ILLINOIS INSTITUTE OF TECHNOLOGY

ELECTRIC POWER AND POWER ELECTRONICS CENTER

ROEL OF SECURITY IN OPETIMAL MANITENANCE SCHEDULING

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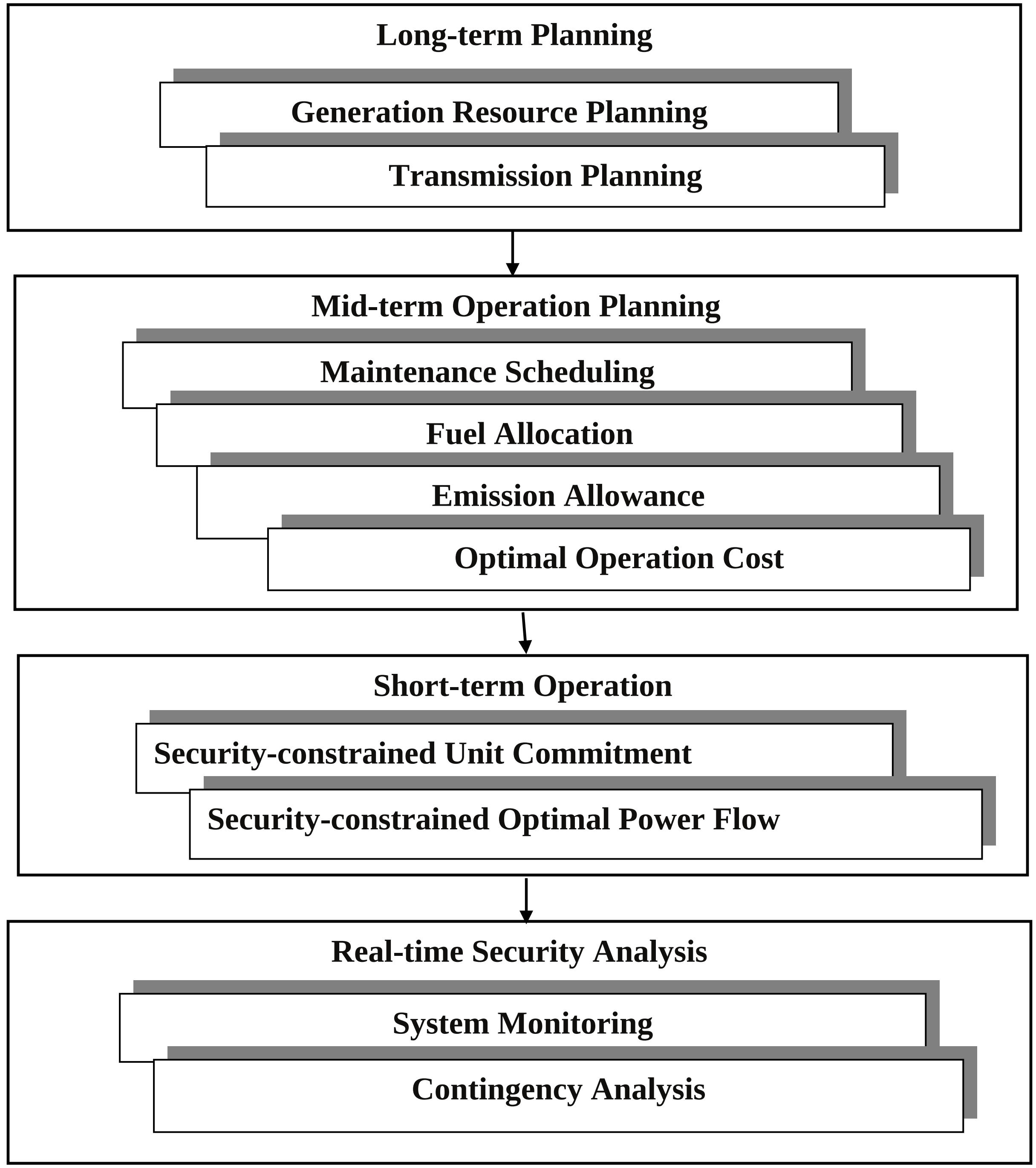
Security Time Scales

- Real-time (on-line) security analysis which maintains the system security in real-time
- Short-term (day ahead and weekly) operation which encompasses security-constrained unit commitment (SCUC) and security-constrained optimal power flow (SCOPF)
- Mid-term (monthly and yearly) operation planning which encompasses optimal maintenance scheduling of equipments and optimal allocation of resources (fuel and hydro) for maintaining the system security
- Long-term (yearly and beyond) planning which encompasses generation resource and transmission system planning for maintaining the system security

