Iskustva sa studijskog boravka na Universidad de Castilla-La Mancha

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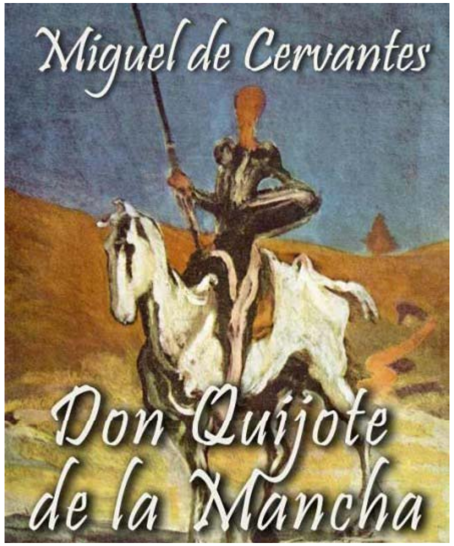
FER - Zagreb

Općenito

- Usavršavanje u trajanju 3 mjeseca (12.09.-23.12.2010)
- Ciudad Real
  - 70 000 stanovnika
  - Don Quijote
  - Rukomet



UCLM

- Osnovano 1982. godine
- 4 kampusa:
  - Albacete
  - Ciudad Real
  - Cuenca
  - Toledo
- GSEE – Electric Energy Systems Group

Kako? Zašto?

- Područje doktorata: određivanje optimalnog rasporeda održavanja elemenata elektroenergetskog sustava korištenjem matematičkog programiranja
- Najzastupljeniji u literaturi:
  - Mohammad Shahidehpour (IIT)
  - Antonio Conejo (UCLM)

120 CC i SCI radova

Financije

- Plaća MZOS (bez prijevoza)
- Stipendija NZZ 17 300 kn
- Troškovi:
  - put
  - osiguranje
  - viza
  - stanarina
  - hrana i ostalo

Predmet istraživanja

- Određivanje optimalnog termina održavanja prijenosnih vodova
- Ograničenja:
  - sigurnost prijenosnog sustava
  - utjecaj na tržište
- Bilevel problem:
  - gornja razina: minimizacija visokih opterećenja vodova
  - donja razina: *social welfare* (simulacija tržišta, odnosno *market clearing*)

Vremenski horizont

- Godina podijeljena na 52 tjedna
- Svaki tjedan podijeljen na radni dio tjedna te vikend
- Omogućeno održavanje samo tijekom nekoliko vikenda zaredom, kada je opterećenje u pravilu niže nego tijekom radnog tjedna

Funkcija cilja

- Mješovito-cjelobrojni problem:

$$\underset{\Delta_{\mathrm{U}}}{\text{Maximize}}$$

$$\sum_{t=1}^{T}\left[\frac{\sum_{l\in\Omega^{\mathrm{NM}}}\left(\left(p_l^{\max}-\sum_{h\in\Phi}p_{lh}^{\mathrm{abs}}(t)\cdot U_h\right)\cdot k_l\right)}{\sum_{j\in\Omega^{\mathrm{D}}}\sum_{c\in\Omega_j}d_{jc}^{\max}(t)}+\right.$$
$$\left.+\frac{\sum_{l\in\Omega^{\mathrm{M}}}\left(\left((1-x_l(t))\cdot p_l^{\max}-\sum_{h\in\Phi}p_{lh}^{\mathrm{abs}}(t)\cdot U_h\right)\cdot k_l\right)}{\sum_{j\in\Omega^{\mathrm{D}}}\sum_{c\in\Omega_j}d_{jc}^{\max}(t)}\right]$$

Problem gornje razine

- Ograničenja tokova snaga:

$$\sum_{h \in \Phi} p_{lh}^{\text{abs}}(t) = p_l^{\text{abs}}(t) \quad \forall l \in \left\{\Omega^{\text{M}} \cup \Omega^{\text{NM}}\right\}, t \leq T \quad (1b)$$

$$p_{lh}^{\text{abs}}(t) \leq V_h \cdot p_l^{\max} \quad \forall h \in \Phi, l \in \left\{\Omega^{\text{M}} \cup \Omega^{\text{NM}}\right\}, t \leq T \quad (1c)$$

$$p_l^{\text{abs}}(t) \geq p_l(t) \quad \forall l \in \left\{\Omega^{\text{M}} \cup \Omega^{\text{NM}}\right\}, t \leq T \quad (1d)$$

$$p_l^{\text{abs}}(t) \geq -p_l(t) \quad \forall l \in \left\{\Omega^{\text{M}} \cup \Omega^{\text{NM}}\right\}, t \leq T \quad (1e)$$

Problem gornje razine

- Ograničenja rasporeda održavanja:

$$x_l(t) \in \{0,1\} \quad \forall l \in \Omega^{\mathrm{M}}, t \leq T \tag{1f}$$

$$\sum_{t=1}^{T/2} x_l(2t-1) = Wd_l \quad \forall l \in \Omega^{\mathrm{M}} \tag{1g}$$

$$\sum_{t=1}^{T/2} x_l(2t) = We_l \quad \forall l \in \Omega^{\mathrm{M}} \tag{1h}$$

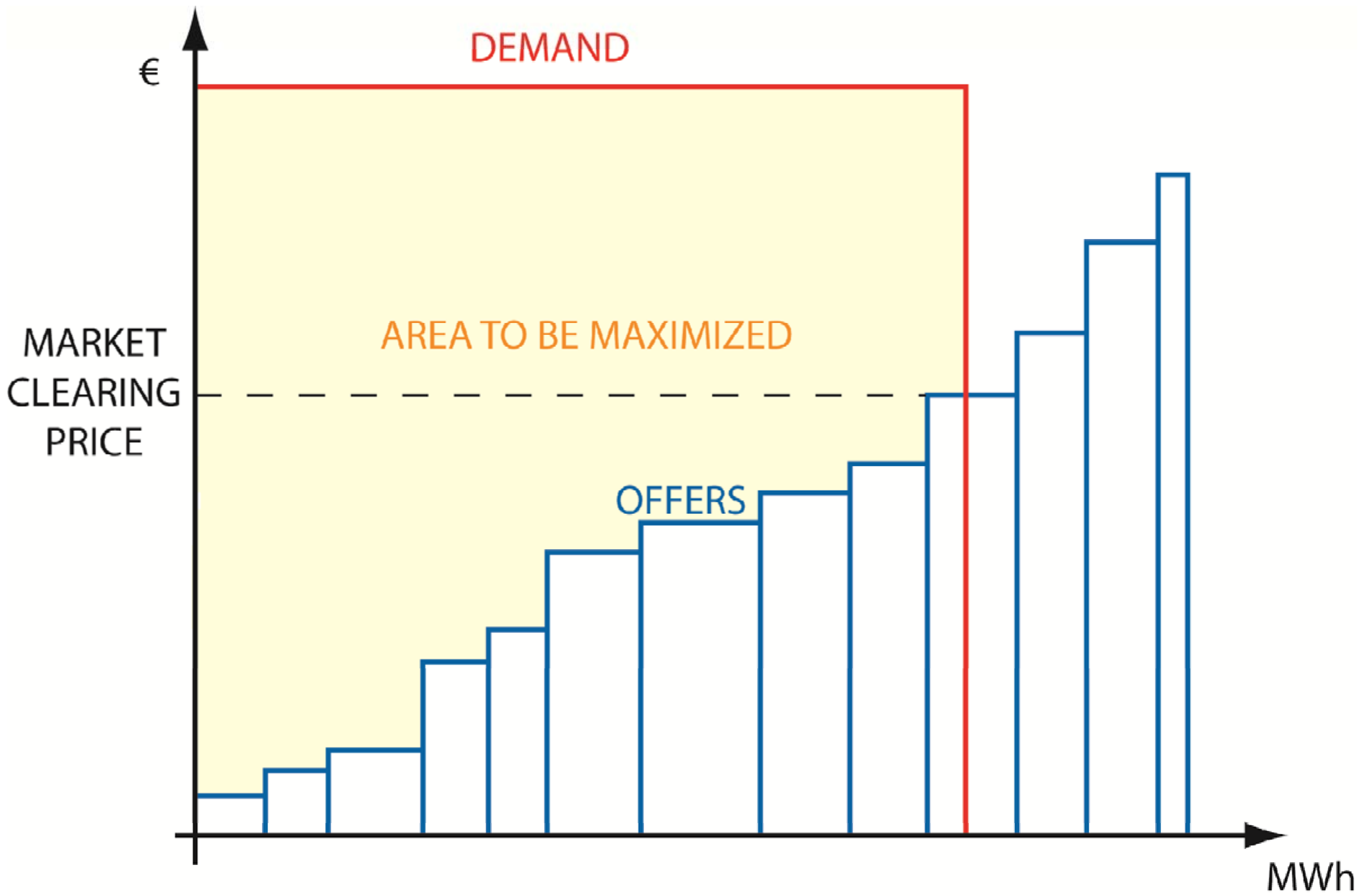
$$x_l(2t-1) - x_l(2t-3) \leq x_l(2t-1+(2Wd-2)) \quad \forall t \leq \frac{T}{2} \tag{1i}$$

$$x_l(2t) - x_l(2t-2) \leq x_l(2t+(2We-2)) \quad \forall t \leq \frac{T}{2} \tag{1j}$$

$$x_l(t) - x_l(t-1) \leq x_l(t+(Wd+We-1)) \quad \forall t \leq T \tag{1k}$$

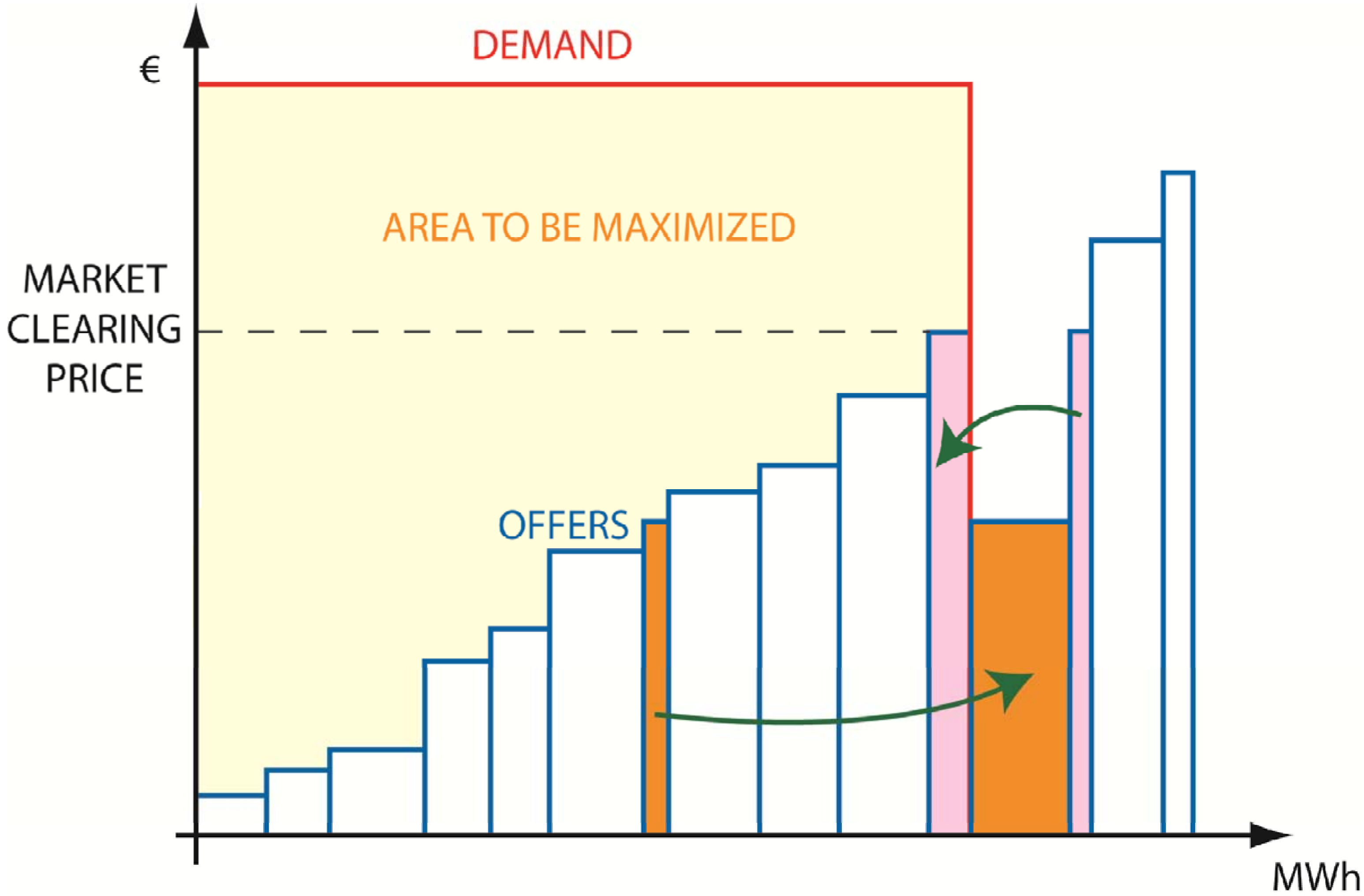
Problem donje razine

- Social welfare:



Problem donje razine

- Ovo ne želimo:



Problem donje razine

- Funkcija cilja:

$$p_l(t)\,\forall l \in \arg\left\{\underset{\Delta_{\mathrm{L\_P}}}{\mathrm{Maximize}}\right.$$

$$\left[\sum_{j\in\Omega^{\mathrm{D}}}\sum_{c\in\Omega_j}\lambda_{Djc}(t)\cdot d_{jc}(t)-\right.$$

$$\left.-\sum_{i\in\Omega^{\mathrm{G}}}\sum_{b\in\Omega_i}\lambda_{Gib}(t)\cdot g_{ib}(t)\right]$$

Problem donje razine

- Ograničenja:

$$\sum_{i\in\Psi_s^{\mathrm{G}}}\sum_{b\in\Omega_i} g_{ib}(t) - \sum_{l|o(l)=s} p_l(t) + \sum_{l|d(l)=s} p_l(t) = \\ = \sum_{i\in\Psi_s^{\mathrm{D}}}\sum_{c\in\Omega_j} d_{jc}(t) \quad : \alpha_s(t)\, \forall s \in \Pi \tag{2b}$$

$$p_l(t) = b_l\left(1 - x_l(t)\right)\cdot\left(\theta_{o(l)}(t) - \theta_{d(l)}(t)\right) \\ : \beta_l(t)\, \forall l \in \Omega^{\mathrm{M}} \tag{2c}$$

$$p_l(t) \le p_l^{\max} \quad : \beta_l^{\max}(t)\, \forall l \in \Omega^{\mathrm{M}} \tag{2d}$$

$$p_l(t) \ge -p_l^{\max} \quad : \beta_l^{\min}(t)\, \forall l \in \Omega^{\mathrm{M}} \tag{2e}$$

$$p_l(t) = b_l\cdot\left(\theta_{o(l)}(t) - \theta_{d(l)}(t)\right) \quad : \kappa_l(t)\, \forall l \in \Omega^{\mathrm{NM}} \tag{2f}$$

$$p_l(t) \le p_l^{\max} \quad : \kappa_l^{\max}(t)\, \forall l \in \Omega^{\mathrm{NM}} \tag{2g}$$

Problem donje razine

- Ograničenja:

$$p_l(t) \geq -p_l^{\max} \quad : \kappa_l^{\min}(t)\, \forall l \in \Omega^{\mathrm{NM}} \tag{2h}$$

$$g_{ib}(t) \leq g_{ib}^{\max}(t) \quad : \gamma_{ib}^{\max}(t)\, \forall b \in \Omega_i, i \in \Omega^{\mathrm{G}} \tag{2i}$$

$$d_{jc}(t) \leq d_{jc}^{\max}(t) \quad : \zeta_{jc}^{\max}(t)\, \forall c \in \Omega_j, j \in \Omega^{\mathrm{D}} \tag{2j}$$

$$\theta_s(t) \leq \pi \quad : \eta_s^{\max}(t)\, \forall s \in \Pi \backslash s : \text{reference bus} \tag{2k}$$

