Computing Locational Contingency Reserves

-Simulation and DyMonDs application to Bulk Power System Reliability-

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Managing uncertainty is a key challenge of future smart grids

- Forced outages are an important source of uncertainty in bulk power systems operation
  - Generating units and transmission lines
  - Impact reliability and security of operations
- Reliability standards seek to prevent it
  - N-1 criterion: requires the system to withstand the loss of one major component without interruption

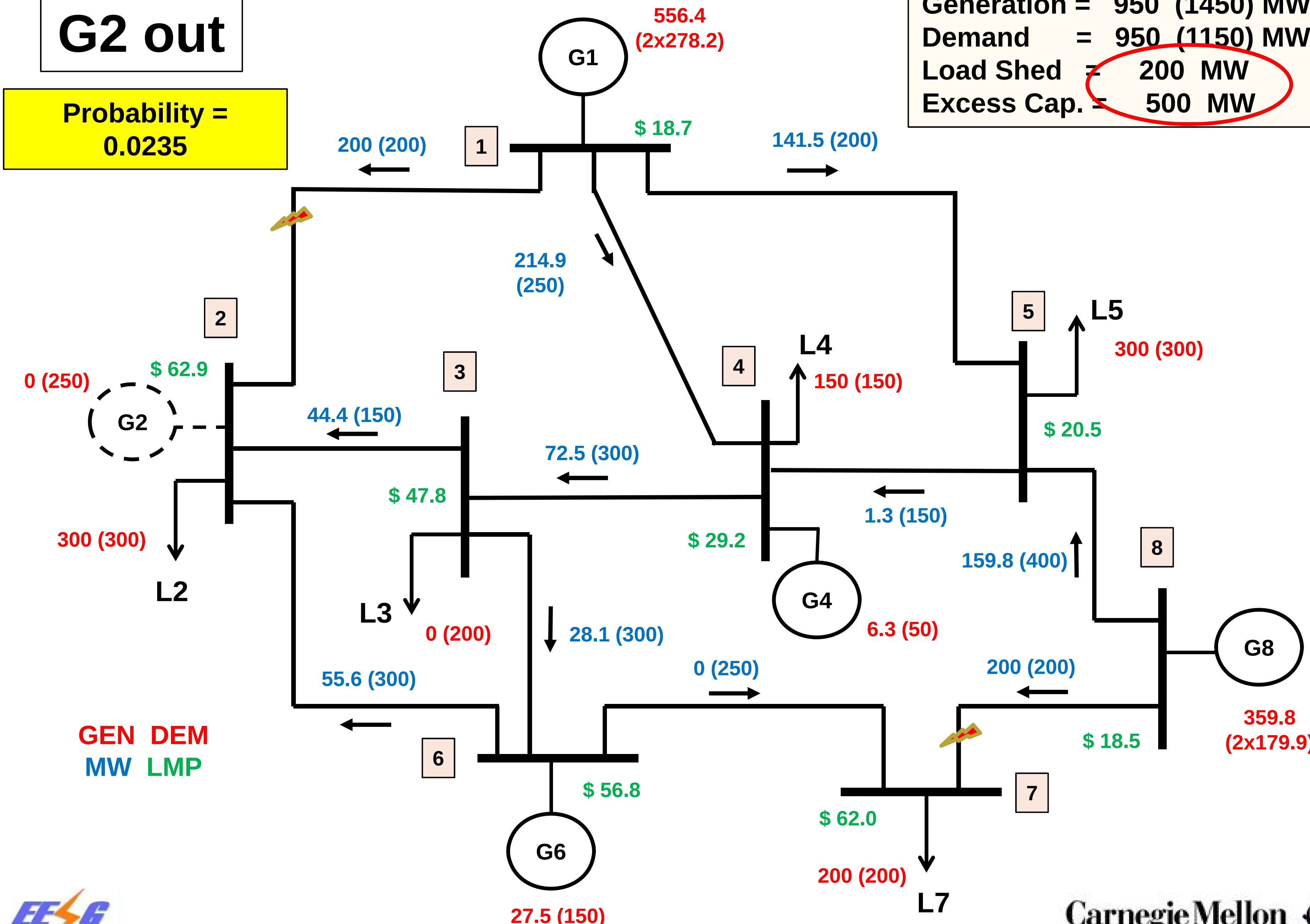
But the traditional approach to operational security is insufficient

- Spare capacity is reserved to provide for generation outages
- The reserve requirement is a fixed amount
  - Equivalent to losing the biggest generator online and/or some percentage of expected demand.
- This contingency reserve may not be deliverable when a contingency occurs
  - Due to transmission constraints in the network
  - As a result, N-1 is weakly enforced or costly manual adjustments are required

G2 out

Probability = 0.0235

Generation = 950 (1450) MW
Demand = 950 (1150) MW
Load Shed = 200 MW
Excess Cap. = 500 MW



A different approach to allocate contingency reserves is needed

- Abandon the traditional reserve requirement
  - Lack of technical basis for a fixed requirement
- Identify required locational contingency reserves
  - To fully satisfy N-1 criterion, taking into account all credible generation outages
- Conceptual approach:
  - Co-optimize expected cost of energy plus cost of providing reserves, considering credible outages

Stochastic SCUC for energy and reserves

$$\min_{x_{it}, u_{it}, g_{it}^{(0),(k)}} \sum_{i \in G} \sum_{t \in T} \sum_{k \in K} \left[S_i x_{it} + w^{(0)} C_i \left(g_{it}^{(0)}, u_{it} \right) + O_{it}(r_{it}) + w^{(k)} C_i \left(g_{it}^{(k)}, u_{it} \right) \right]$$

$$\sum_{i \in G_n} g_{it}^{(0)} + \sum_{p \in P_n} B_{pn}{}^{(l)} \theta_{pn,t}{}^{(l)} = D_{nt} \;;\; \forall_n, \forall_t, \forall_l$$

$$\sum_{i \in G_n} g_{it}^{(k)} + \sum_{p \in P_n} B_{pn}{}^{(k)} \theta_{pn,t}{}^{(k)} = D_{nt} \;;\; \forall_n, \forall_t, \forall_k$$

Nodal power balances (DCPF) w/ unit contingencies

$$r_{jt} = max[g_j^{(k)} - g_{jt}^{(0)}]^+ \,,\; \forall_{j \in G_{fast}}, \forall_t$$

$$RD_j \le g_{jt}^{(k)} - g_{jt}^{(0)} \le RU_j \;;\; \forall_{j \in G_{fast}}, \forall_t$$

$$RD_i \le g_{i,t} - g_{i,t-1} \le RU_i \;;\; \forall_i, \forall_t$$

$$-T_{pn,t} \le B_{np}{}^{(k,l)} \theta_{np,t}{}^{(k,l)} \le T_{np,t} \;;\; \forall_{np}, \forall_{k,l}, \forall_t$$

$$x_{it} + u_{i,t-1} \ge u_{i,t}$$

l : index of line contingencies

k : index of generation contingencies, 0 when normal state

O_i : cost of reserves provided by unit i

w : contingency probability

$$R_t = \sum r_{jt}$$

No previously fixed reserve requirement

EESG

Carnegie Mellon

Practical solution: decompose the problem in two deterministic stages

- Proposed formulation achieves a better allocation of contingency reserves, but the stochastic SCUC problem is hard to solve.
- Separate the problem into a centralized UC (1st stage) and co-optimization of energy and reserves (2nd stage)
  - Both are deterministic
  - In second stage simulate credible (single) unit outages to identify needed reserves

Network constrained economic dispatch (2nd stage)

For each period t, minimize energy and reserve costs **across all *k* contingencies**:

$$\min_{g_{it}^{(k)},\, r_{it}^{(k)}} \sum_{i} [\, C_i\left(g_{it}^{(k)}\right) + O_i\left(r_{it}^{(k)}\right)] \;; \qquad (7)$$

Subject to:

$$\sum_{i \in N_n} g_{it}^{(k)} + \sum_{p \in P_n} B_{pn}.\,\theta_{jn,t}^{(k)} = D_{nt} \;;\; \forall_n, \forall_t, \forall_k \quad (8)$$

$$g_{it}^{(k)} = g_{it}^{(0)} \;; \qquad \forall_{i \neq s} \qquad (9)$$

$$g_i^{min} \leq g_{it}^{(k)} \leq g_i^{max} \;; \qquad \forall_i, \forall_t, \forall_k \quad (10)$$

$$RD_s \leq g_{st}^{(k)} - g_{st}^{(0)} \leq RU_s \;; \qquad \forall_s, \forall_t \quad (11)$$

$$r_{it}^{(k)} = max[0, (g_{it}^{(k)} - g_{it}^{(0)})] \;,\; \forall_{i=s} \quad (12)$$

$$-T_{pn,t} \leq B_{np}.\,\theta_{np,t}^{(k)} \leq T_{np,t} \;;\; \forall_p, \forall_n, \forall_k, \forall_t \quad (13)$$

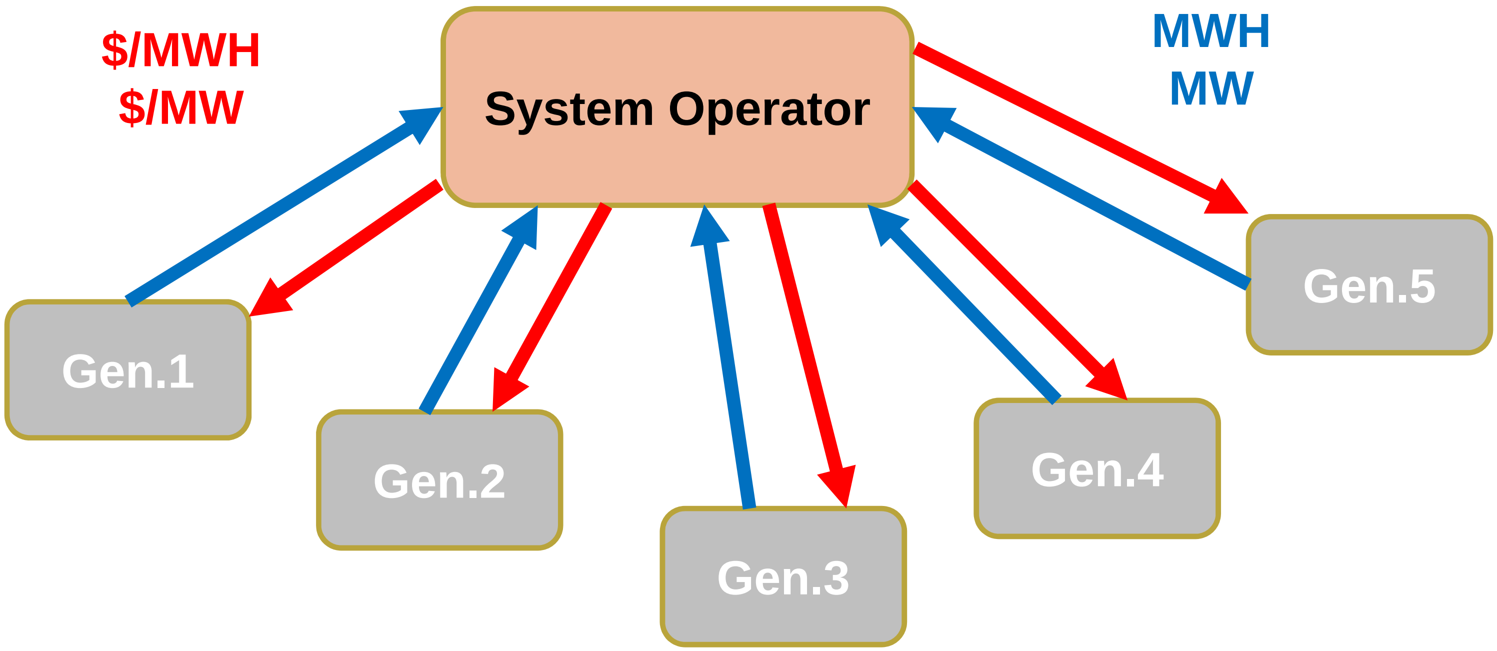
NCED can be solved in a decentralized way using DyMonDs approach

- To facilitate computation and processing
- DYMONDS approach
  - Replace centralized problem solution by system operator (SO)
  - Let generators optimize energy and reserve bids, based on prices posted by the system operator
  - Solution within the time framework of Real-Time markets

Locational reserves with DyMonDS

- System operator posts estimated energy and reserve prices
- Generators optimize energy and reserve bids subject to posted prices
  - Max. profit, incorporating generation constraints
- SO receives and clears the bids and compute a new set of energy and reserve prices.
- The process is iterated until all problem constraints are met.

Simulation of decentralized NCED



Energy and Reserve Prices

Energy and Reserve Bids

Solution can be simulated in a small test system with DyMonDS

- To prove feasibility of approach
- To measure convergence time
- To establish communication requirements
- To verify protocols for information exchange
- To verify quality of the solution

Thank you

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