Effect of Voltage Constraints on the Exchange of Flexibility Services in Distribution Networks

S. Mathieu
F. Olivier
D. Ernst
B. Cornélusse
University of Liège, Belgium

LIÈGE université

IEEE PES Power & Energy Society®

IEEE

Introduction

- European energy sector and regulation
- Gredor project
  - Collaborative project with actors of Belgian electricity sector (TSO, 2 DSO, producers and retailers)
  - Think about new ways to operate the distribution sytems of the future, from investment planning to real-time control

GREDOR

Gestion des Réseaux Electriques de Distribution Ouverts aux Renouvelables

Unbundling in Europe Energy Sector

- A DSO cannot
  - directly control the production means connected to its network
  - be a retailer
- European directive (Article 26 of the directive 2009/72/EC)

2. In addition to the requirements under paragraph 1, where the distribution system operator is part of a vertically integrated undertaking, it shall be independent in terms of its organisation and decision-making from the other activities not related to distribution. In order to achieve this, the following minimum criteria shall apply:

(c) the distribution system operator must have effective decision-making rights, independent from the integrated electricity undertaking, with respect to assets necessary to operate, maintain or develop the network. In order to fulfil those

Fit and forget Vs.Transactive energy

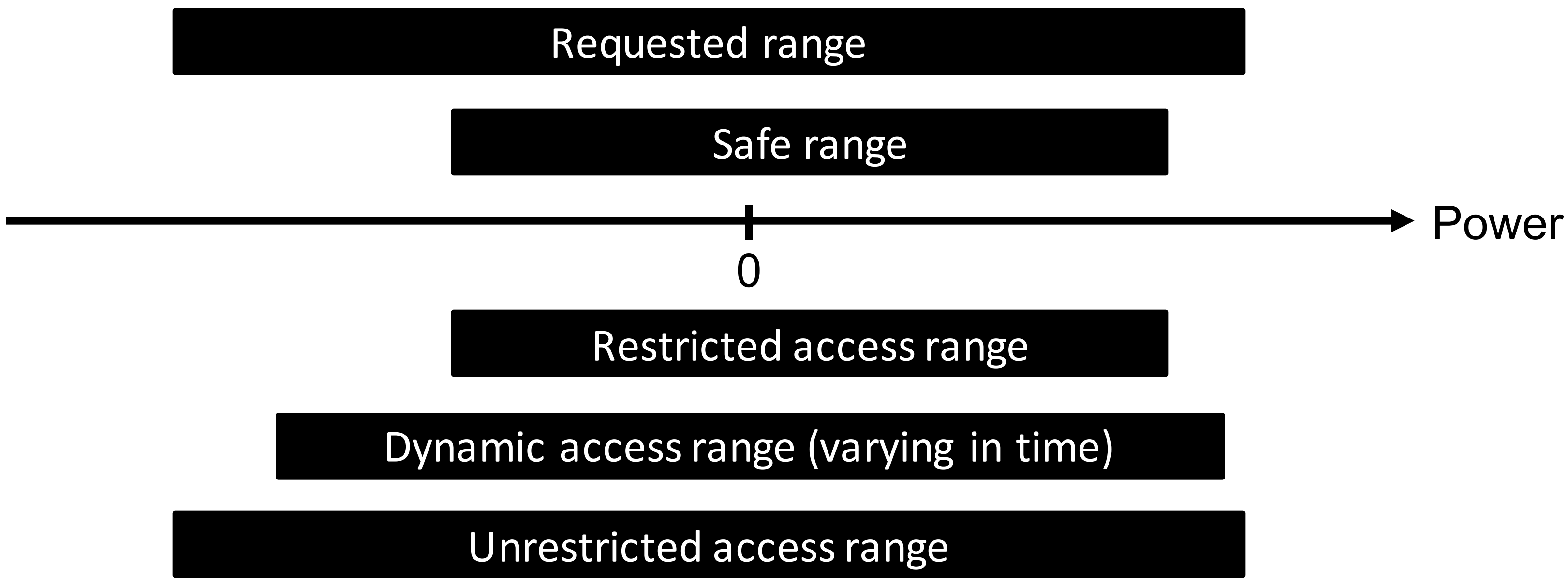
- Fit and forget
  - Network planning based on critical scenarios
  - Operational margins always ensured without control over the loads or the generation sources
  - May lead to prohibitive reinforcement costs
- Transactive energy (active network management)
  - Network planning using the flexibility services proviced by generation sources, loads and storage