Hierarchical power system security

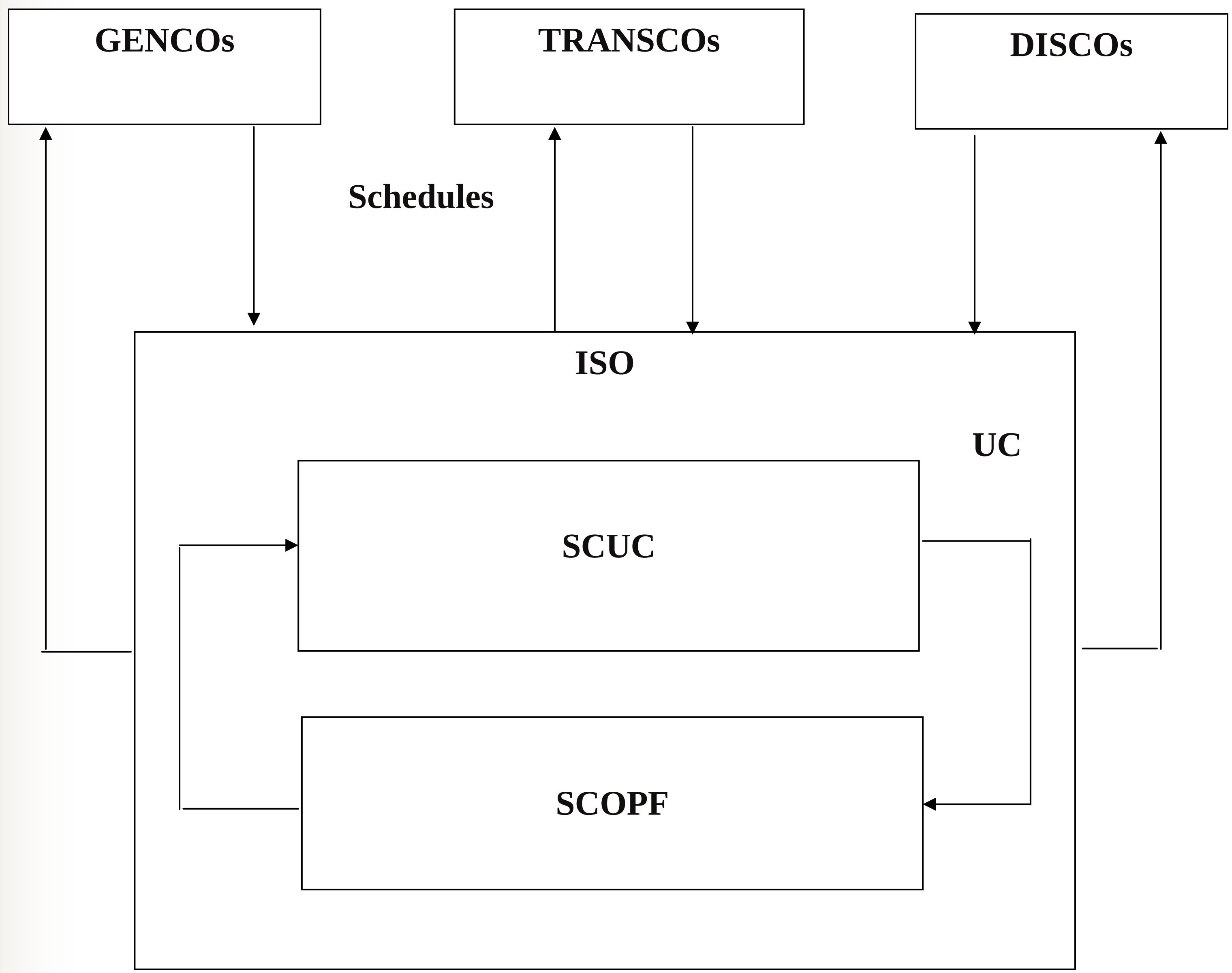


Security Time Scales

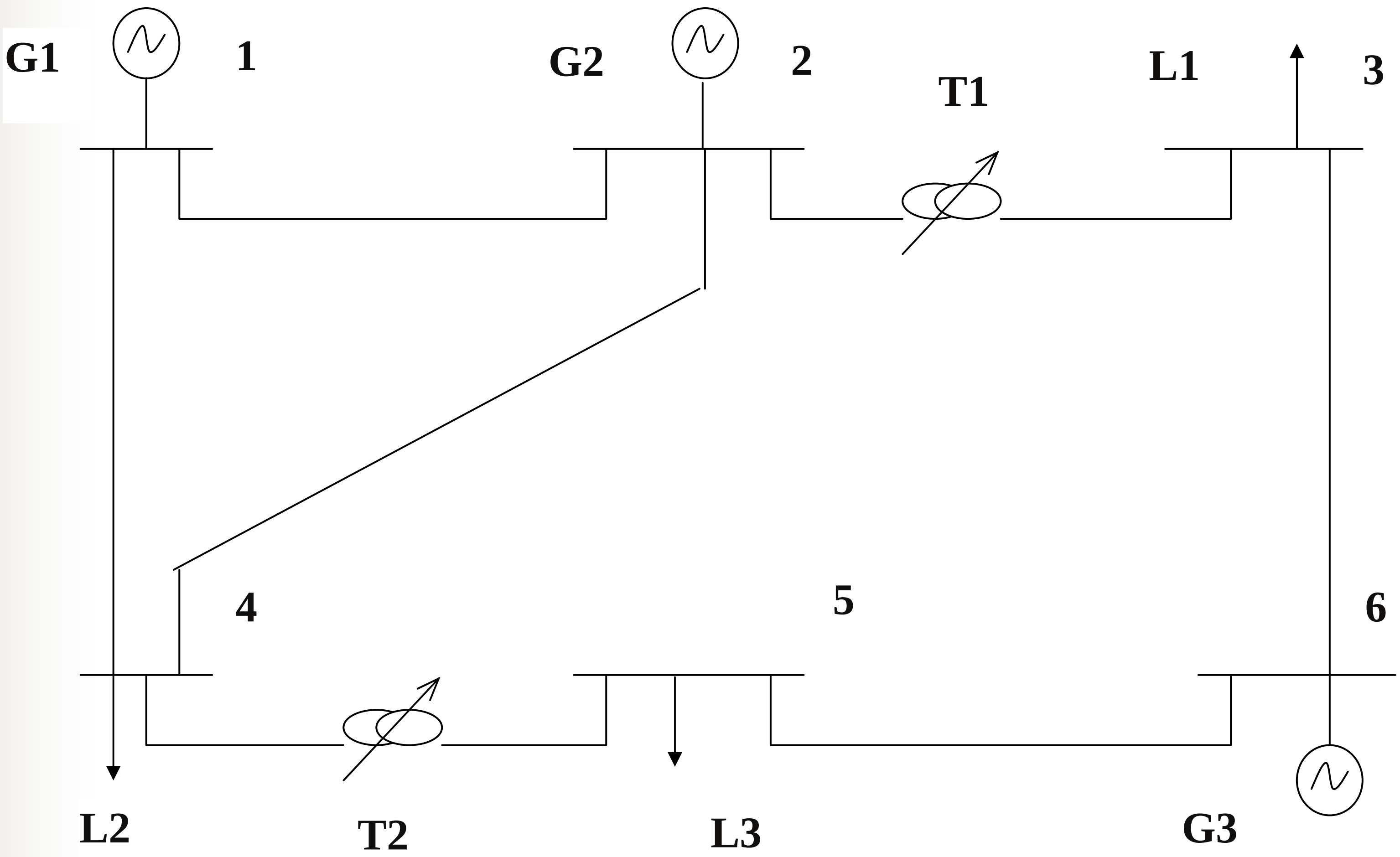
- Real-time and short-term operation risks are associated with power system failures, and hourly load fluctuations due to sudden changes in weather conditions.
  - Short-term operation is exposed to financial risks associated with volatility of electricity prices.
- Mid-term operation planning risks are associated with the procurement of fuel or the availability of natural resources such as water inflows.
  - Mid-term operation planning is exposed to financial risks associated with prices of forward electricity and fuel.
- Long-term planning risks are associated with the construction of generating plants and transmission facilities.
  - Financial risks are great due to the construction lead time and interest rates.

Security Time Scales

- A global analysis of security options could provide additional opportunities for seeking optimal states in time scales
  - Long-term and mid-term operation planning could provide a wider range of options for managing security in short-term and real-time power systems operations.
  - Power system operation strategies over shorter time periods (real-time and short-term) could yield security signals for longer-term scheduling (mid-term and long-term).


