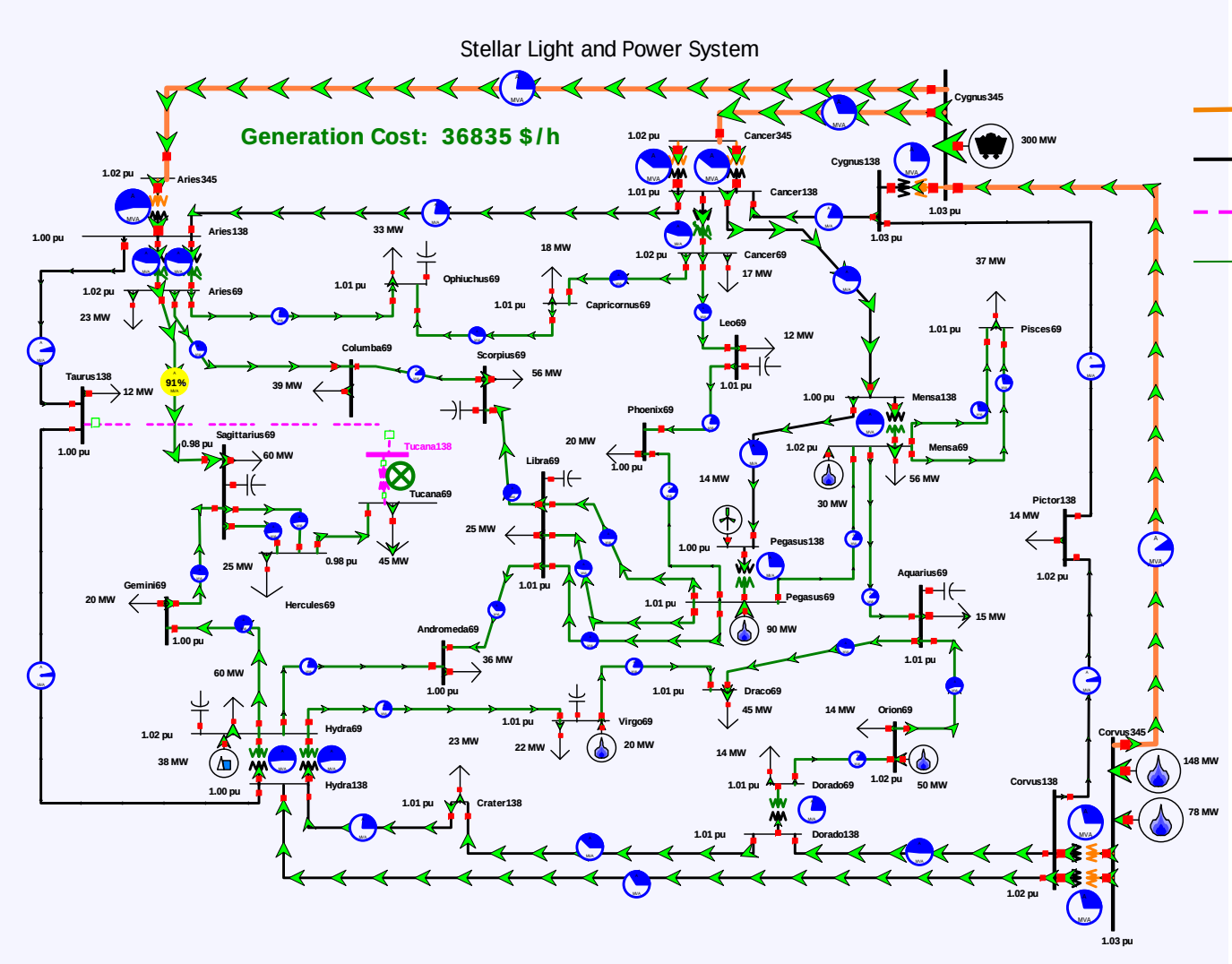
Power System Model

- Choose **File → Open Case…**
- Navigate to the case directory with the File Dialog and open **InteractiveSimulations.pwb**
- If not already selected, choose **Run Mode**



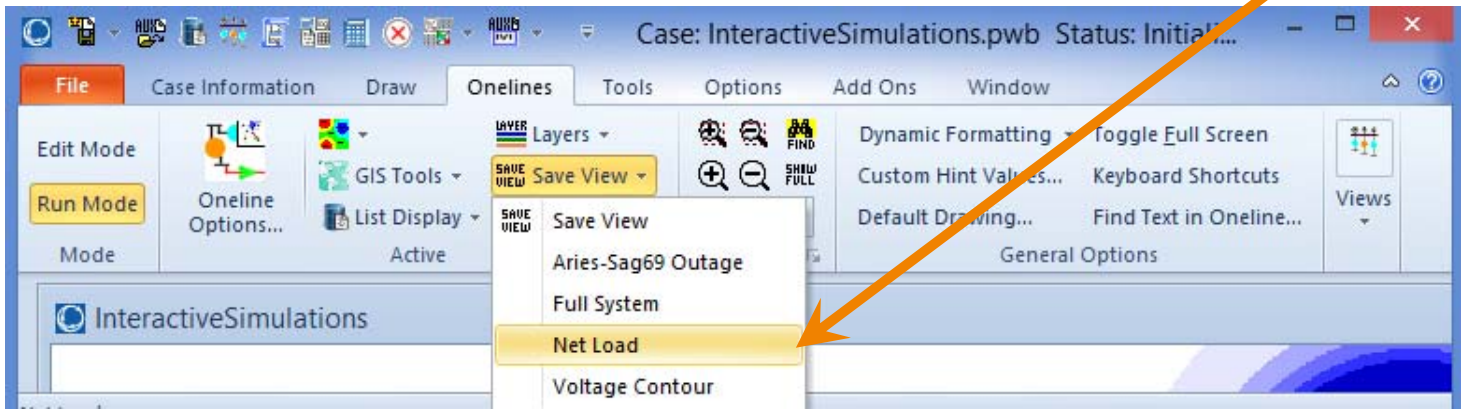


System Diagram



Visualize Load and Generation

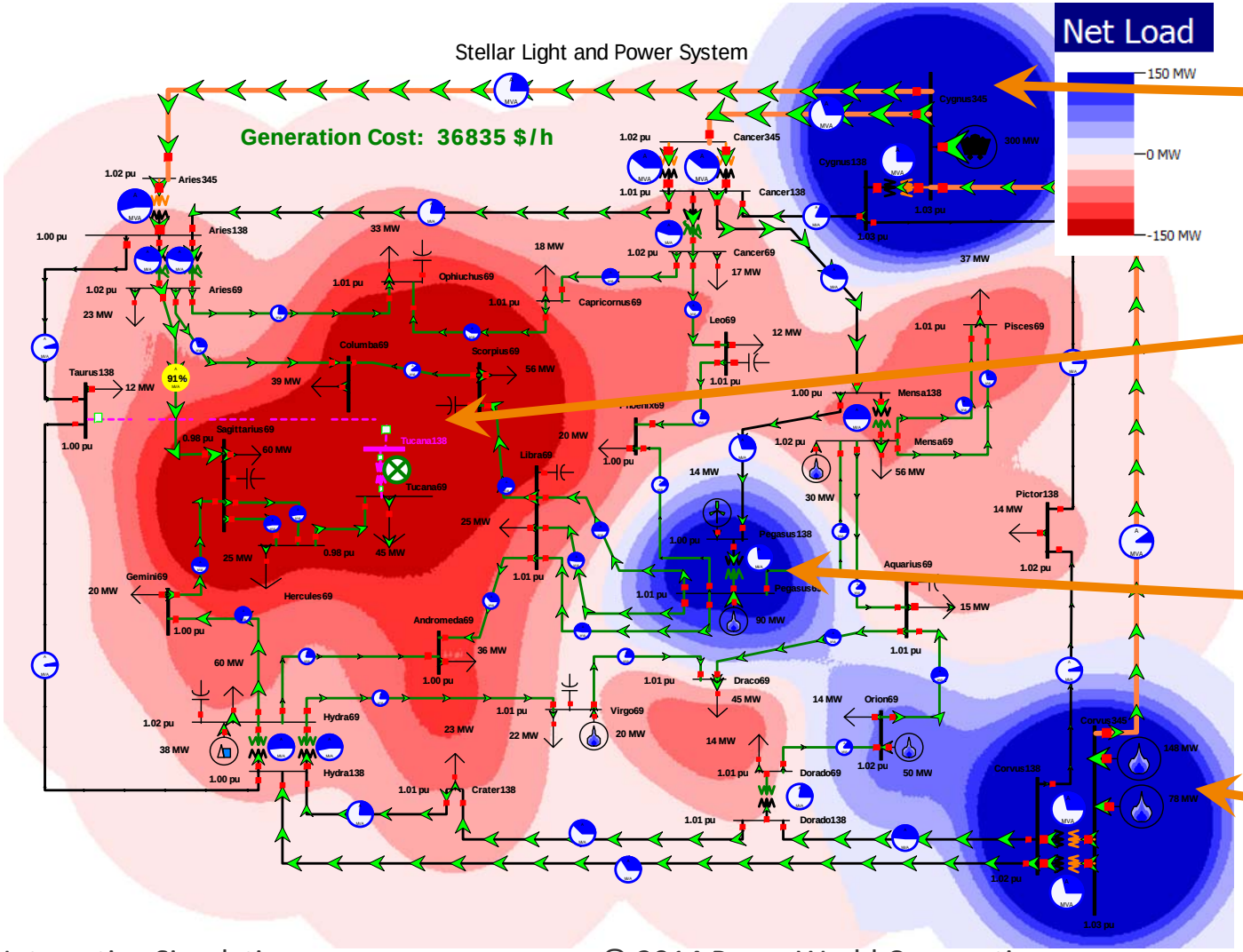
- Make the “InteractiveSimulations” window active
- Choose **Onelines → Save View → Net Load**