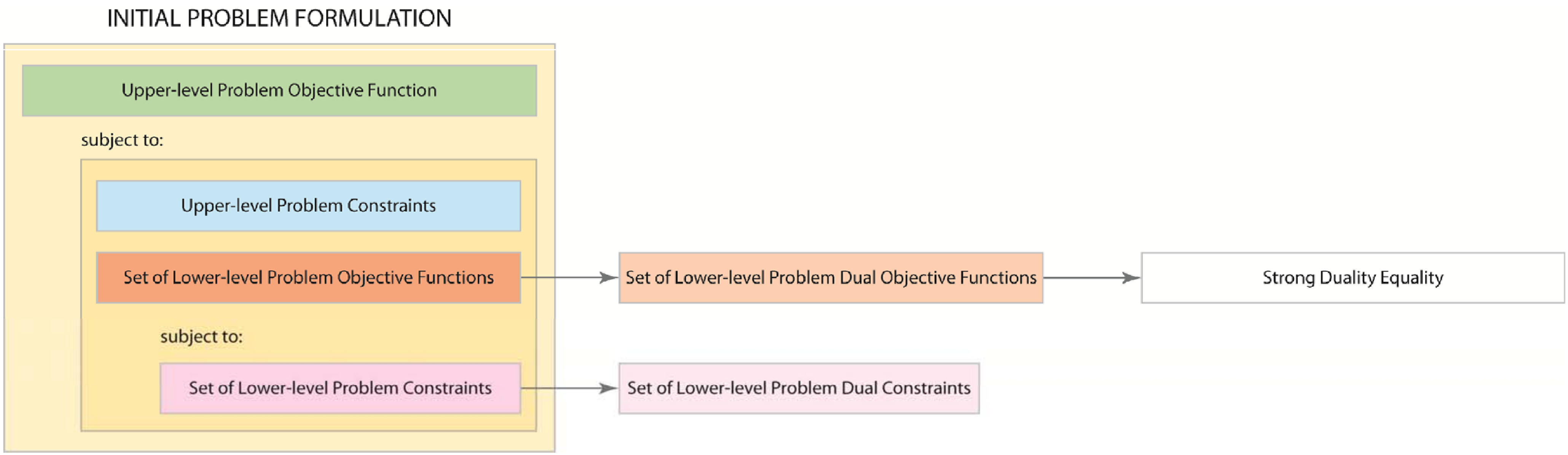
$$\theta_s(t) \geq -\pi \quad : \eta_s^{\min}(t)\, \forall s \in \Pi \backslash s : \text{reference bus} \tag{2l}$$

$$\theta_s(t) = 0 \quad : \xi(t)\, s : \text{reference bus} \tag{2m}$$

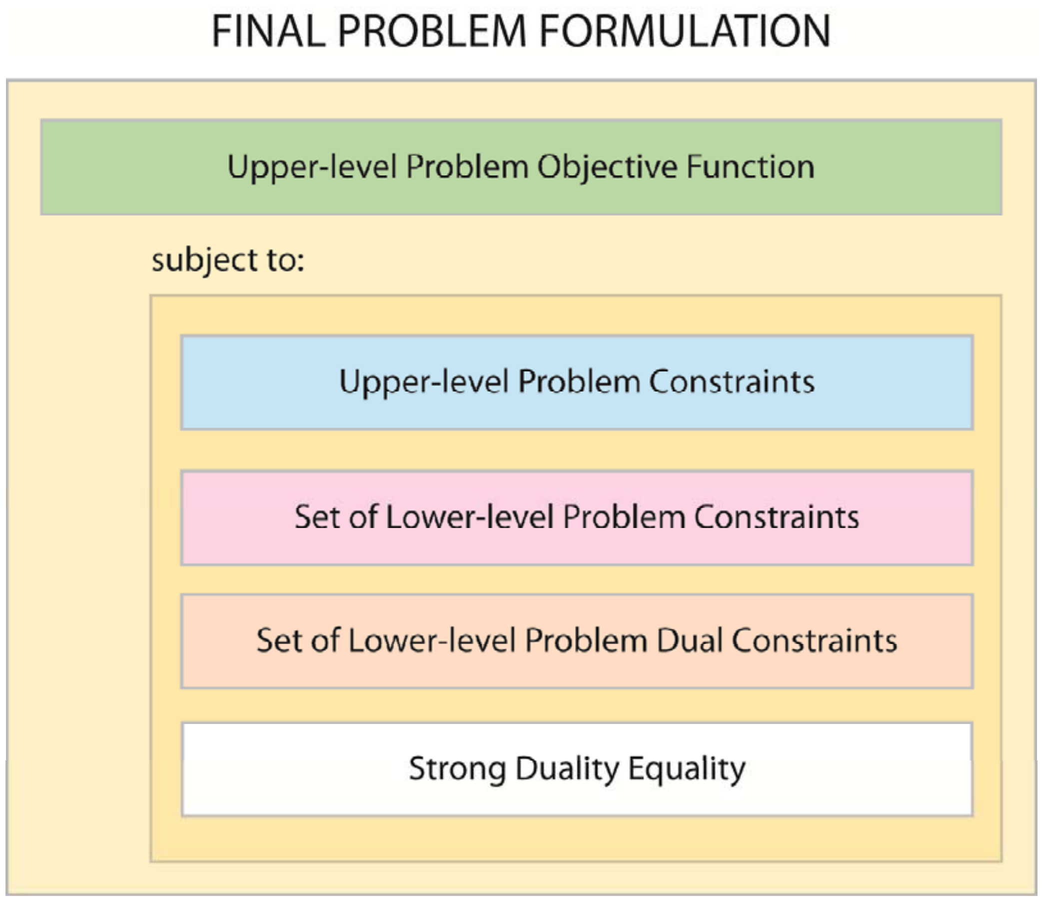
$$g_{ib}(t) \geq 0 \quad \forall b \in \Omega_i, i \in \Omega^{\mathrm{G}} \tag{2n}$$

$$d_{jc}(t) \geq 0 \quad \forall c \in \Omega_j, j \in \Omega^{\mathrm{D}} \tag{2o}$$