Flexibility services covered by

Interaction models

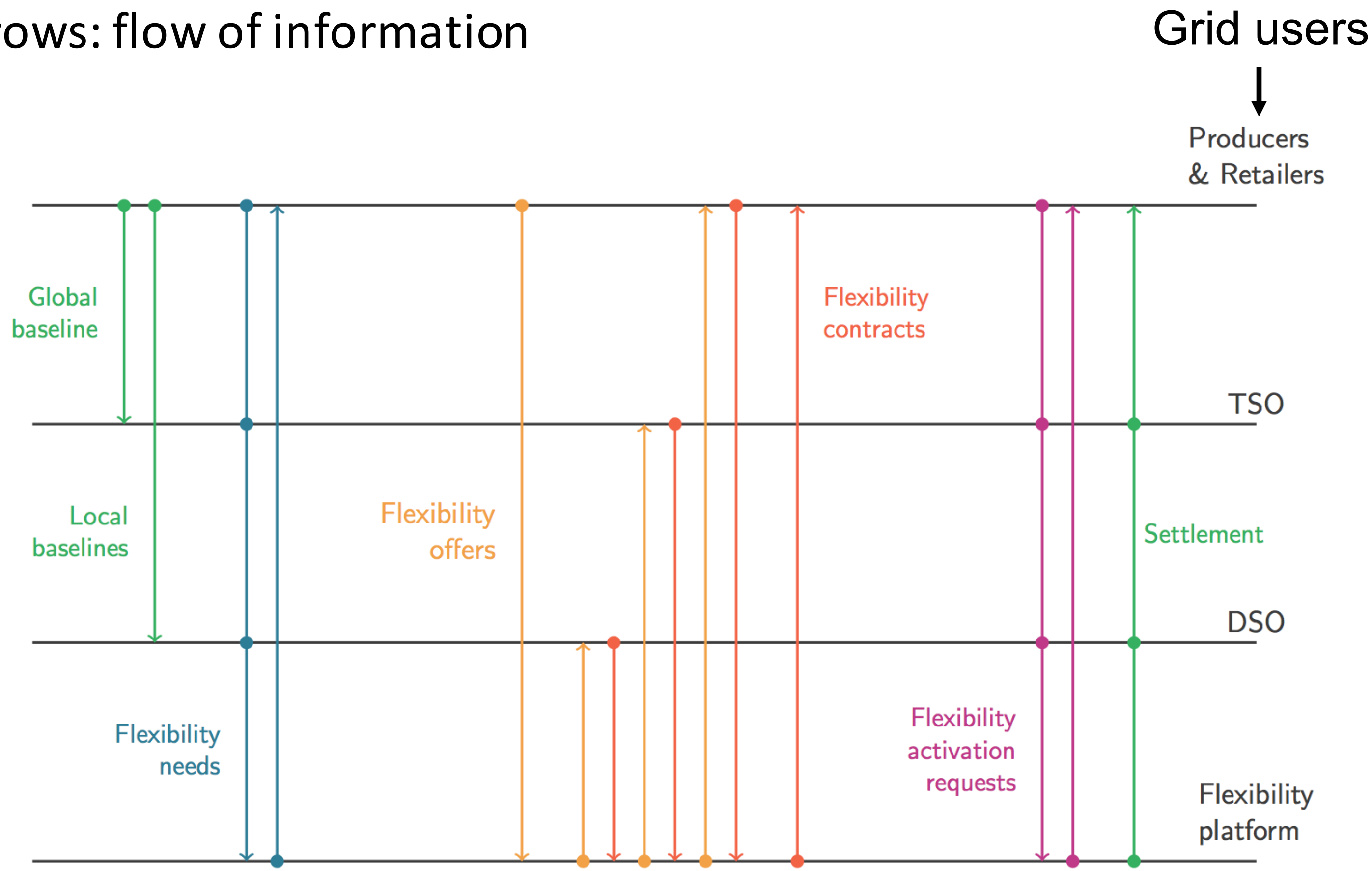
Framework defining the interactions between the actors

Access bounds and access contracts



Flow of interactions

- Bullets: optimization problems
- Arrows: flow of information



A day in the life of a grid user

1. Sends its baseline to the TSO and DSO
2. Obtains flexibility needs of the flexibility service users
3. Proposes flexibility offers
4. Receives activation requests
5. Decides the final realizations

Studied interaction models

	Model 0	Model 1	Model 2
Access type	Restricted	Dynamic	Unrestricted
Financial compensation	None	None	Full

Full financial compensation:

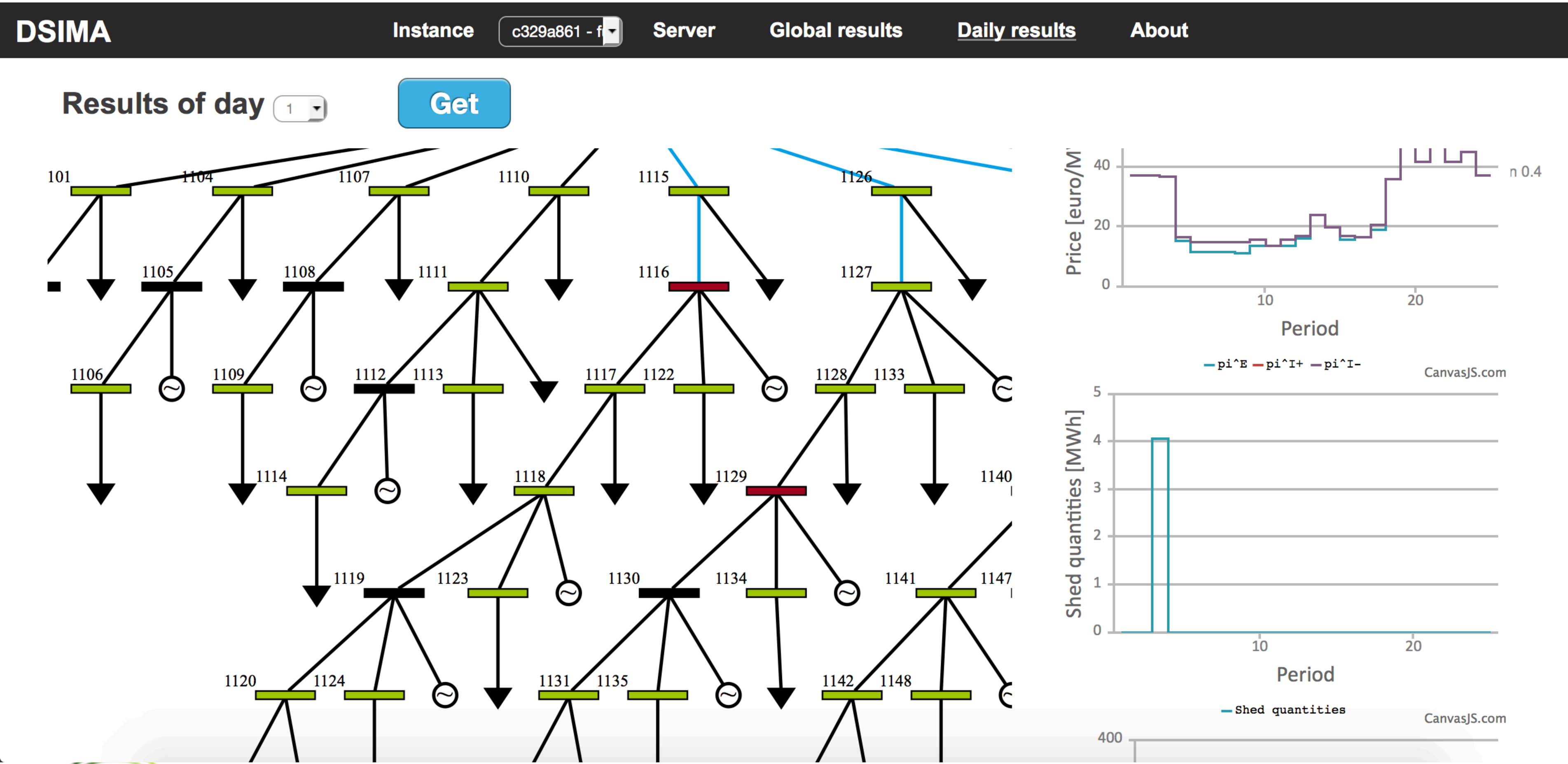
- DSO pays a reservation and activation cost
- DSO pays for the resulting imbalance cost caused by the activation of flexibility services

DSIMA

- Distribution System Interaction Model Analysis
- Open source test bed available at http://www.montefiore.ulg.ac.be/~dsima/
- Implemented in Python
- Every agent modelled individually with mixed-integer linear programs
- Optimization written in ZIMPL and optimized using SCIP

DSIMA

- HTML interface to visualize the results

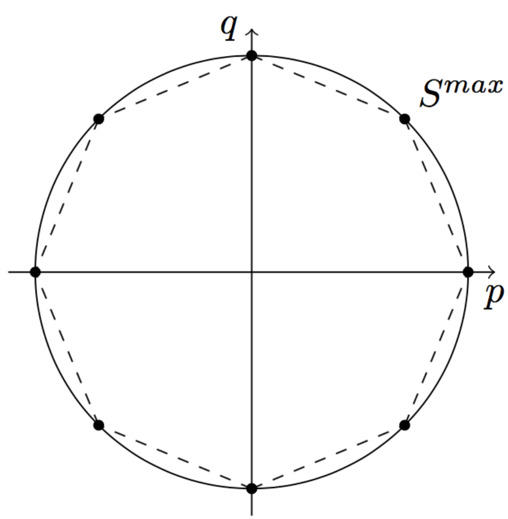


Network flow Vs. Linear power flow

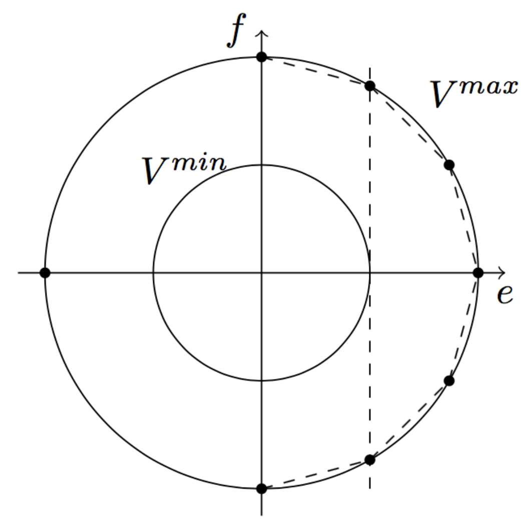
- Network flow
  - Takes into consideration line capacity constraints
- Linear power flow
  - Takes into consideration line capacity and voltage constraints, but neglect losses
  - S. Bolognani and S. