DEI Doctoral Research Seminars
POLITECNICO DI BARI

The Ancillary Service Markets (ASM): The Italian case

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Cycle XXXV

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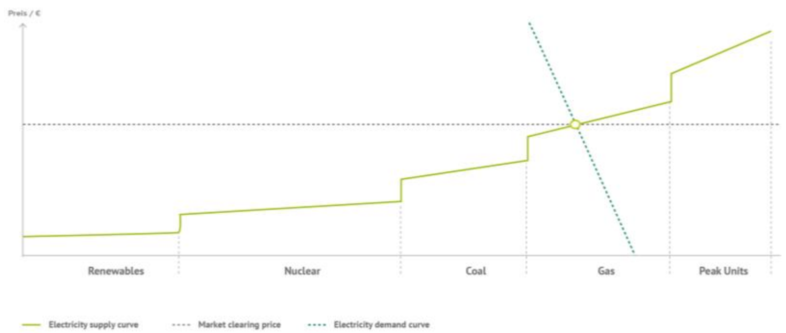
Seminar topics

- Introduction to Electrical Markets
- Evolution and challenges of Electrical Network and Markets
- Italian ASM Ex-Ante
- Proposed ASM model

Introduction to Electrical Markets

Energy Markets

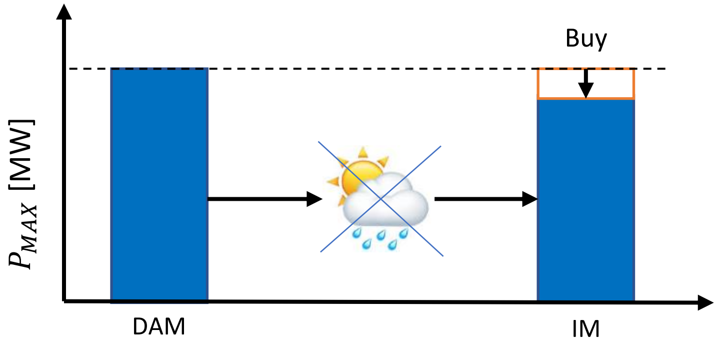
- Minimization of generation costs
- Zonal market
- Constraints
  - Power balance
  - Unit Commitment (UC)
  - Net Transfer Capacity (NTC)



Merit order curve

Zonal market representation

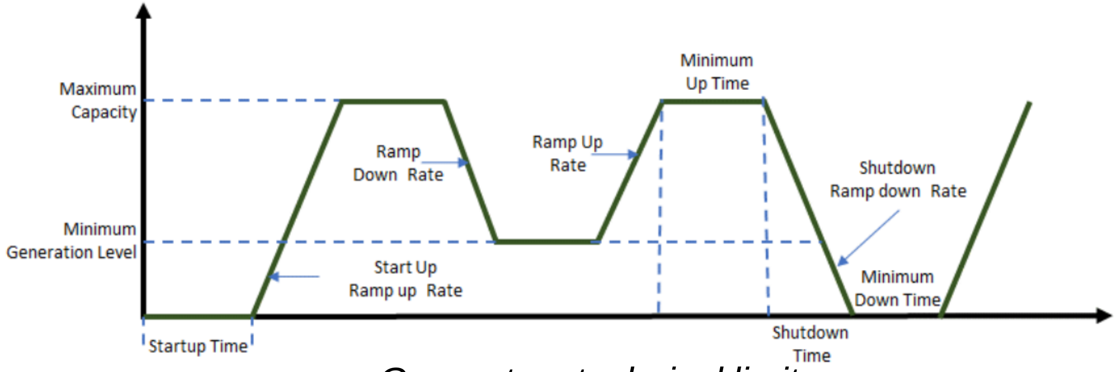
- Day Ahead Market (DAM)
  - Treading of the most daily energy
- Intraday Market (IM)
  - Adjustment of generators DAM program



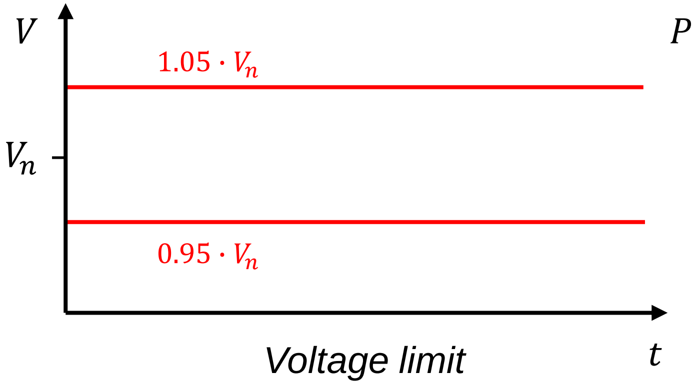
Influence of weather on unit production

ASM Ex-Ante—Structure

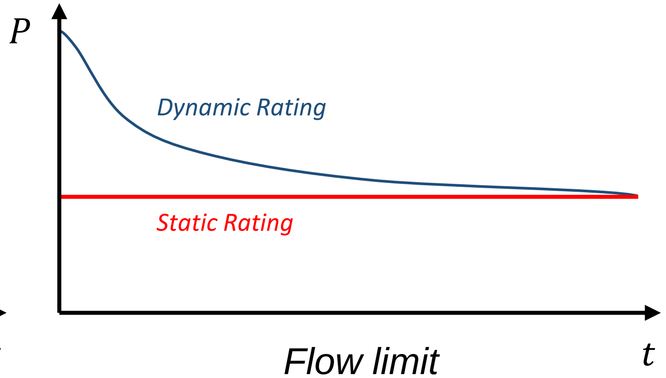
- Intrazonal branch overflow
- Cost minimization to provide hourly energy reserves
  - Generators technical limits
    - Production
    - Ramps
    - Minimum up/down time
  - Transmission network
    - Lines power flow
    - Buses voltage
    - Power balance
  - Reserves requirements
    - Active power
    - Reactive power



Generators technical limits



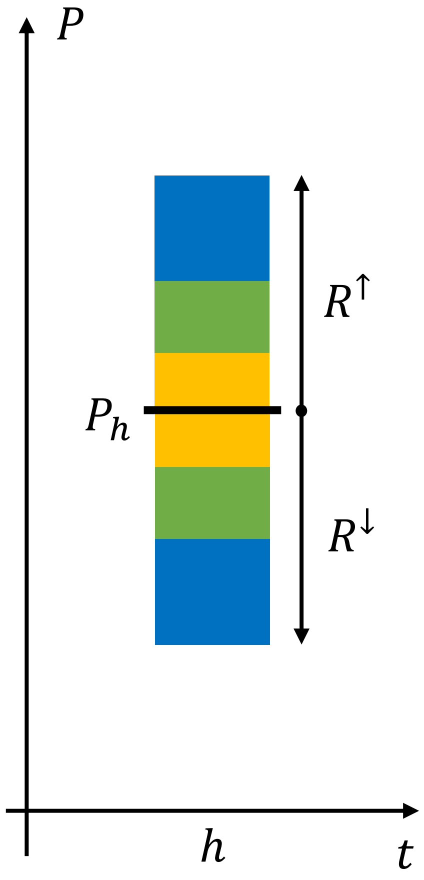
Voltage limit



Flow limit

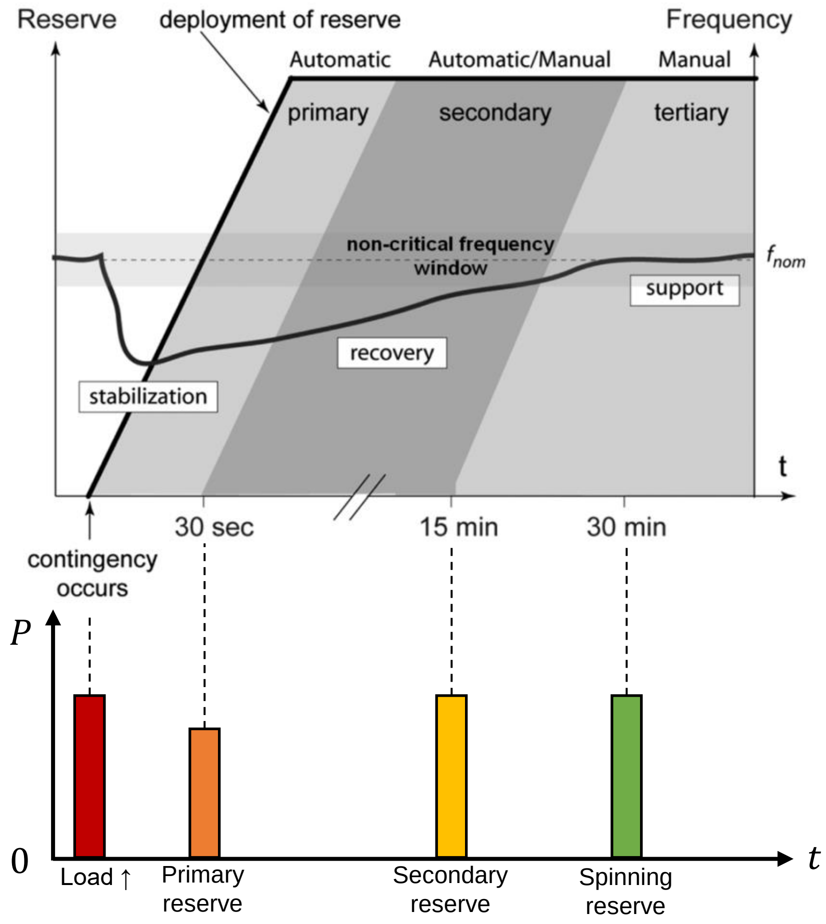
ASM Ex-Ante— Active power reserves

- Primary reserve
  - Generators response to perturbation
- Secondary reserve
  - Automatic control to restore
    - Primary reserve
    - Power balance (frequency)
  - Reserve requirement depends on demand estimation
- Tertiary reserve
  - Spinning reserve
    - Restore the secondary reserve
  - Replacement reserve
    - Overcome load and renewable forecast variation and unexpected generator/load outage



ASM Ex-Post—Balancing market

- Real time market
- Exploitation of hourly Ex-Ante accepted offers
  - Primary reserve response
  - Secondary reserve employed constantly
  - Spinning reserve deployed quarter hour
  - Replacement reserve delivered within 2 hours
- Only power plants with specific features are enabled to participate to the ASM

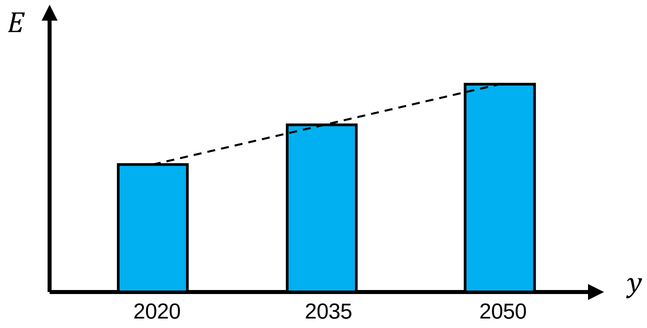


Reserves employment

Evolution and challenges of Electrical Network and Markets

Forecast of European Energy Demand and Supply

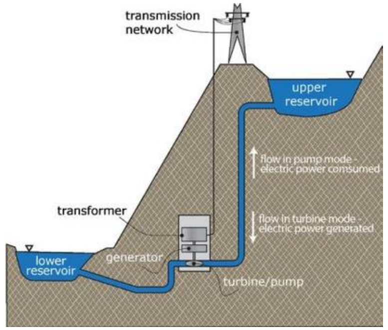
- In 2050 power demand grows by 40%
  - Yearly growth of 1.3%
  - From 3,500 TWh in 2020 to 4,900 TWh in 2050
  - Reduction of CO_2 emissions
    - Shifting from Carbon-fuels to electrical power
      - Transport
      - Facility heating/cooling



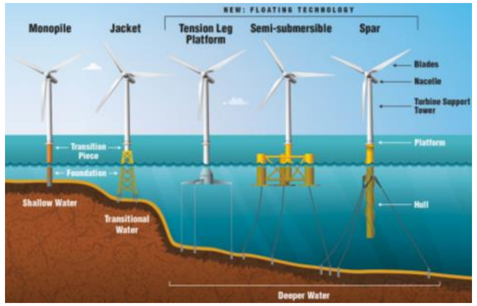
Demand growth forecast


Electrical vehicle

- Generation decarbonization
  - Replacement of coal- and gas-fired power generation
    - Offshore renewables resources
    - Nuclear power plant
  - Spreading of Pumped Storage Hydro Generation (PSHG)
    - Power and voltage control



PSHG



Offshore wind turbine

Transmission System Challenges

- Dispatching of high penetration of intermittent generation
  - Not proportionally distributed (overflow)
  - Forecast according to expected weather
  - Curtailment
  - Distributed generation
  - Reduction of system inertia
- Voltage control
  - Reduction of dispatchable generators
  - Higher voltage
- Enhance interconnections (HVAC/DC)
  - Increase resources exchange
  - Improve system stability

> 2,500 MW
1,000 MW - 2,500 MW
0 MW - 1,000 MW

PV capacity 2021 22.4 GW

> 2,500 MW
1,000 MW - 2,500 MW
0 MW - 1,000 MW

WT capacity 2021 11.4 GW

Development of European Markets— Energy Market

- Benefits
  - Improve resource sharing
  - Reduce price volatility
- Day Ahead Market Coupling (2012)
  - Spot market
- Intraday Market Coupling (2021)
  - Continuous treading market
- Nowadays the efforts are focused on Pan-European ASM development.

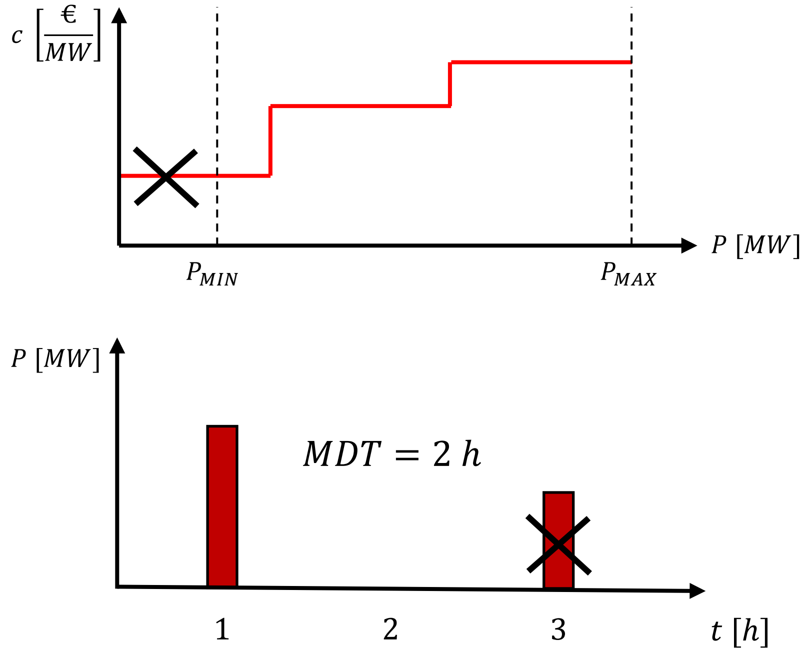
Nominated Electricity Market Operators

Coupling Markets

Italian ASM Ex-Ante

Energy markets characteristics

- DAM and IM goal is the cost minimization
- Interzonal flow bounds
- Generation constraints:
  - Stepwise selling/buying offers
  - Steps maximum power
  - Generator rated power
- DAM+IM infeasible global optimum solution



Examples of infeasible generators supply conditions

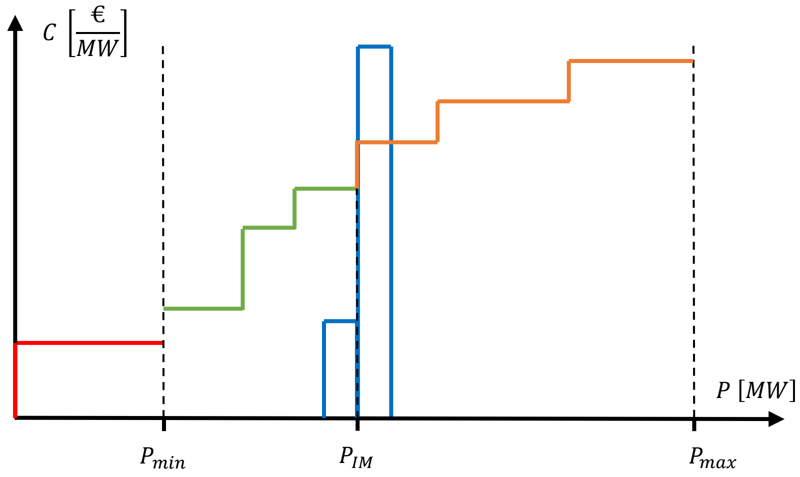
ASM Ex-Ante model

- Zonal market representation
- OF: Secondary reserve costs and

  Redispatching costs minimization
  - Start-up costs
  - Shut-down costs
  - Upward/Downward steps costs
- Constraints
  - NTC bounds
  - Power balance
  - UC and Economic Dispatch (UCED)
  - Secondary and tertiaries reserves requirements provision
  - Minimum number of active generators per market zone

Rete Elettrica Nazionale

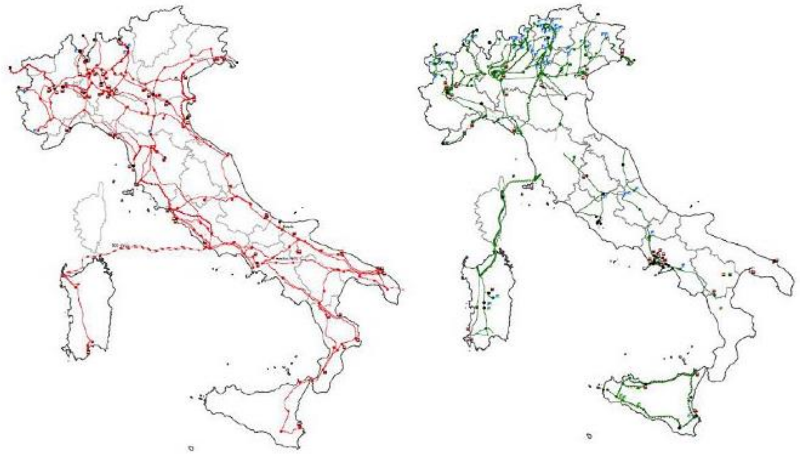
Italian TSO



Example of generator ASM offers

Reserve requirements typologies

- Active power market (reserves)
- Secondary and tertiaries reserves requirements
  - Continent and Islands
    - Islands self-sufficient reserves in the event of interconnection outage
- Market zone tertiary reserves requirements
  - External zones provision depends on NTS bounds
- Manual operation according to contingency occurred



400 kV and 230 kV Italian TS

Italian market zones

Proposed ASM Model

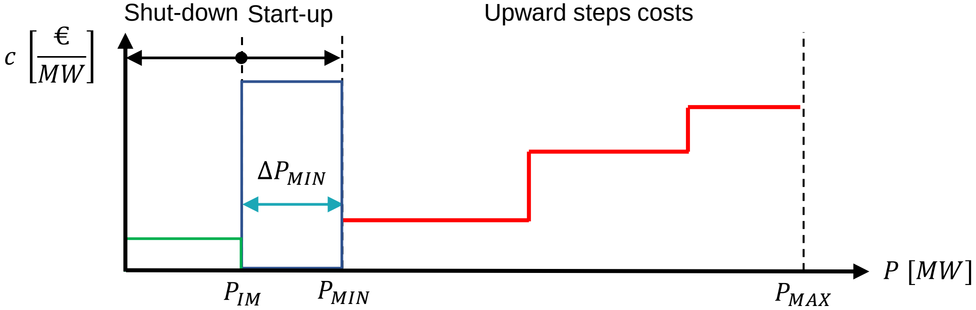
Multi-Stage Model—Reserves provision (1/3)

- MILP Problem developed on Pyomo (Python Optimization Modelling)
- Zonal market representation
- Objective function

$$\min \sum_{g=1}^{N_G}\left[\sum_{s=1}^{N_S}\left(c_{g,s}^{\uparrow}\Delta P_{g,s}^{\uparrow} - c_{g,s}^{\downarrow}\Delta P_{g,s}^{\downarrow}\right) + \left(C_{SU_g}\left(1-\alpha_{g,t-1}\right) + \Delta P_{MIN_g} c_{SU_g}\right)\alpha_g^{SU} - \min\left(P_{MIN_g}, P_{IM_g}\right)^{+} c_{SD_g}\alpha_g^{SD} + \left(c_{SR\,g}^{\uparrow} - c_{SR\,g}^{\downarrow}\right)P_g^{SR}\right]$$

Upward and downward costs | Start-up costs | Shut-down costs | Secondary reserve costs

$$\Delta P_{MIN_g} = \begin{cases} P_{MIN_g} - P_{IM_g} & if\ 0 < P_{IM_g} < P_{MIN_g} \\ P_{MIN_g} & otherwise \end{cases}$$



Multi-Stage Model—Reserves provision (2/3)

- Constraints
  - Zonal and total power balance
  - UCED
    - Power limits
    - Start-up or shut-down
    - Start-up before upward movement
  - NTC bounds
  - Secondary reserve provision
- Model tests on 3 bus system
- Next steps:
  - Tertiaries reserves provision
  - Suitable voltage control
  - Test the model on IEEE 118-bus system

$$\Delta P_g^{ASM} = \sum_{s=1}^{N_S} \left(\Delta P_{g,s}^{\uparrow} - \Delta P_{g,s}^{\downarrow}\right) + \Delta P_{MIN_g} \alpha_g^{SU} - \min\left(P_{MIN_g}, P_{MI_g}\right)^{+} \alpha_g^{SD}$$

Power limits:

$$\begin{cases} P_{IM_g} + \Delta P_g^{ASM} - P_g^{SR} \geq P_{MIN_g} \alpha_g & \forall\, g \in N_G \\ P_{IM_g} + \Delta P_g^{ASM} + P_g^{SR} \leq P_{MAX_g} \alpha_g & \forall\, g \in N_G \end{cases}$$

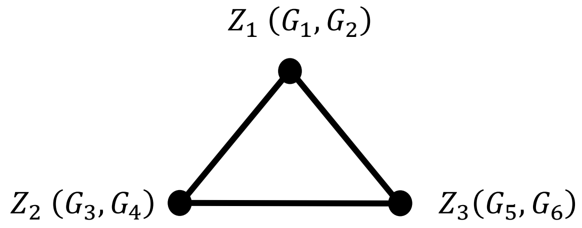
Start-up or shut-down:

$$\alpha_g^{SU} + \alpha_g^{SD} = 1 \quad \forall \quad 0 < P_{MI_g} < P_{MIN_g} \quad (g \in N_G)$$

Start-up before upward movement:

$$\alpha_g^{SU} - \alpha_g^{\uparrow} \geq 0 \quad \forall \quad P_{IM_g} < P_{MIN_g} \quad (g \in N_G)$$

19 constraints for each generator



3-bus test system

Multi-Stage Model—Reserves provision (3/3)

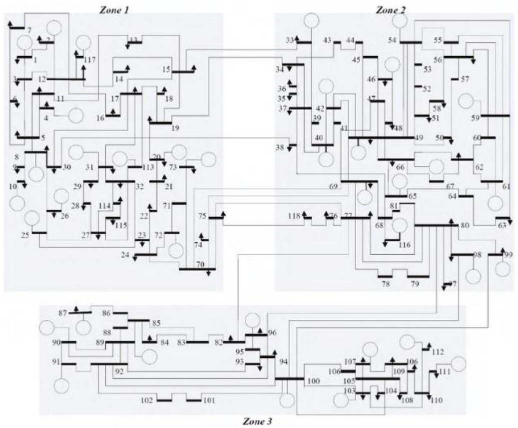
- Input data
  - DAM+IM results
    - Zonal demand load and renewable generation
    - Dispatchable power plants
  - Generator datasheets
    - Minimum and maximum power
    - MUT and MDT
    - Secondary reserve half-bandwidth
    - …
  - ASM inputs
    - Reserve requirements
    - NTC bounds
    - Redispatching offers
    - Secondary reserve offers

- Output data
  - Total cost
  - Interzonal flows
  - Redispatching and reserve provided by generators

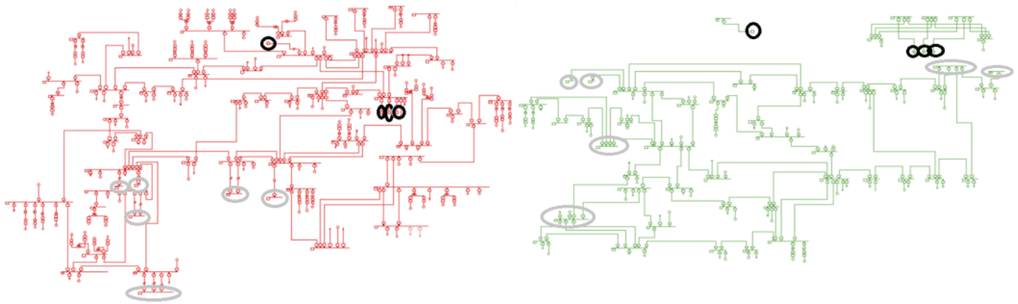
```
Objectives:
  cost_min : Size=1, Index=None, Active=True
      Key  : Active : Value
      None :   True : 52657.56

Variables:
  F_i : Size=3, Index=F_i_index
      Key   : Lower : Value             : Upper : Fixed : Stale : Domain
      Z1-Z2 :  None :  183.333333333333 :  None : False : False :  Reals
      Z2-Z3 :  None :  253.333333333333 :  None : False : False :  Reals
      Z3-Z1 :  None : -436.666666666667 :  None : False : False :  Reals
 DP_asm_g : Size=6, Index=DP_asm_g_index
     Key : Lower : Value : Upper : Fixed : Stale : Domain
      G1 :  None : 150.0 :  None : False : False :  Reals
      G2 :  None :   0.0 :  None : False : False :  Reals
      G3 :  None :   0.0 :  None : False : False :  Reals
      G4 :  None :   0.0 :  None : False : False :  Reals
      G5 :  None :  20.0 :  None : False : False :  Reals
      G6 :  None :   0.0 :  None : False : False :  Reals
 Prs_g : Size=6, Index=Prs_g_index
     Key : Lower : Value : Upper : Fixed : Stale : Domain
      G1 :     0 :  30.0 :  None : False : False : NonNegativeReals
      G2 :     0 :  21.2 :  None : False : False : NonNegativeReals
      G3 :     0 :   0.0 :  None : False : False : NonNegativeReals
      G4 :     0 :   0.0 :  None : False : False : NonNegativeReals
      G5 :     0 :  28.8 :  None : False : False : NonNegativeReals
      G6 :     0 :   0.0 :  None : False : False : NonNegativeReals
```

Multi-Stage Model—Network requirements

- Solution fulfills network requirements
  - Intrazonal branch flows
  - Nodal voltages
- Test case IEEE 118-bus system
- AC load flow with sensitivity analysis
  - DIgSILENT PowerFactory
  - Nodal distribution of optimization results
  - Power transfer distribution factors (PTDFs)
    - Minimization of decongestion costs
- Apply proposed method to South Italy TS



118-bus test system



400 kV and 230 kV South Italy TS