Početna struktura problema



Konačna struktura problema



Lower-level problem dual constraints

$$-\alpha_{s(j)}(t) + \zeta_{jc}^{\max} \geq \lambda_{Djc} \quad \forall c, j \tag{3b}$$

$$\alpha_{s(i)}(t) + \gamma_{ib}^{\max} \geq -\lambda_{Gib} \quad \forall b, i \tag{3c}$$

$$\begin{aligned} &-\alpha_{o(l)}(t) + \alpha_{d(l)}(t) + \beta_l(t) + \beta_l^{\max}(t) + \beta_l^{\min}(t) + \\ &+ \kappa_l(t) + \kappa_l^{\max}(t) + \kappa_l^{\min}(t) = 0 \quad \forall l \end{aligned} \tag{3d}$$

$$\begin{aligned} &- \sum_{l|o(l)=s} b_l \cdot \left(1 - x_l(t)\right) \cdot \beta_l(t) + \\ &+ \sum_{l|d(l)=s} b_l \cdot \left(1 - x_l(t)\right) \cdot \beta_l(t) - \\ &- \sum_{l|o(l)=s} b_l \cdot \kappa_l(t) + \sum_{l|d(l)=s} b_l \cdot \kappa_l(t) + \eta_s^{\max}(t) + \\ &+ \eta_s^{\min}(t) = 0 \quad \forall s \in \Pi \backslash s : \text{reference bus} \end{aligned} \tag{3e}$$

Lower-level problem dual constraints

$$\begin{aligned}
&- \sum_{l|o(l)=s} b_l \cdot \left(1 - x_l\left(t\right)\right) \cdot \beta_l\left(t\right) + \\
&+ \sum_{l|d(l)=s} b_l \cdot \left(1 - x_l\left(t\right)\right) \cdot \beta_l\left(t\right) - \\
&- \sum_{l|o(l)=s} b_l \cdot \kappa_l\left(t\right) + \sum_{l|d(l)=s} b_l \cdot \kappa_l\left(t\right) + \\
&+ \xi_s\left(t\right) = 0 \quad s : \text{reference bus}
\end{aligned} \tag{3f}$$

$$\alpha_s\left(t\right) \quad \text{free} \quad \forall s \tag{3g}$$

$$\beta_l\left(t\right) \quad \text{free;} \quad \beta_l^{\max}\left(t\right) \geq 0; \quad \beta_l^{\min}\left(t\right) \leq 0 \quad \forall s \tag{3h}$$

$$\kappa_l\left(t\right) \quad \text{free;} \quad \kappa_l^{\max}\left(t\right) \geq 0; \quad \kappa_l^{\min}\left(t\right) \leq 0 \quad \forall s \tag{3i}$$

Lower-level problem dual constraints

$$\gamma_{ib}^{\max}(t) \geq 0 \quad \forall b, i \tag{3j}$$

$$\zeta_{jc}^{\max}(t) \geq 0 \quad \forall c, j \tag{3k}$$

$$\eta_{s}^{\max}(t) \geq 0; \quad \eta_{s}^{\min}(t) \leq 0 \quad \forall s \tag{3l}$$

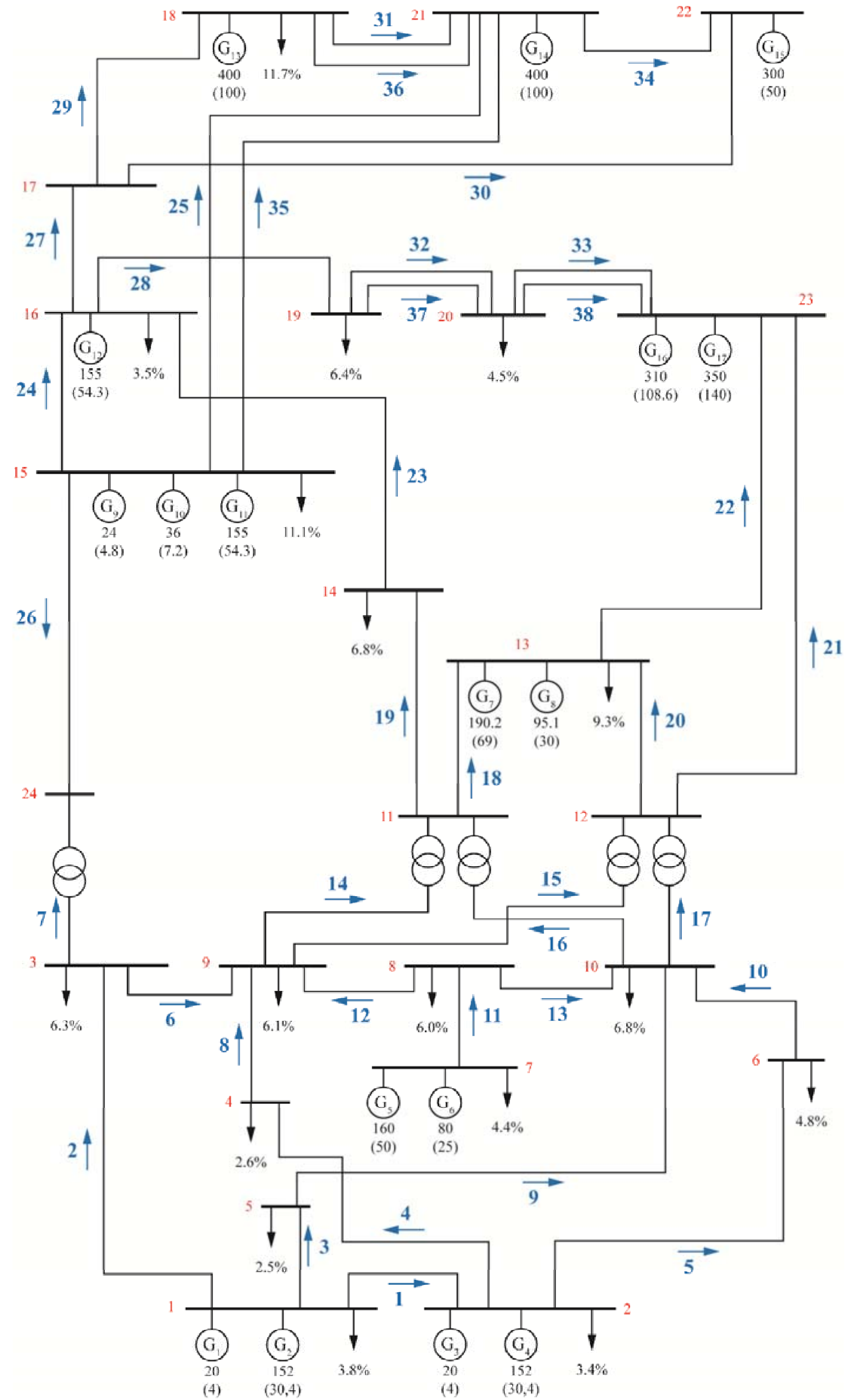
$$\xi(t) \quad \text{free} \quad s : \text{reference bus} \tag{3m}$$

Strong duality equality

$$
\begin{aligned}
&\sum_{j\in\Omega^{\mathrm{D}}}\sum_{c\in\Omega_j}\lambda_{Djc}(t)\cdot d_{jc}(t)-\\
&-\sum_{i\in\Omega^{\mathrm{G}}}\sum_{b\in\Omega_i}\lambda_{Gib}(t)\cdot g_{ib}(t)=\\
&=\sum_{l\in\Omega^{\mathrm{M}}}\left(\beta_l^{\max}(t)-\beta_l^{\min}(t)\right)\cdot p_l^{\max}+\\
&+\sum_{l\in\Omega^{\mathrm{NM}}}\left(\kappa_l^{\max}(t)-\kappa_l^{\min}(t)\right)\cdot p_l^{\max}+\\
&+\sum_{i\in\Omega^{\mathrm{G}}}\sum_{b\in\Omega_i}\gamma_{ib}^{\max}(t)\cdot g_{ib}^{\max}(t)+\\
&+\sum_{j\in\Omega^{\mathrm{D}}}\sum_{c\in\Omega_j}\varsigma_{jc}^{\max}(t)\cdot d_{jc}^{\max}(t)+\\
&+\sum_{s\in\Pi}\left(\eta_s^{\max}(t)-\eta_s^{\min}(t)\right)\cdot\pi
\end{aligned}
$$

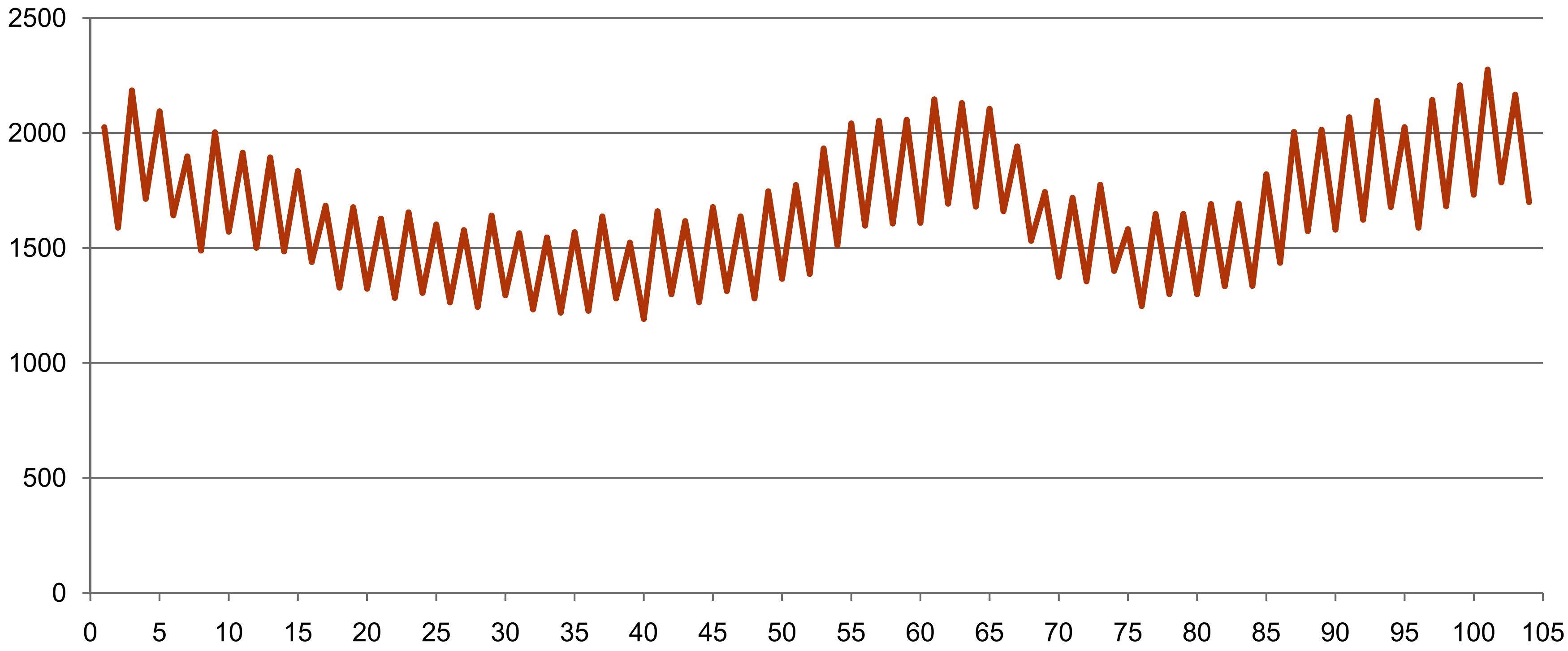
Case study

- Modificirana IEEE 24-bus mreža:
  - 38 vodova
  - 17 generatora
  - 17 tereta



Opterećenje u sustavu

- Godina podijeljena na 104 perioda:
  - radni dio tjedna (52)
  - vikend (52)



Ulazni podaci

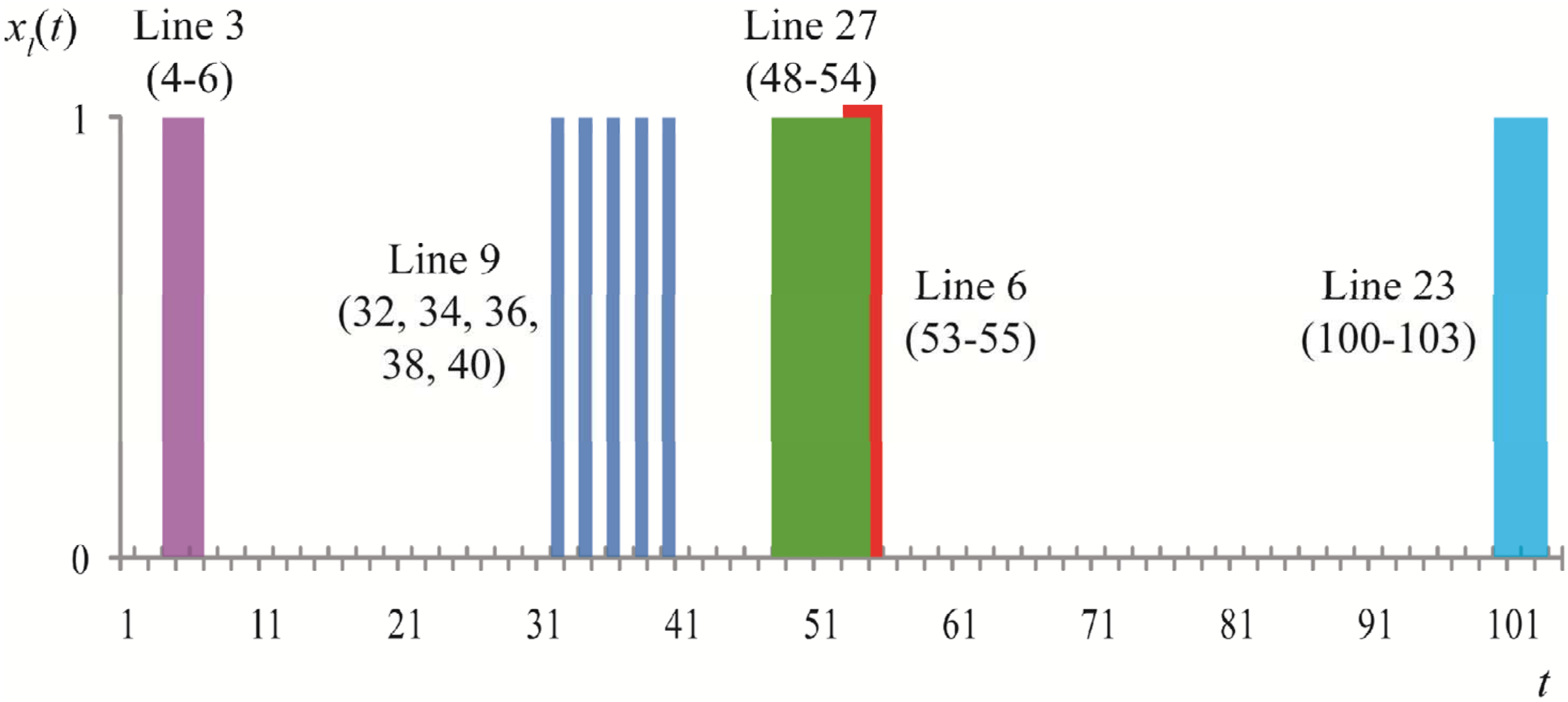
- Topologija mreže
- Susceptancije i kapaciteti vodova
- Ponuđeni blokovi generatora
- Ukupno opterećenje sustava za svako vremensko razdoblje
- Distribucija opterećenja po sabirnicama
- Težinski faktori (važnost) vodova
- Granice razina opterećenja vodova te težinski faktori

Zahtjevi održavanja

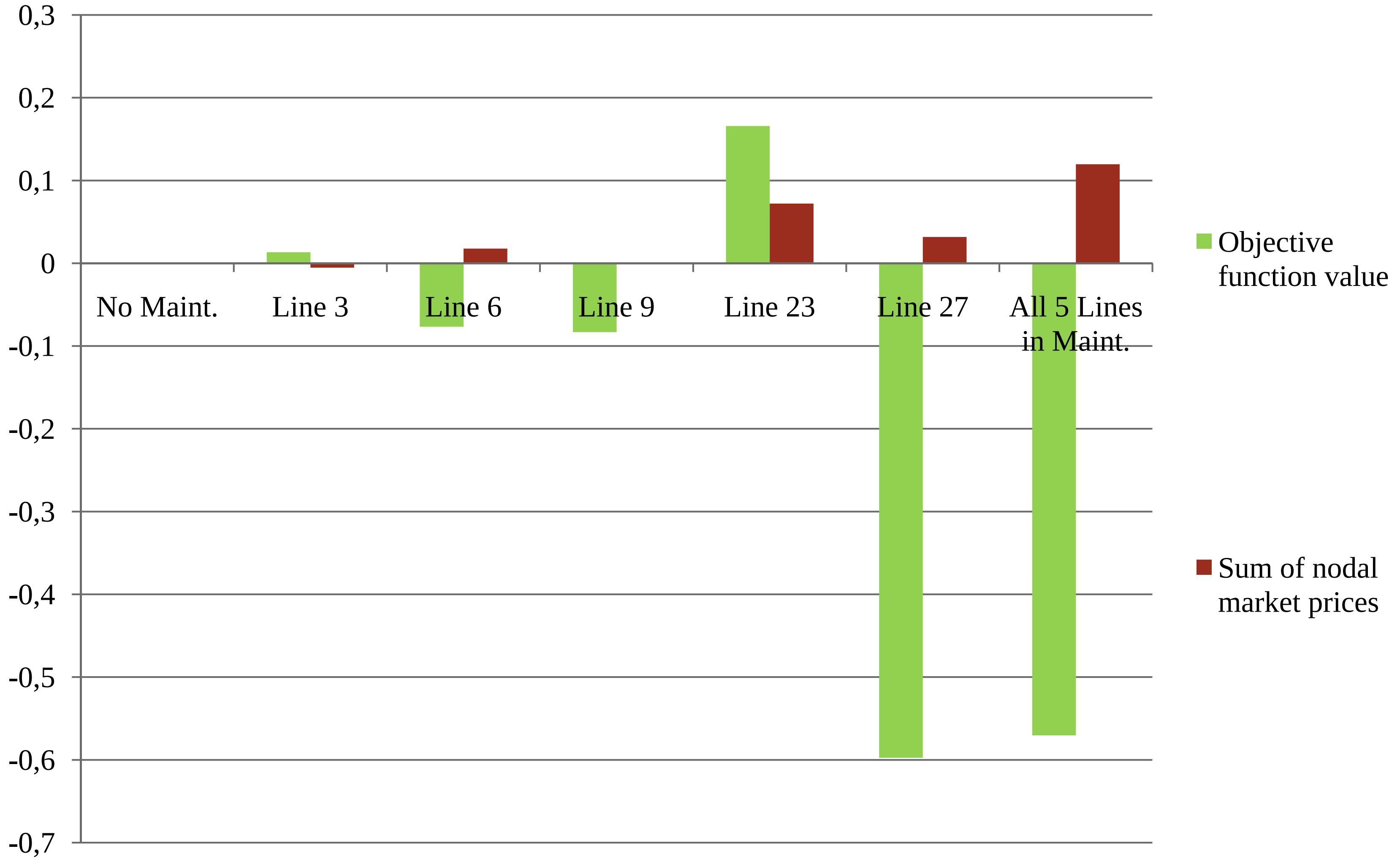
Line	3	6	9	23	27
Number of working week periods	1	2	0	2	3
Number of weekend periods	2	1	5	2	4
Exclusion constraints	-	-	-	-	-
Priority constraints	Before line 9	-	After line 3	-	-
Time periods overlap constraints	-	First 2 with line 27	-	-	Last 2 with line 6

Rezultat

- Optimalni raspored održavanja:



Analiza



0,3
0,2
0,1
0
-0,1
-0,2
-0,3
-0,4
-0,5
-0,6
-0,7
No Maint.
Line 3
Line 6
Line 9
Line 23
Line 27
All 5 Lines in Maint.
Objective function value
Sum of nodal market prices

Doprinosi istraživanja

- Formulacija problema održavanja vodova u tržišnim uvjetima
- Primjena bilevel programiranja na problem održavanja u elektroenergetici
- Linearizacija funkcije cilja i ograničenja u podproblemu
- Podjela na radni dio tjedna i vikend

FER vs. UCLM

- UCLM:
  - stipendija na 4 godine
  - ne drže nastavu
  - tijekom doktorata odlazak na bar 2 strana sveučilišta
  - iznimno kvalitetni doktorati s međunarodnom komisijom
  - slabo poznaju struku

Motivacija

- Osobna:
  - skupljena golema količina znanja i iskustva
  - osnova za doktorsku disertaciju
  - daljnja suradnja
- FER:
  - međunarodna suradnja
  - prijenos znanja na studente
  - objava radova

Ali najvažnije…

- … neprocjenjivo iskustvo i prijatelji