Concentration of Load and Generation

Blue denotes Net Generation

Red denotes Net Load



Coal Generator (345 and 138 kV transmission)

Commercial and Residential Load Pocket (69 kV)

Wind Farm and Natural Gas (138 and 69 kV)

Combined-Cycle Plant (345 and 138 kV)

Good Power System Operation

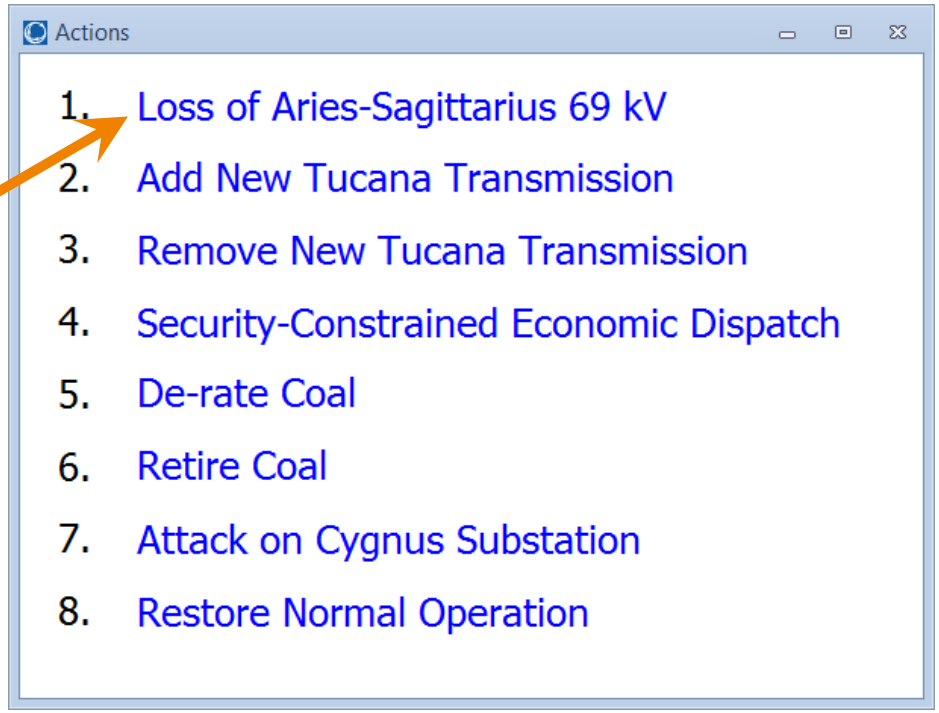
- Good power system operation requires that there be no reliability violations for either the base condition or in the event of statistically likely contingencies
  - Reliability requires as a minimum that there be no transmission line/transformer thermal limit violations and that bus voltages be within acceptable limits (perhaps 0.95 to 1.08)
  - Example: consider the loss of any single facility. This is known as n-1 reliability.

System Reliability Issues

- Not N-1 Reliable: some forced outages (contingencies) will cause transmission thermal overloads and low bus voltages
- Example: loss of Aries-Sagittarius 69 kV line results in 2 thermal overloads and 4 low bus voltages on the 69 kV network

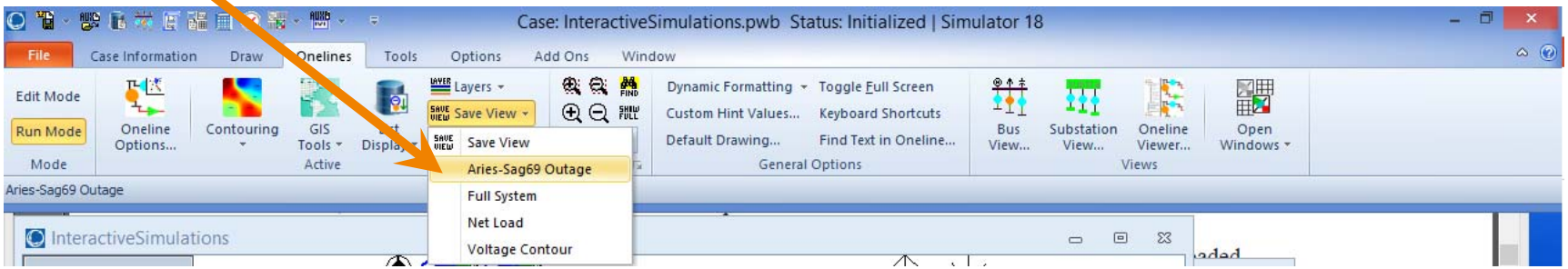
Loss of Aries-Sagittarius 69 kV

- Activate the “Actions” window
- Click Loss of Aries-Sagittarius 69 kV

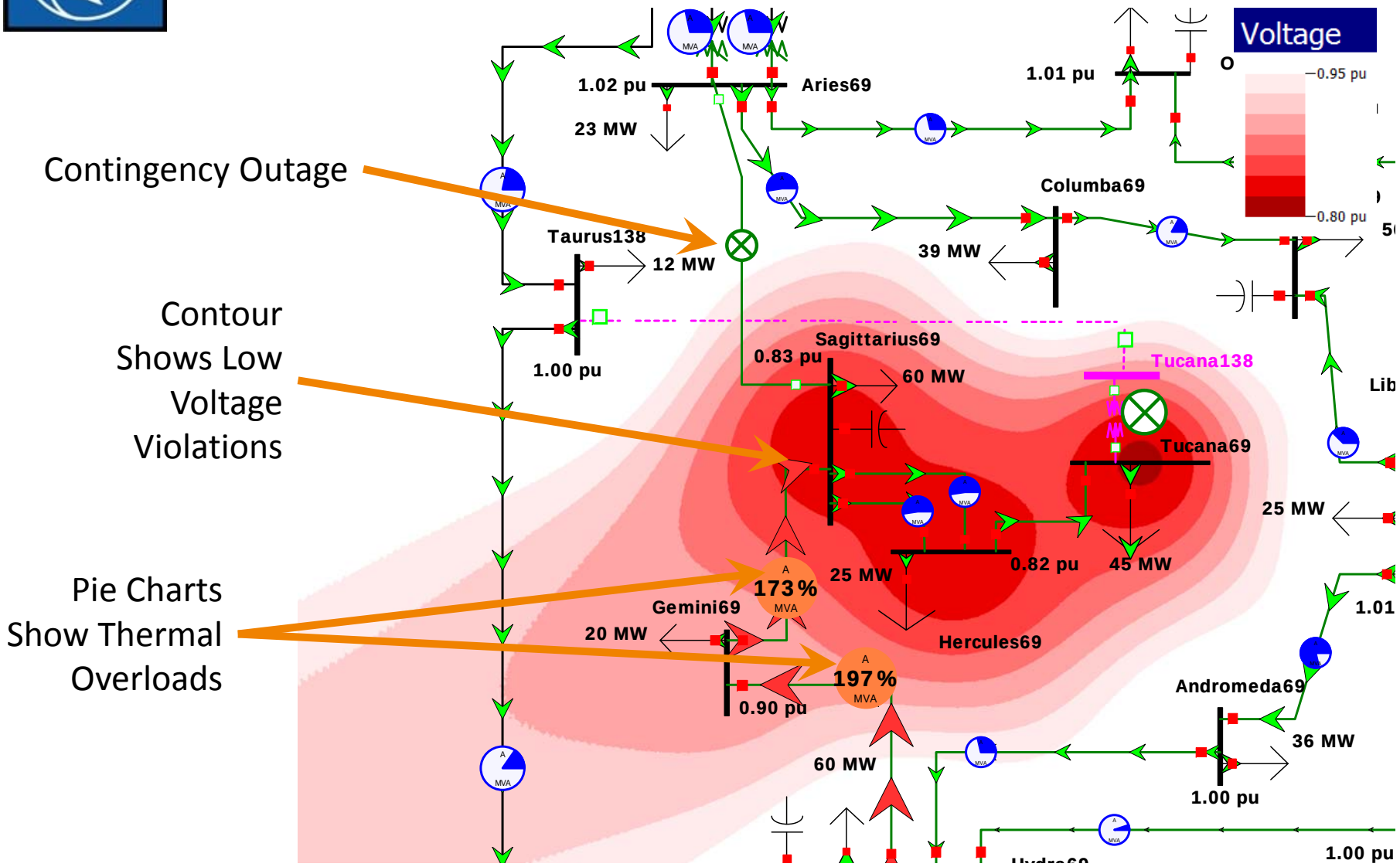


Loss of Aries-Sagittarius 69 kV

- Activate the “InteractiveSimulations” window
- Choose **Onelines → Save View → Aries-Sag69 Outage**

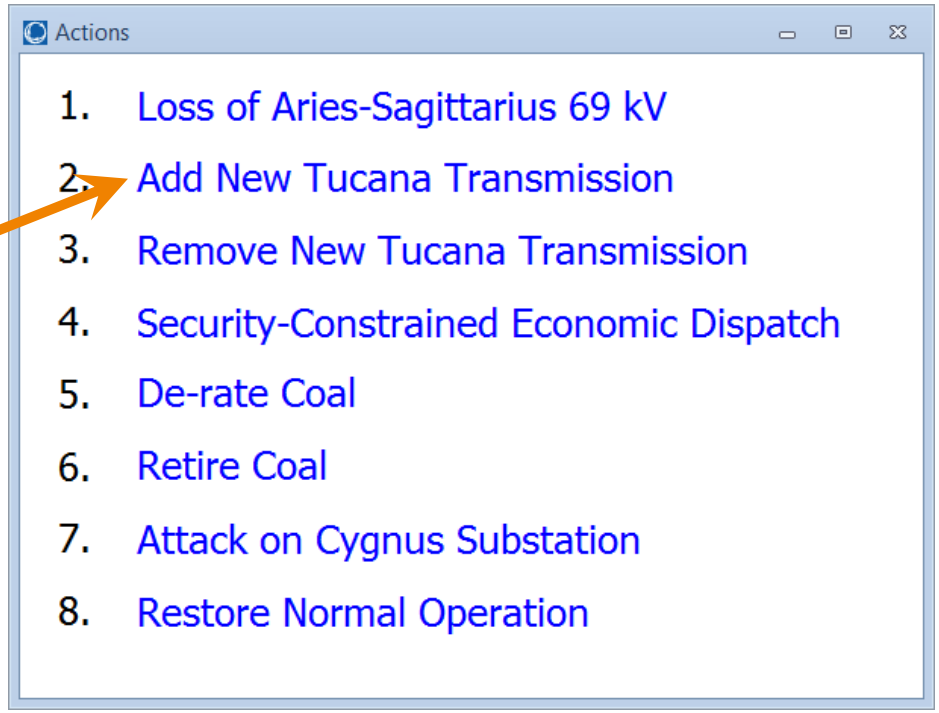


Loss of Aries-Sagittarius 69 kV



Possible Solution: New Taurus-Tucana 138 kV Line

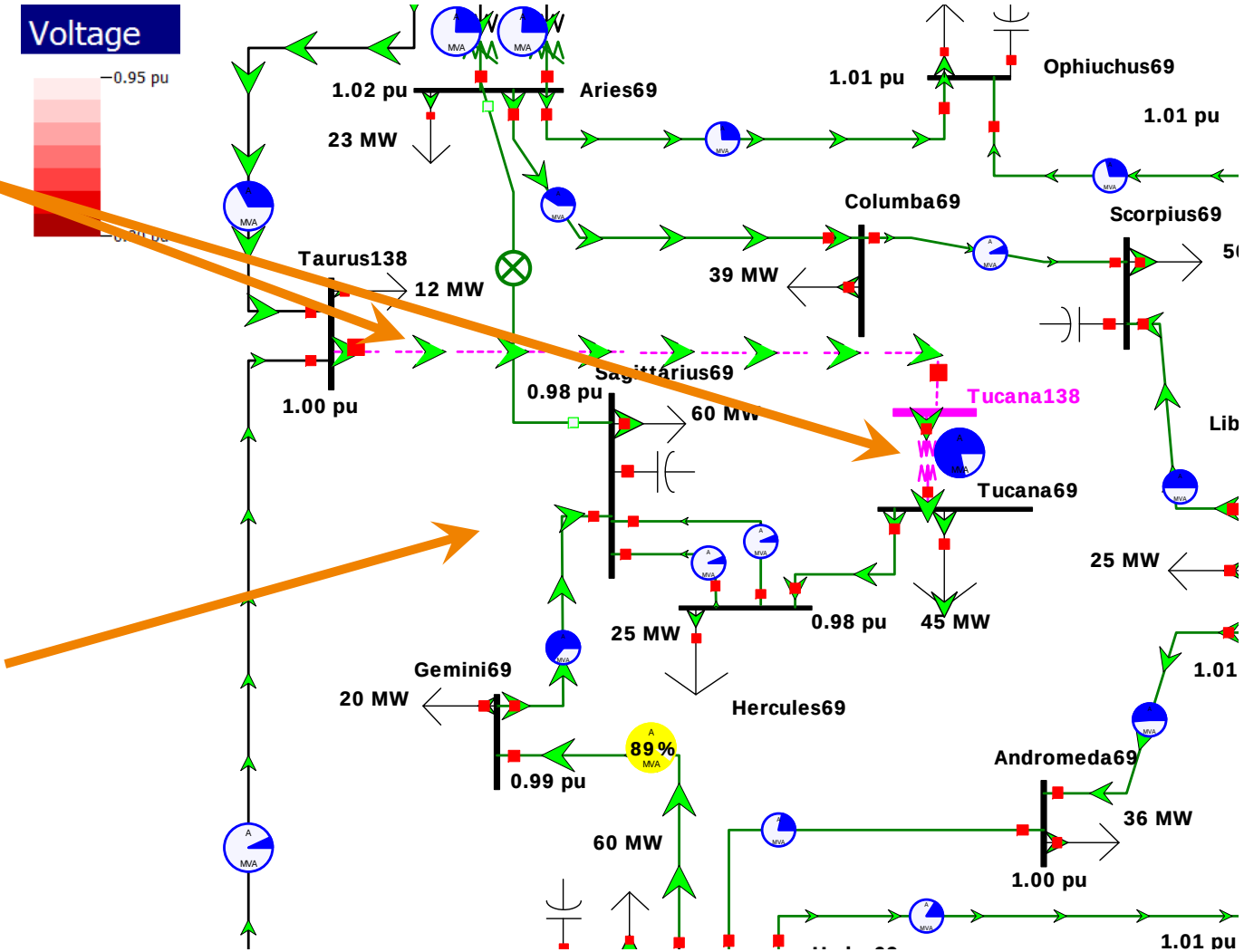
- Activate the “Actions” window
- Click Add New Tucana Transmission



Possible Solution: New Taurus-Tucana 138 kV Line

New line and 138/69kV transformer provide more reliable service into the load center

Thermal and voltage violations are alleviated during the Aries-Sagittarius 69 kV contingency

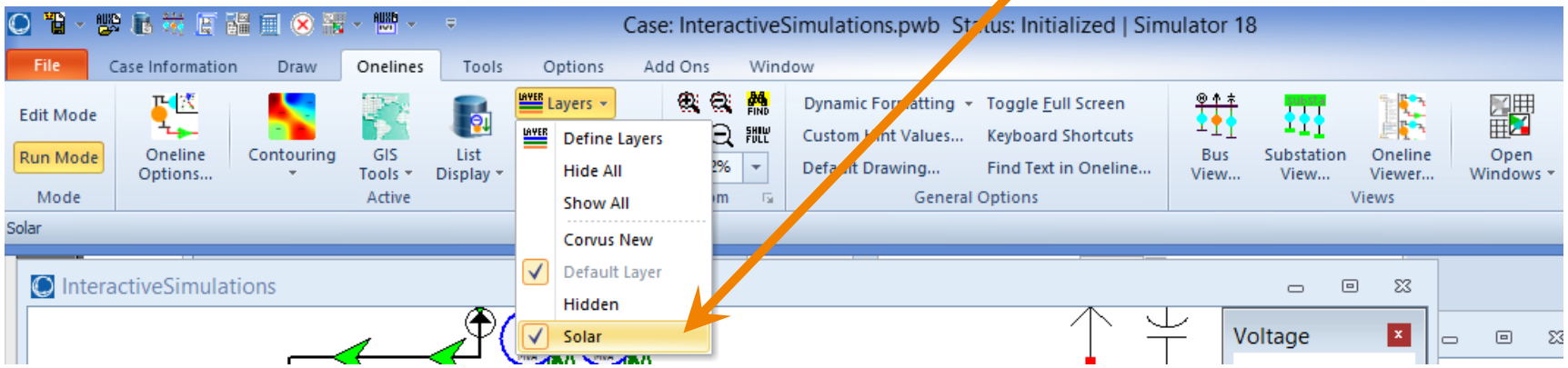


Alternate Solution: Distributed Generation

- Assume rooftop solar is available at Tucana, Hercules, Sagittarius, and Gemini substations, with capacity of 60% of load at each
- These could also improve N-1 reliability, IF the sun is shining OR the generation is dispatchable (e.g. diesel backup units) OR demand response is available to reduce load by the same amount
- Transmission solutions may also be desirable

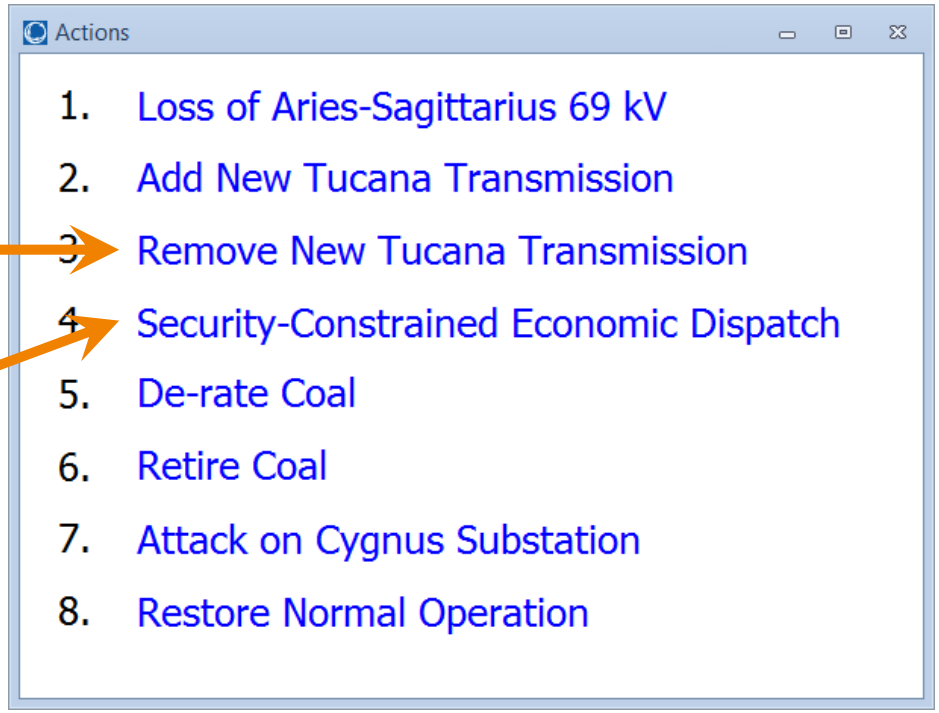
Distributed Generation

- Activate the “InteractiveSimulations” window
- Choose **Onelines → Layers → Solar** to show the solar units on the diagram



Distributed Generation

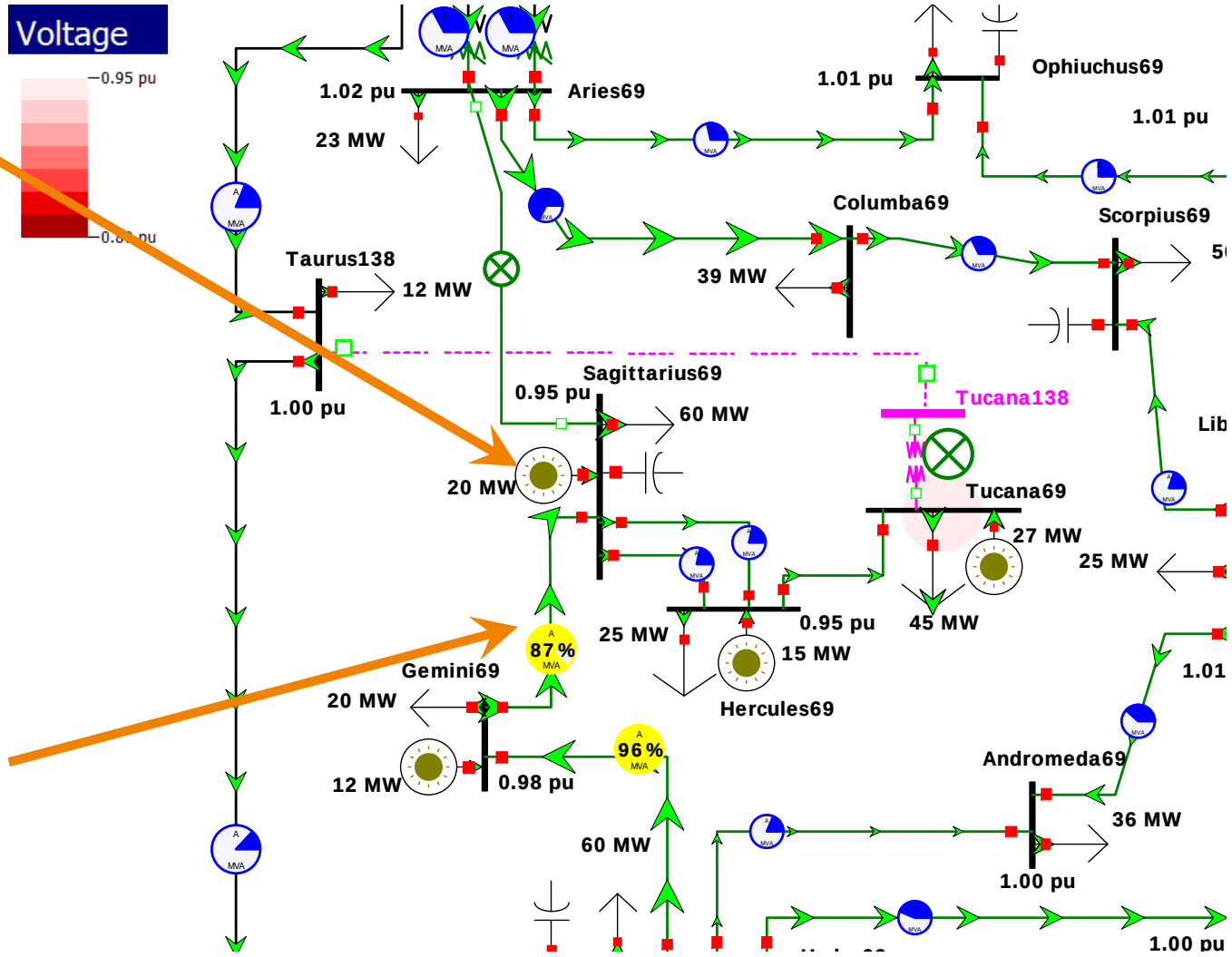
- Activate the “Actions” window
- Click Remove New Tucana Transmission
- Then click Security-Constrained Economic Dispatch
- Wait a moment to allow the calculations to process, then click Loss of Aries-Sagittarius 69 kV



Distributed Generation

Solar generation improves N-1 reliability

Thermal violations are alleviated and voltages are improved during contingencies (Aries-Sagittarius 69 kV outage shown)

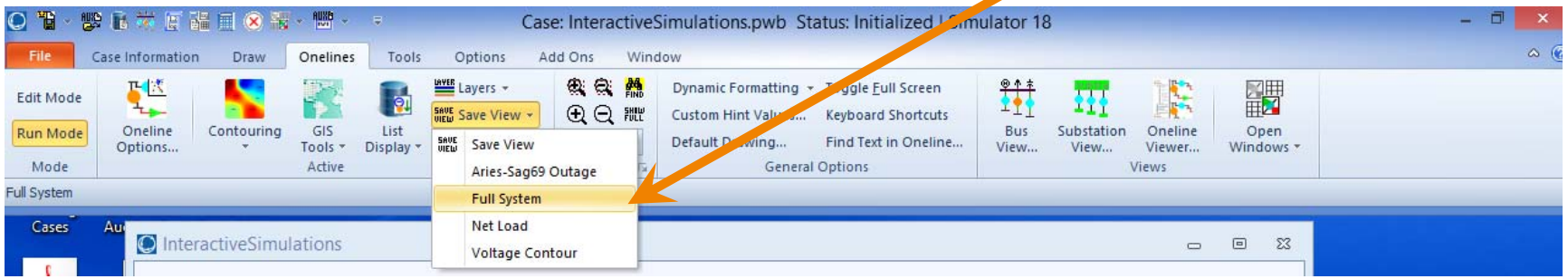


De-rate Coal Unit

- Assume increasingly stringent emissions regulations are requiring the coal-fired plant at Cygnus to reduce its output to 300 MW
  - Make up power at more expensive simple-cycle Natural Gas units
  - Cost of operating the system increases

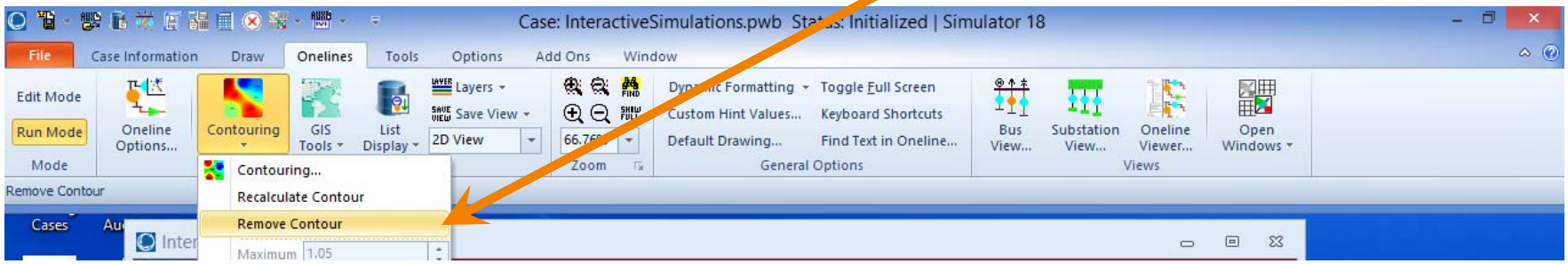
De-rate Coal Unit

- Activate the “InteractiveSimulations” window
- Choose **Onelines → Save View → Full System**



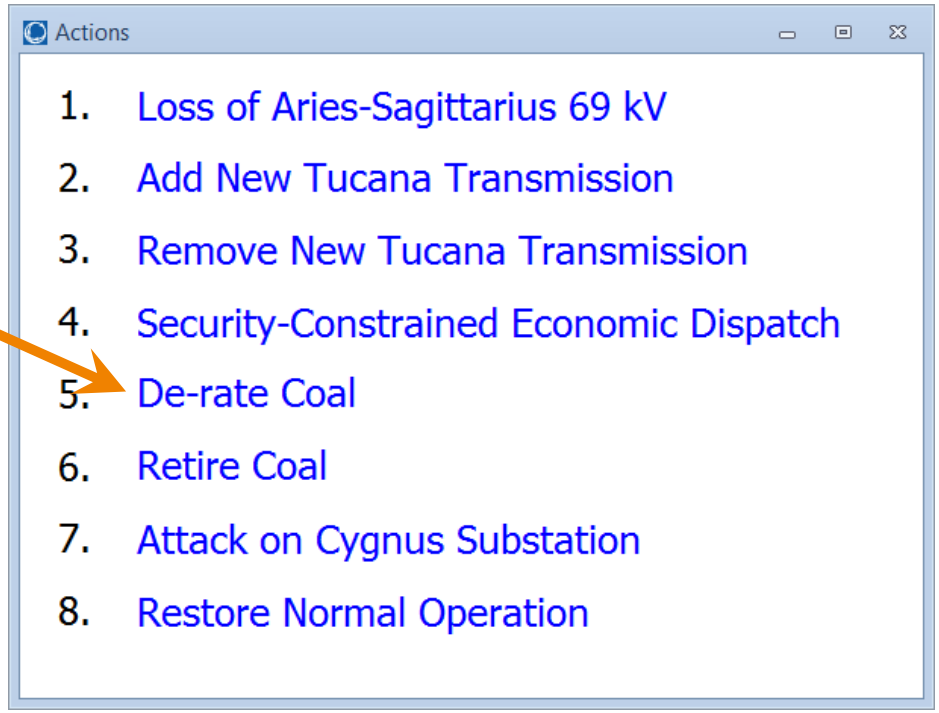
De-rate Coal Unit

- Choose **Onelines → Contouring → Remove Contour**

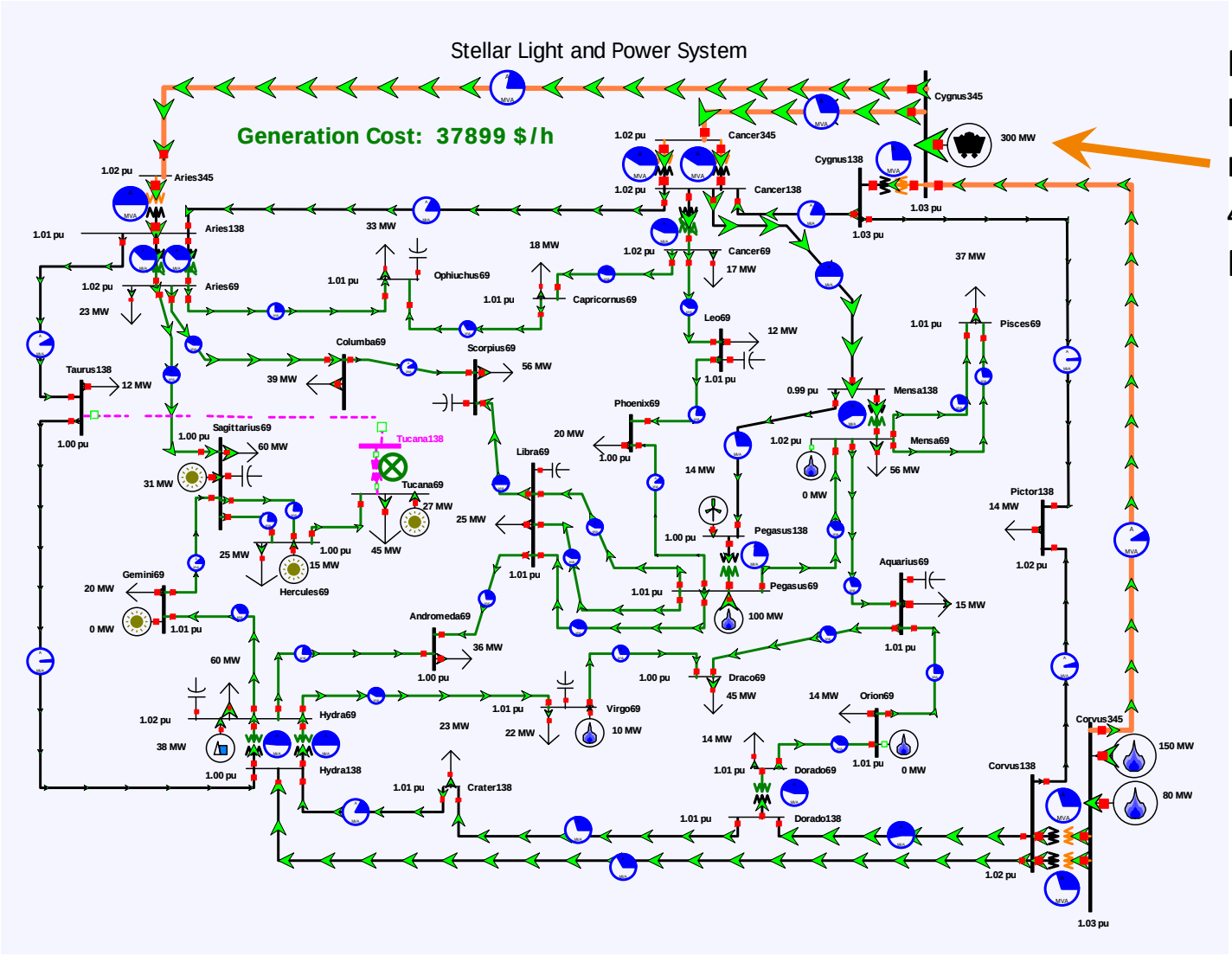


De-rate Coal Unit

- Activate the “Actions” window
- Click De-Rate Coal



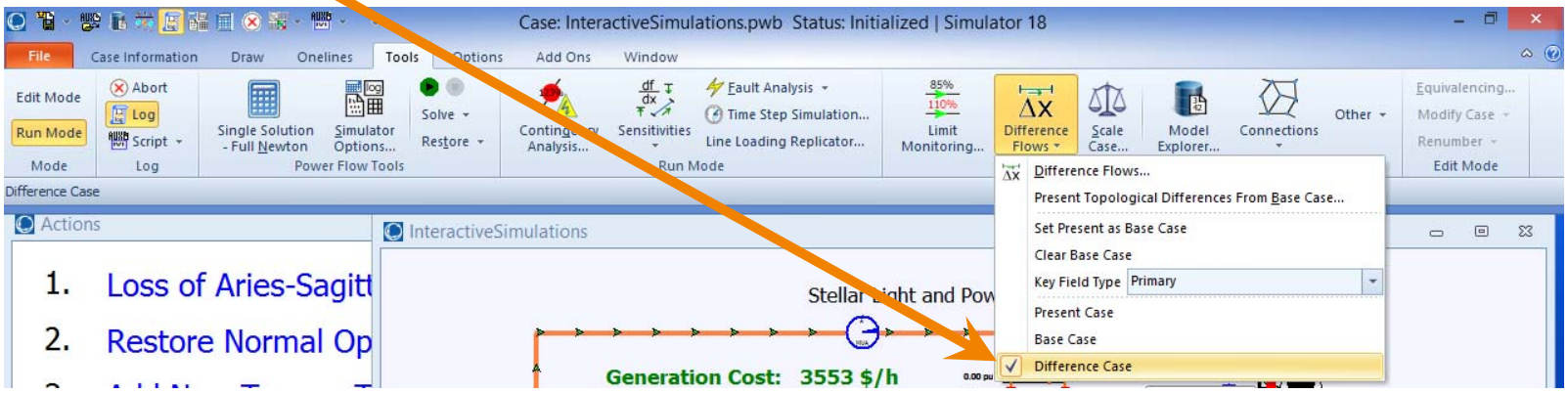
De-rate Coal Unit



Note coal unit has been reduced from 400 MW to 300 MW

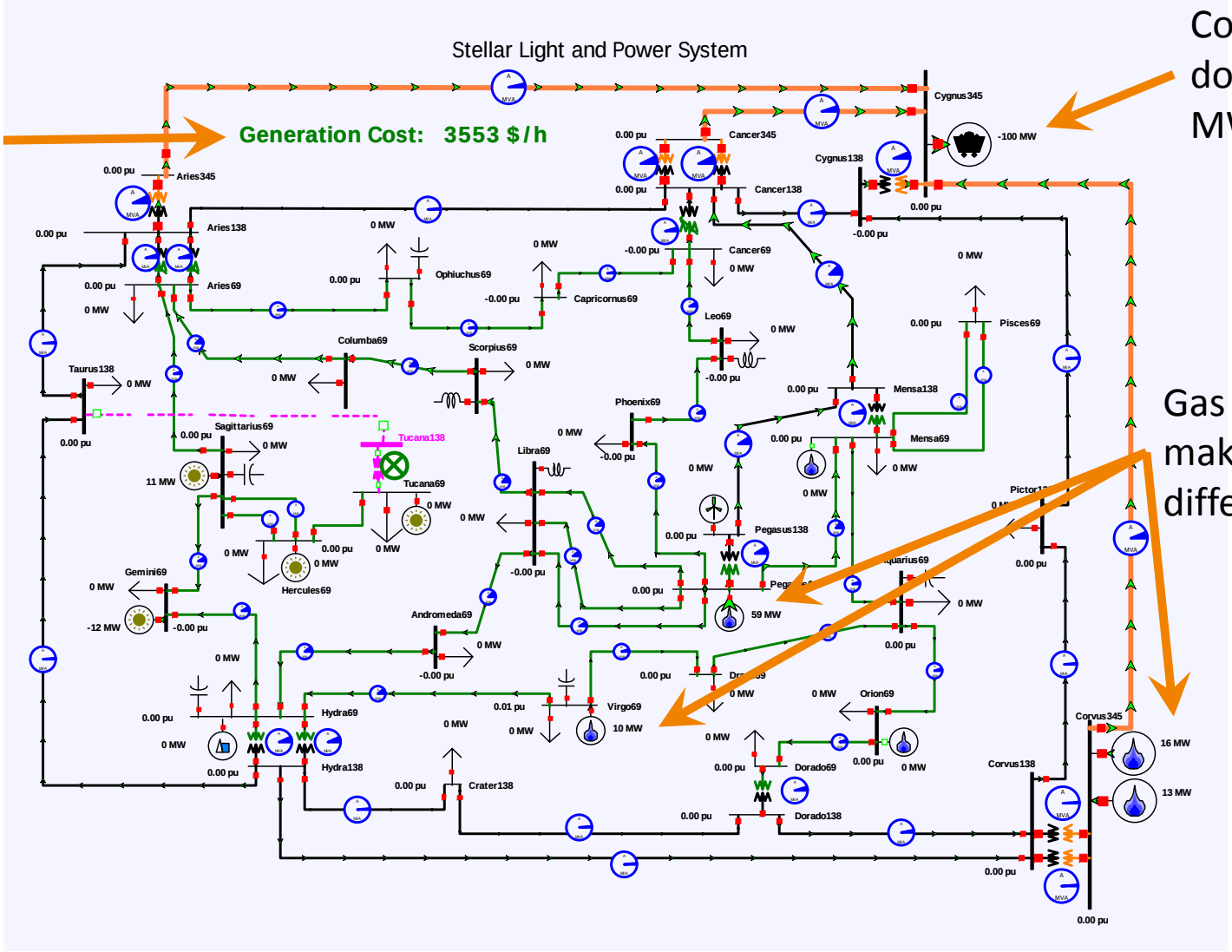
De-rate Coal Unit

- Activate the “InteractiveSimulations” window
- Choose **Tools → Difference Flows → Difference Case**



Case Comparison

Increased total cost of generation



Coal unit down 100 MW

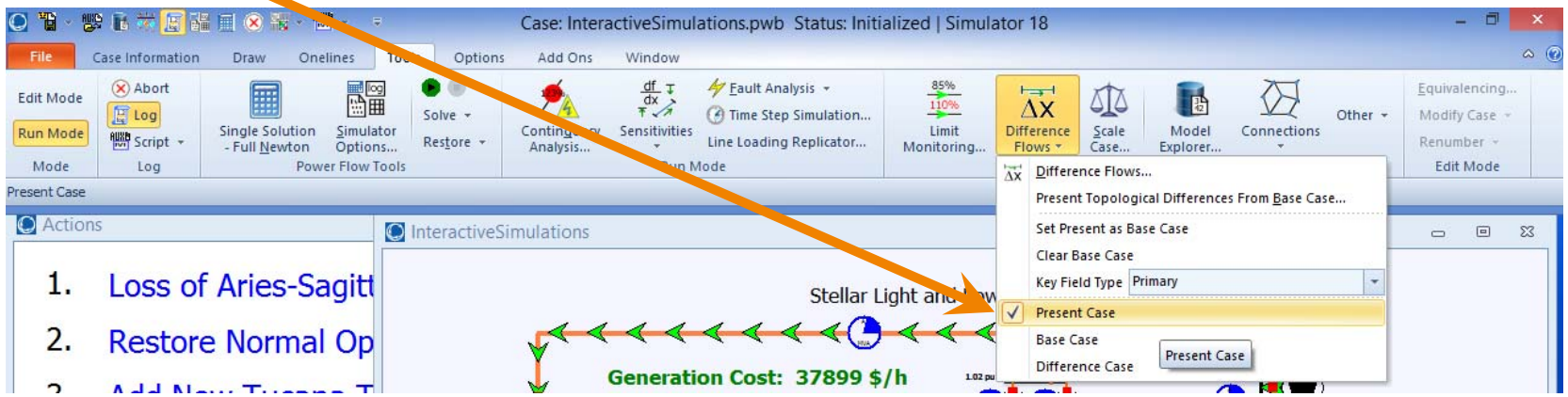
Gas units make-up the difference

Retire Coal Unit

- Now assume the Cygnus coal-fired unit will eventually be retired, with capacity replaced by an additional combined-cycle unit at Corvus
- Perform a new security-constrained economic dispatch

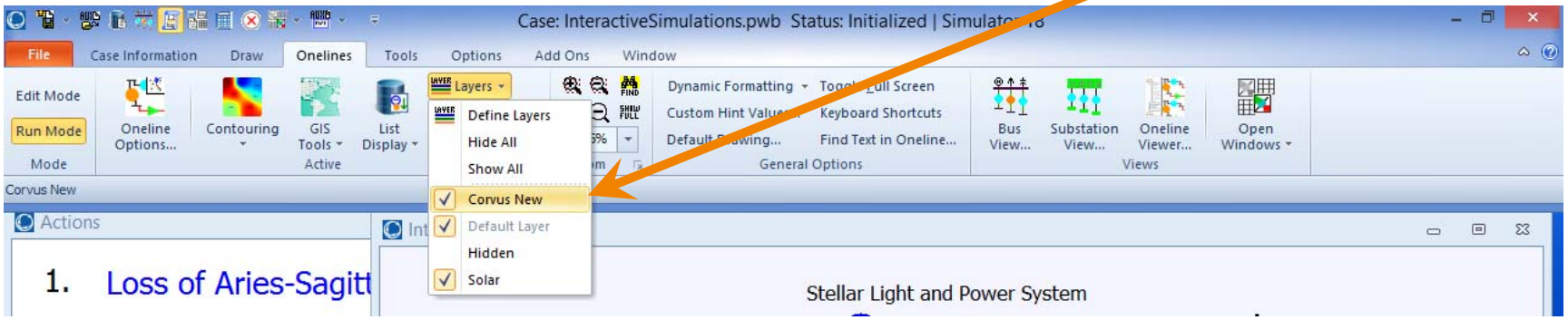
Retire Coal Unit

- Activate the “InteractiveSimulations” window
- Choose **Tools → Difference Flows → Present Case**



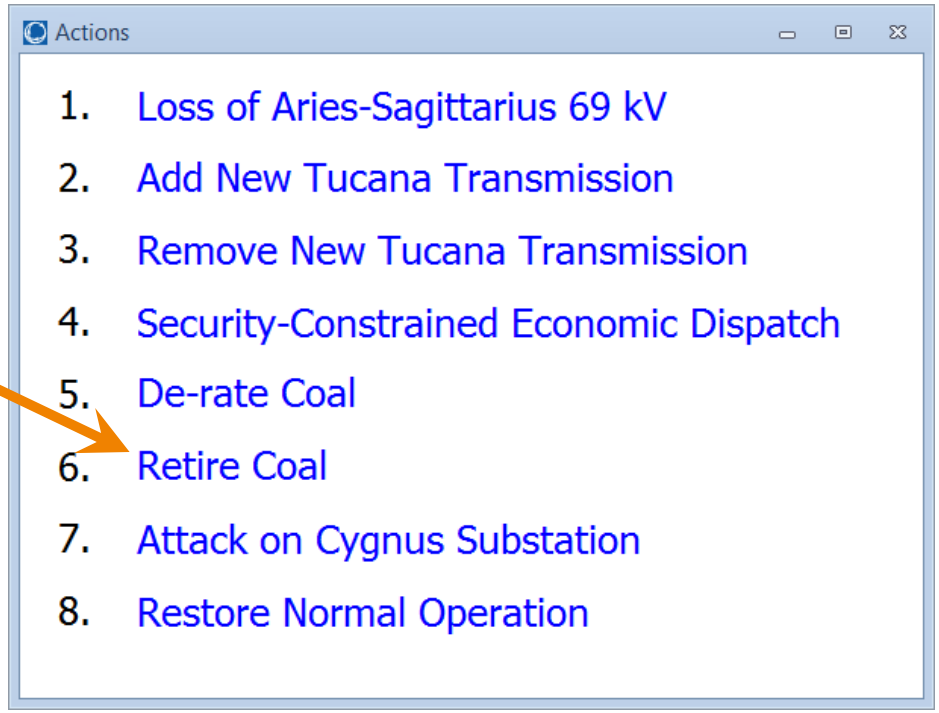
Retire Coal Unit

- Then choose **Onelines → Layers → Corvus New**

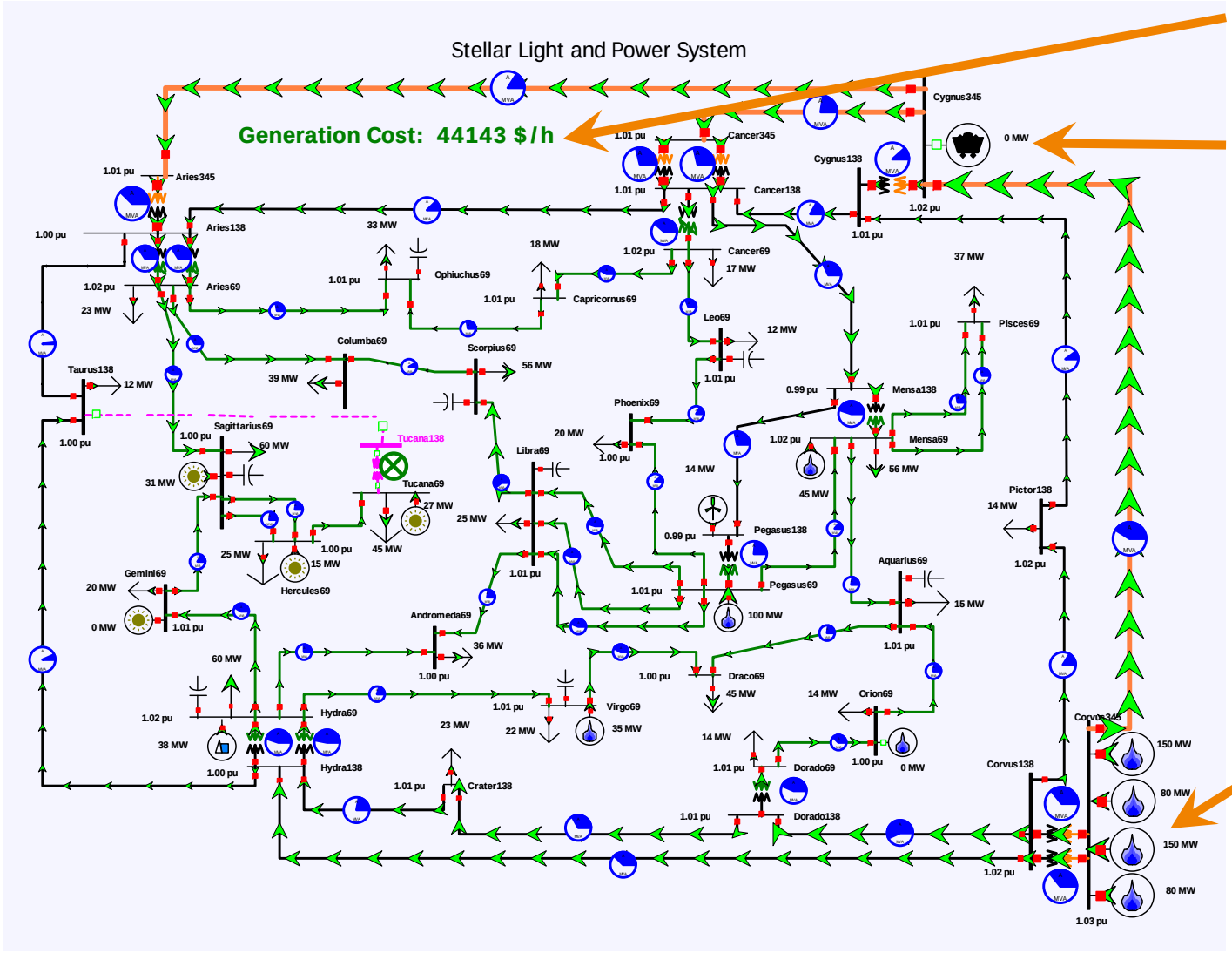


Retire Coal Unit

- Activate the “Actions” window
- Click Retire Coal



Retire Coal Unit



Further increased cost of operation

Coal unit offline

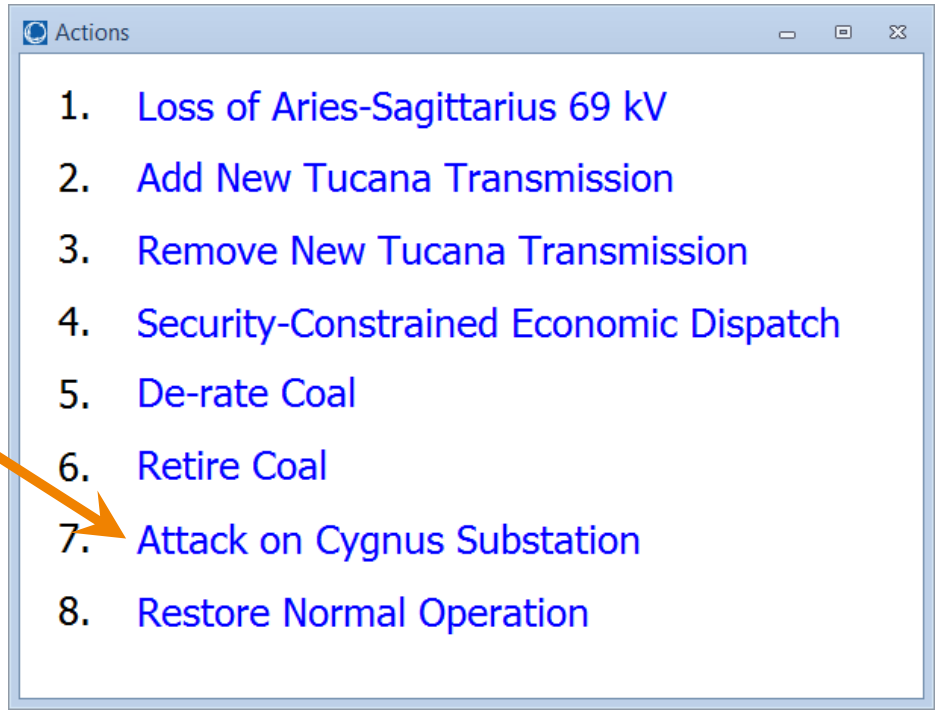
New Corvus Combined-Cycle Units are maxed out

Physical and Cyber-security

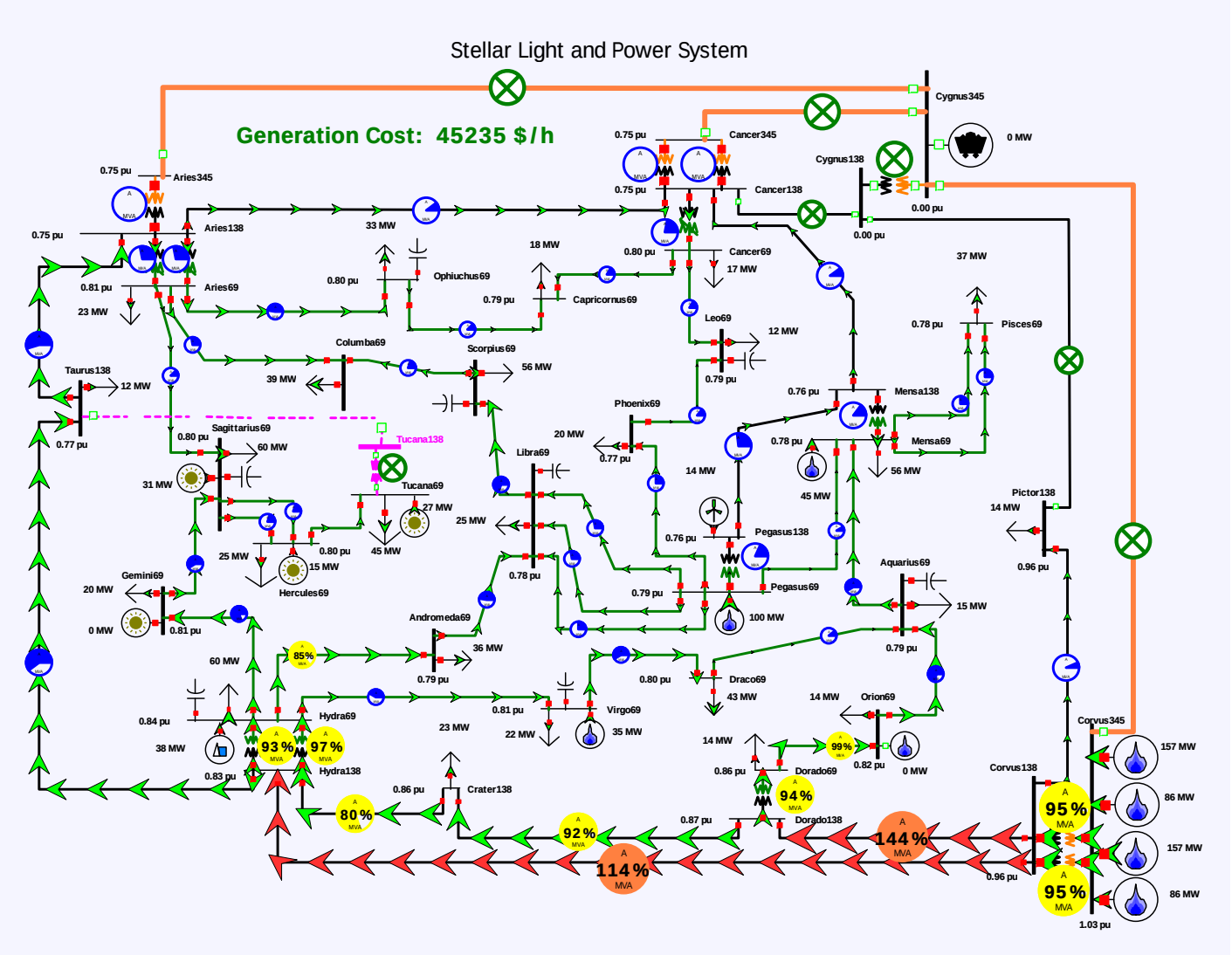
- Model the loss of an entire substation to simulate a physical or cyber attack
- Cygnus is extremely critical as all 345 kV lines pass through it
  - Loss causes severe stress on 138 kV lines and system collapse
- A possible solution could be extending 345 kV into Hydra or other substations closer to the load

Loss of Cygnus Substation

- Activate the “Actions” window
- Click Attack on Cygnus Substation

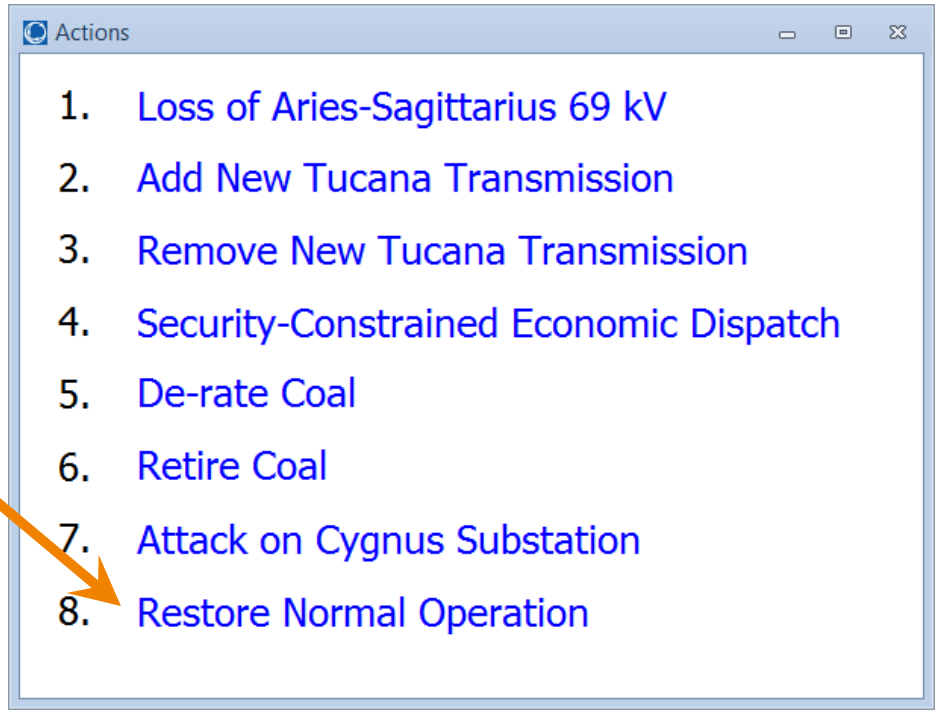


Loss of Cygnus Substation



Restore Normal Operation

- Activate the “Actions” window
- Click Restore Normal Operation



Further Analysis

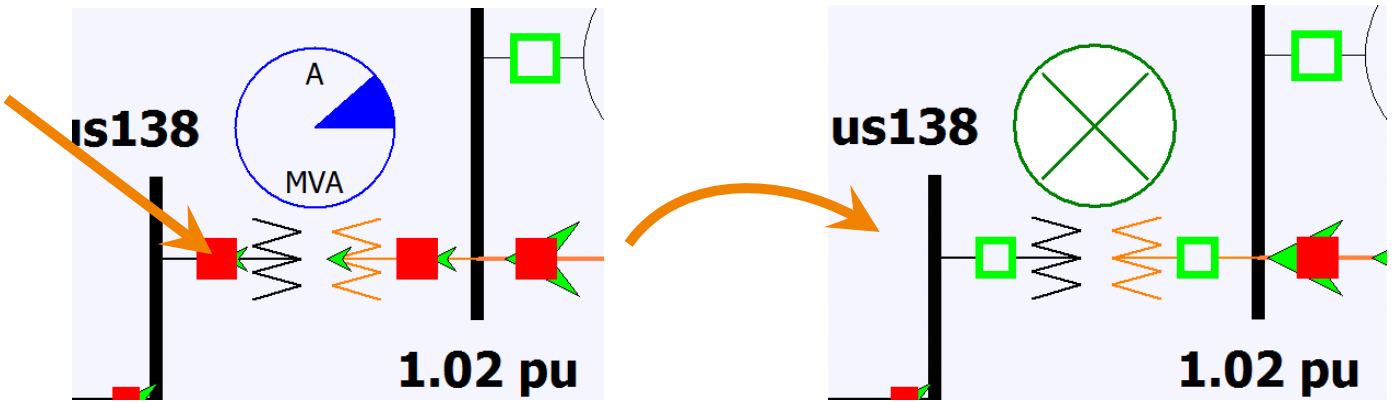
- Conduct your own analysis by outaging transmission facilities, generators, or loads
- Choose **Tools → (Play Button)** to continuously solve the power flow and play the animation

Further Analysis

- Click on “circuit breaker” objects to remove facilities from service or to restore them
  - These appear solid red when closed (in-service)
  - And in green outline when open (out-of-service)
- Example

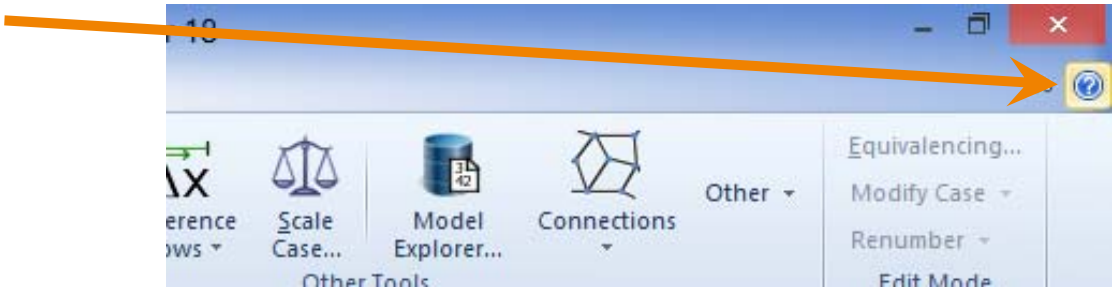
1. Transformer in-service
2. Click here

3. Transformer out-of-service



For More Information

- Help is available by pressing the F1 key or choosing the Help icon in the upper-right corner



- Training slides and videos are available at http://www.powerworld.com/training/online-training