GENCOs
TRANSCOs
DISCOs
Schedules
ISO
UC
SCUC
SCOPF

Example of SCUC



Case 0: UC without transmission and voltage constraints

Daily Cost = $101,598.18
Hours (0-24)
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0

Case 1: Steady state dispatch with ac network constraints

Daily Cost = $103,135.90
Hours (0-24)
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0

Case 2: Outage of line 5-6

Daily Cost = $119,069.80
Hours (0-24)
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

Mid-term Operation Planning

- GENCOs' mid-term objectives are to extend the life span of existing generating units through proper maintenance and to optimize competitive payoffs by trading energy with the market.
- TRANSCOs' mid-term objectives are to maintain transmission security through proper maintenance and to optimize competitive payoffs by wheeling energy.
- The ISO's responsibility is to guarantee the system security and leave out participants' payoffs as a security constraint.

Mid-term Operation Planning

- Mid-term operation planning intends to satisfy the following requirements:
  - Enhance the power systems security based on limited generation and transmission equipment
  - Optimize the allocation of limited natural resources (water, fuel)
  - Extend the life span of generating and transmission units
  - Prolong investment costs for adding new facilities
  - Reduce operation costs for supplying competitive loads (mid-term load and price forecasts, renewable energy availability)

Cost of Mid-term Operation

- Total cost of mid-term operation planning could be divided into production cost and maintenance cost.
  - Production cost of a GENCO is a function of fuel usage for thermal generating units and other operation costs.
  - Maintenance costs of GENCOs and TRANSCOs could be minimized when outages are scheduled according to seasonal load durations and the availability of resources and manpower.
- System security could create a substantial barrier on the cost minimization of mid-term operation planning when available facilities are on maintenance.

Cost of Mid-term Operation

- Competitive objectives and constraints of market participants could be conflicting.
  - It could be impractical to seek an all-encompassing objective for participants' optimal maintenance scheduling in a secure power system environment.
  - Short-term operation (days or weeks) could impact mid-term operation planning and the overall system security when considering limited resources, transmission facilities, and emission allowance.
  - It could be appealing to the mid-term problem to develop a closer coordination strategy between mid-term operation planning and short-term operation solutions.

Features of Mid-term operation Planning

- Generation and transmission maintenance schedules
- MIP-based SCUC (ac constraints)
- Long-term fuel and emission constraints
- Hourly-based variable maintenance cost
- Hourly-based variable maintenance duration

Coordination in the Integrated Model

- Coordination between generation and transmission maintenance
- Coordination between security-constrained generation scheduling and equipment maintenance
- Coordination between resource allocation and optimal generation
- Coordination between transmission security and optimal maintenance & generation scheduling

Objective

minimize

{

operation cost

+

equipment maintenance cost

}

Constraints

1. Generation maintenance constraints
   - maintenance windows
   - resources and crew availability

2. Transmission maintenance constraints
   - maintenance windows
   - resources and crew availability

Constraints (cont.)

3. Generation constraints
   - Load balance
   - System spinning and operating reserve requirements
   - Minimum up and minimum down times
   - Ramp rate limits
   - Startup and shutdown characteristics of units
   - Generating capacity of generating units

4. Fuel consumption and emission allowance constraints

Constraints (cont.)

5. Coupling constraints between generation maintenance and unit commitment decision variables

6. DC transmission coupling constraints between transmission maintenance and economic dispatch decision variables:
   - First Kirchoff's law for bus power balance
   - Second Kirchoff's law for lines
   - Transmission flow limits
   - Limits on phase-shifting transformers

6. DC transmission coupling constraints between transmission maintenance *Y* and economic dispatch *P* decision variables:

First Kirchoff's law for bus power balance: $\mathbf{sf} + \mathbf{wp} = \mathbf{d}$

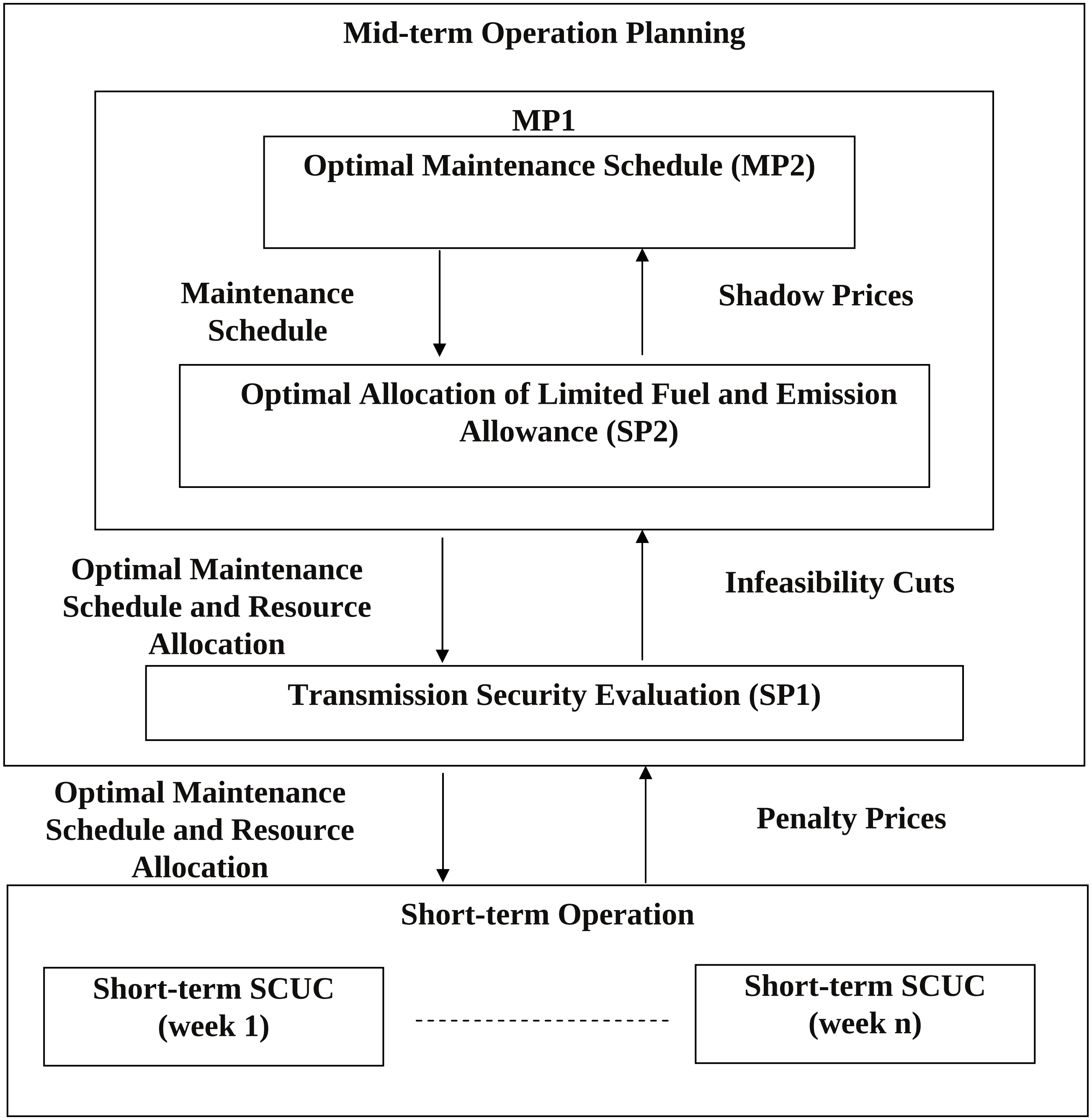
Second Kirchoff's law for lines:

$$\left| f_{mn} - \gamma_{mn} (\theta_m - \theta_n) \right| \le M_j * (1 - Y_{jt}) \quad (j \in m, n)$$

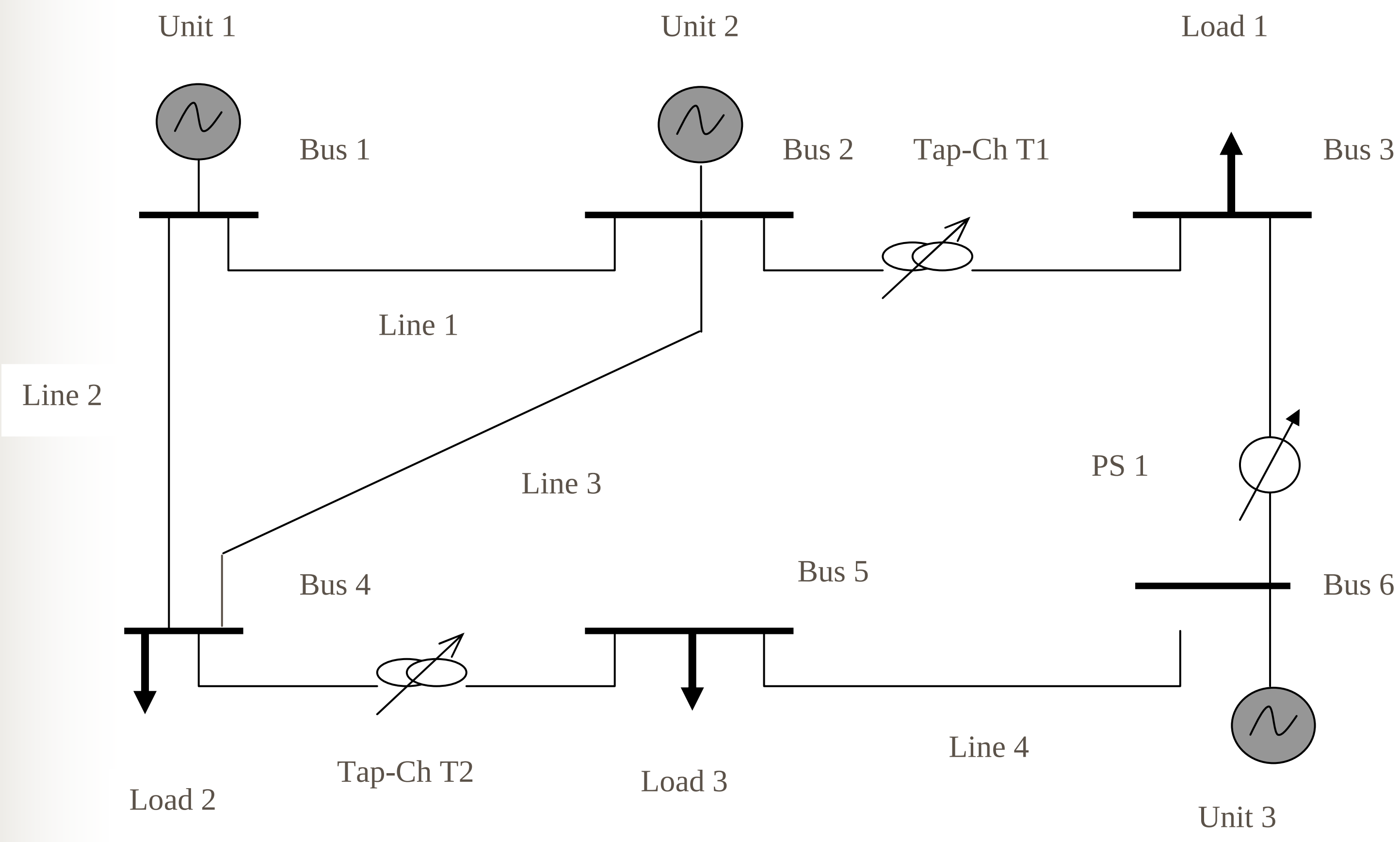
Transmission flow limits:

$$\left| f_{mn} \right| \le PL_{j,\max} * Y_{jt} \qquad (j \in m, n)$$

Mid-term operation planning for security



One-line diagram for 6-bus test system



Unit data

Units	Bus No.	Unit Cost Coefficients			Pmax (MW)	Pmin (MW)
		a (Mbtu)	b (MBtu/MWh)	c (MBtu/MW^{2}h)		
G1	1	176.9	13.5	0.00045	220	100
G2	2	129.9	32.6	0.001	150	50
G3	6	137.4	17.6	0.005	100	20

Units	Ini. St. (h)	Min Down (h)	Min Up (h)	Ramp (MW/h)	StartUp (MBtu)
G1	ON 4	4	4	55	100
G2	ON 2	3	2	50	200
G3	ON 1	1	1	40	0

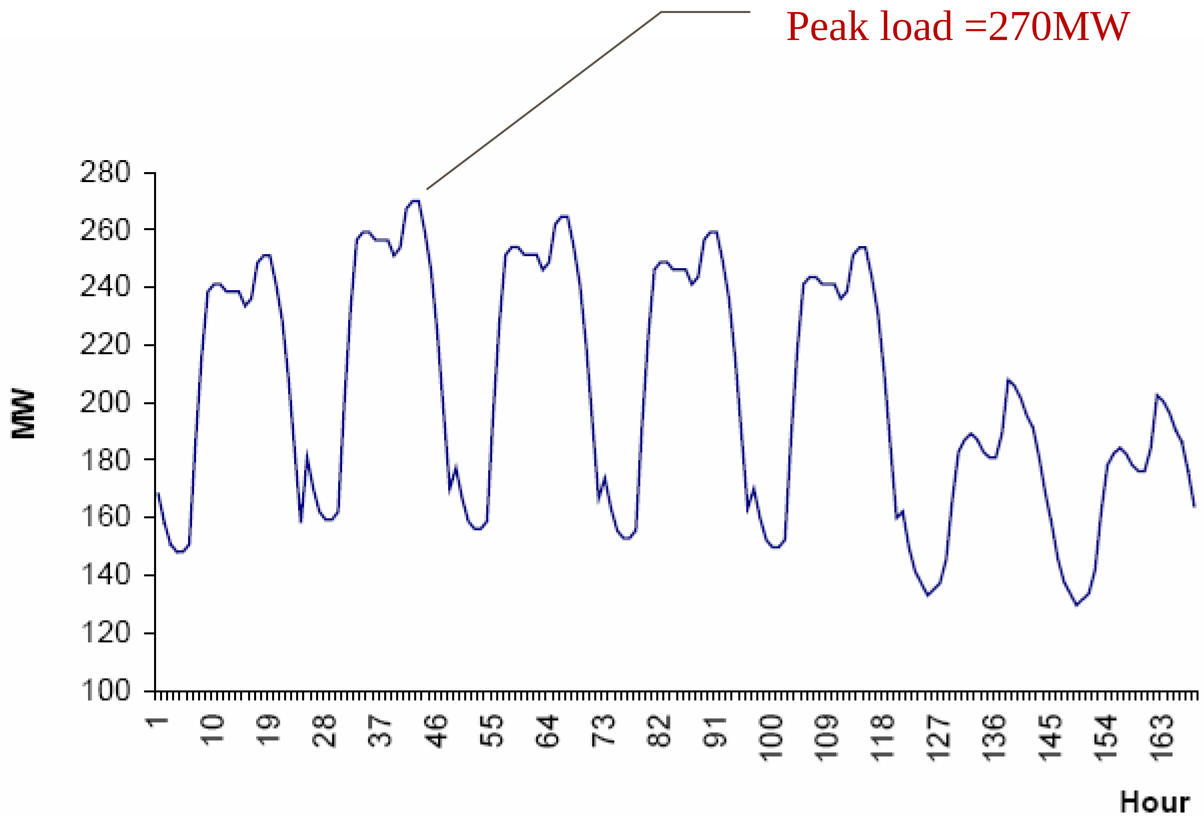
Branch data

Line	From Bus	To Bus	R (pu)	X (pu)	Limit (MW)
Line 1	1	2	0.0050	0.170	200
Line 2	1	4	0.0030	0.258	200
Line 3	2	4	0.0070	0.197	80
Line 4	5	6	0.0020	0.140	100

T.	From Bus	To Bus	X (pu)	Max Tap /Degree	Min Tap /Degree	Limit (MW)
T1	2	3	0.037	1.08	1.02	100
T2	4	5	0.037	1.08	1.02	100
P1	3	6	0.018	30	-30	100

Equipment maintenance limits for 6-bus system

Equip.	From/ At Bus	To Bus	Windows	Duration (hours)	Cost ($/hour)
U1	1	-	Mon. - Sun.	24	84
U2	2	-	Mon. - Sun.	24	125
U3	6	-	Mon. - Sun.	24	167
L1-2	1	2	Tue. - Sat.	24	2080

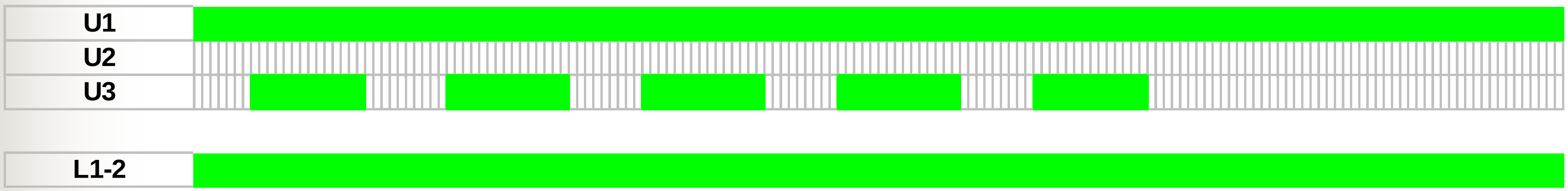


Peak load =270MW
280
260
240
220
200
180
160
140
120
100
MW
1
10
19
28
37
46
55
64
73
82
91
100
109
118
127
136
145
154
163
Hour

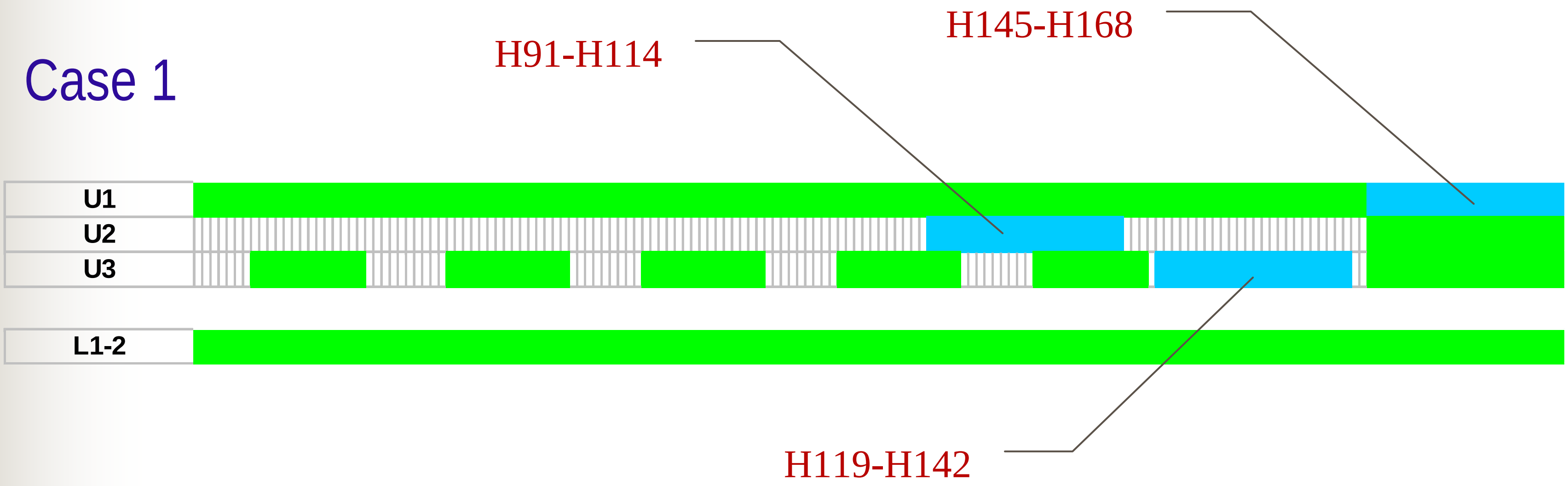
Case studies

- Case 0: Without any equipment maintenance
- Case 1: With generation maintenance
- Case 2: With transmission maintenance
- Case 3: With generation and transmission maintenance

Case 0



Case 1

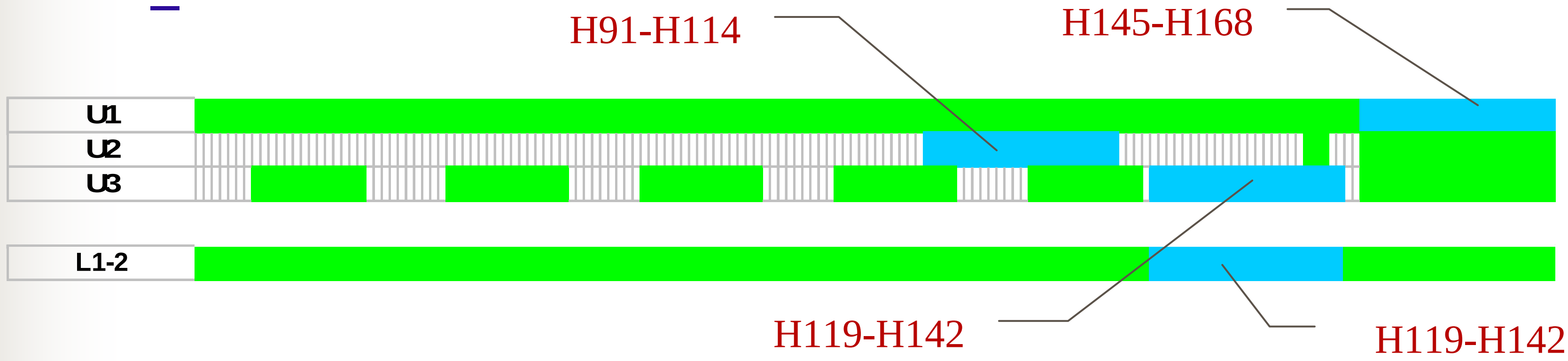


Case 2

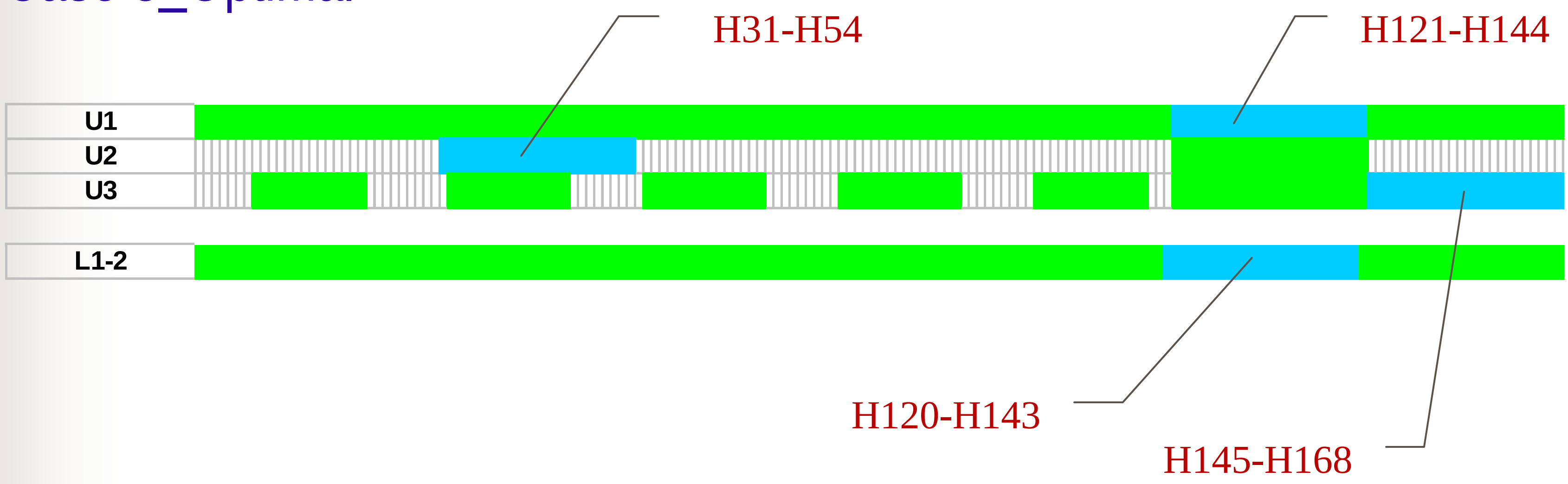
Maintenance of line 1-2 and hourly violations

Iteration	Hours on Maintenance	Hours with Violation
1	75-98	80-93
2	97-120	104-109, 110-118
3	56-79	56-70
4	119-142	138-140
5	25-48	31-47
6	119-142	None

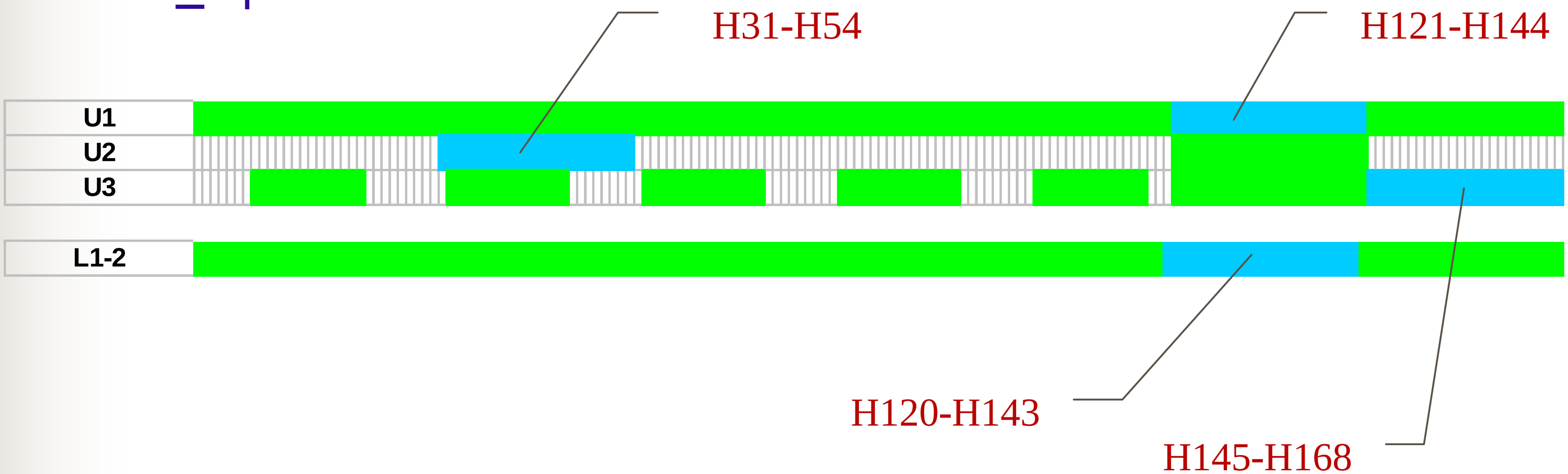
Case 3_Feasible



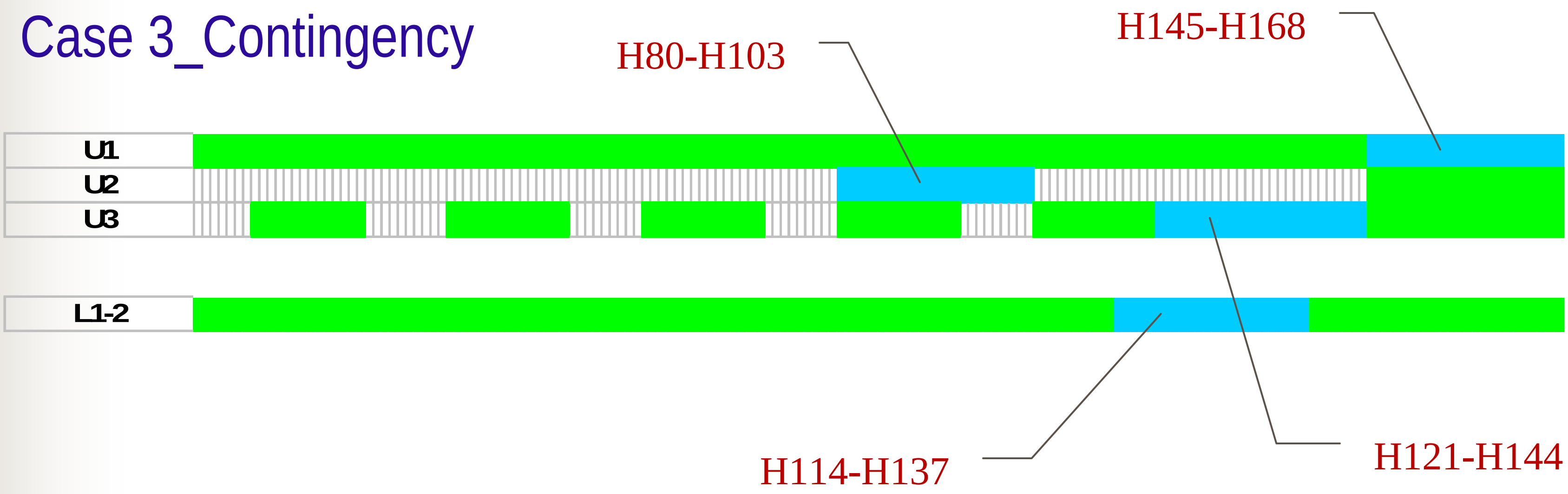
Case 3_Optimal

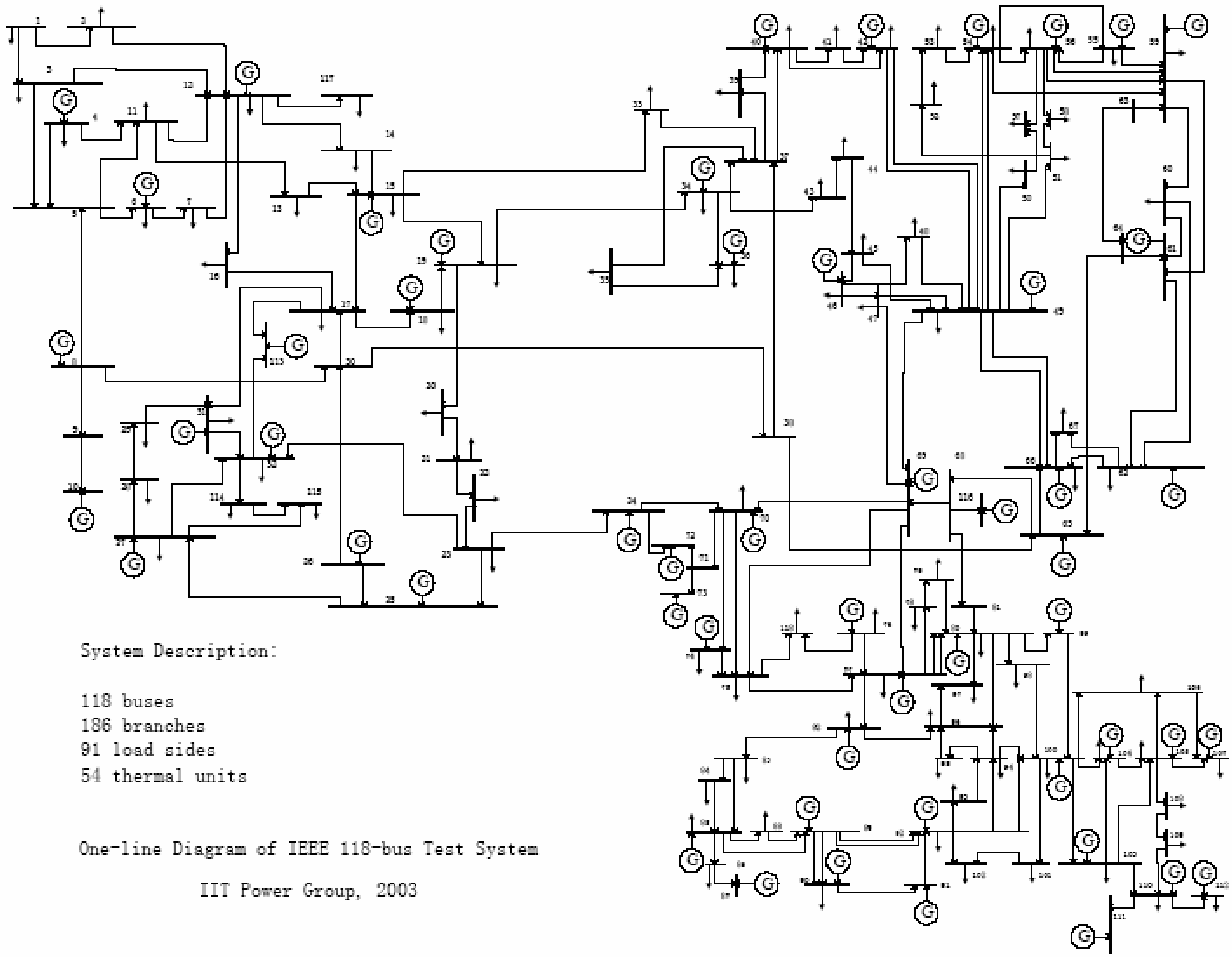


Case 3_Optimal



Case 3_Contingency





System Description:

118 buses
186 branches
91 load sides
54 thermal units

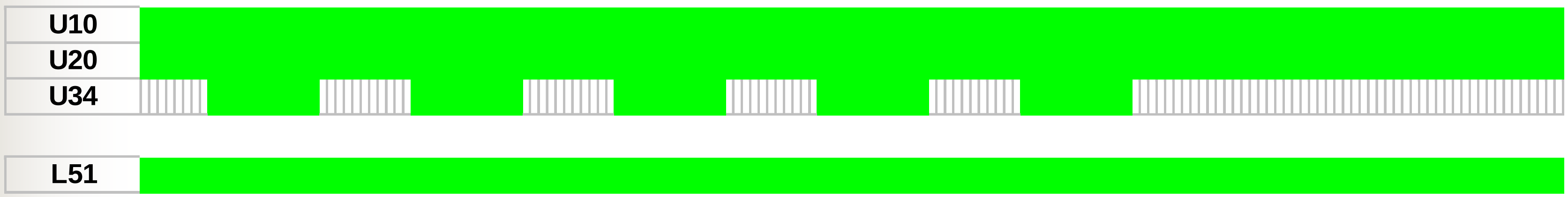
One-line Diagram of IEEE 118-bus Test System

IIT Power Group, 2003

Equipment maintenance limits for 118-bus system

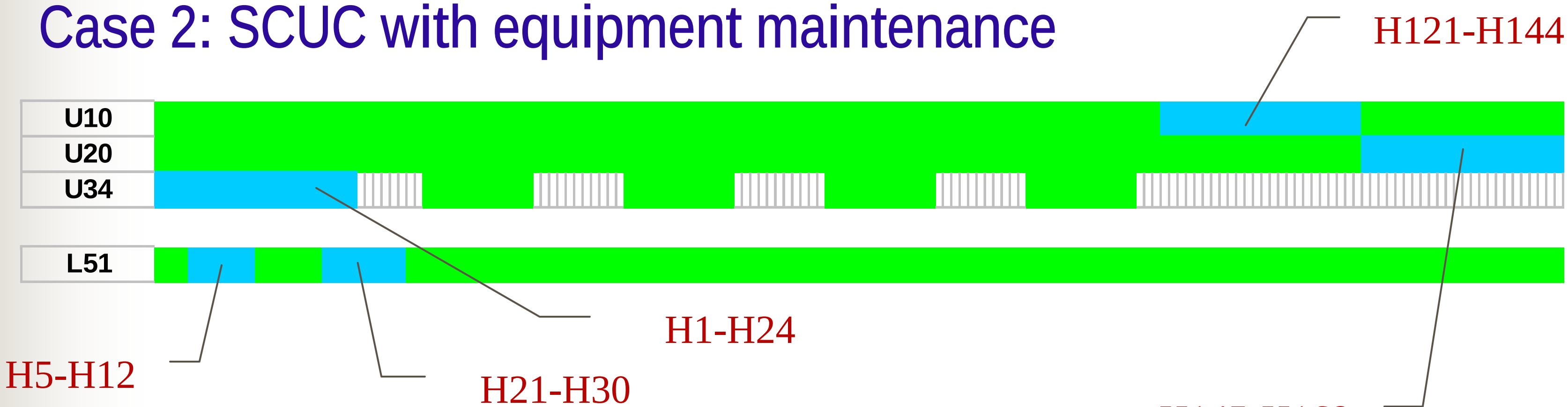
Equip.	From/ At Bus	To Bus	Windows	Duration (hours)	Cost ($/hour)
U10	25	-	Mon. - Sun.	24	1200
U20	49	-	Mon. - Sun.	24	1000
U34	76	-	Mon. - Wed.	24	400
L51	38	37	Mon. - Fri.	18	5000

Case 1: SCUC without equipment maintenance



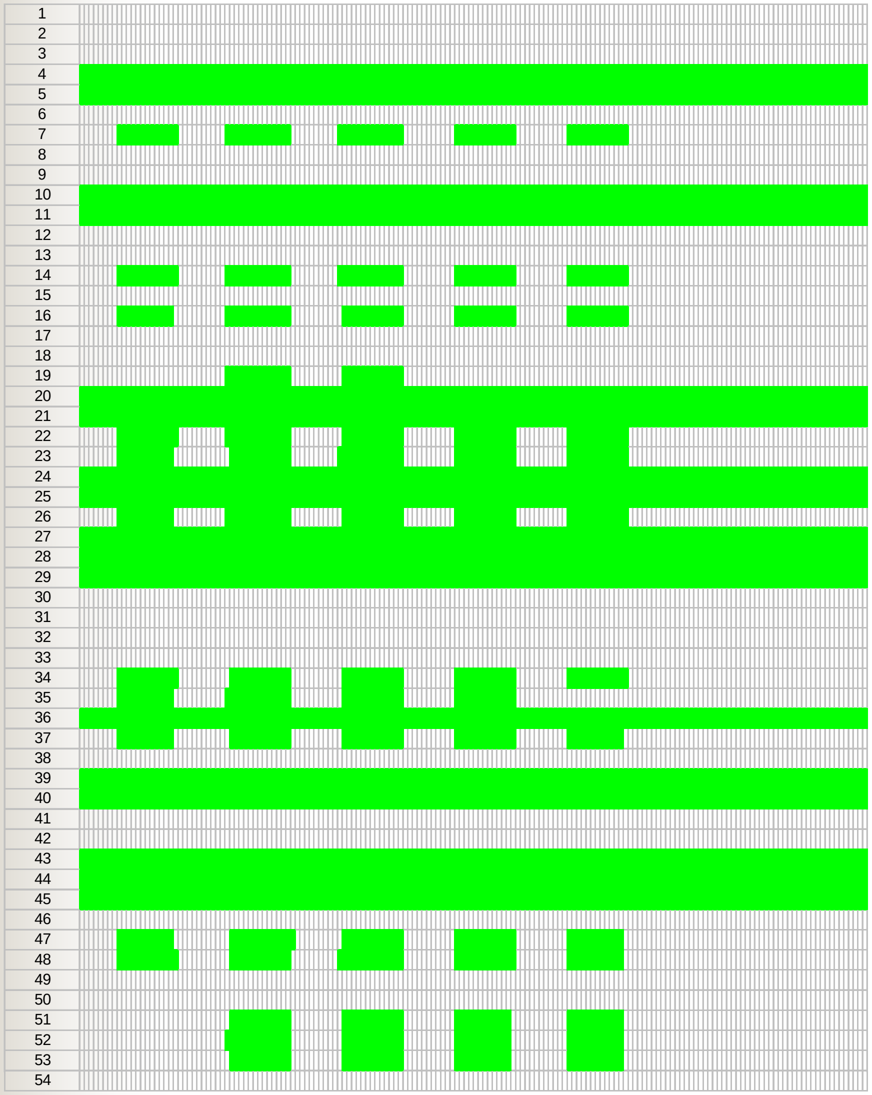
Equipment maintenance cost = $0.00
Operating cost = $10,112,075.13
Total cost = $10,112,075.13

Case 2: SCUC with equipment maintenance



Generator maintenance cost = $62,400.00
Line maintenance cost = $90,000.00
Operating cost = $10,137,660.83
Total cost = $10,290,060.83

UC for Case 1



UC for Case 2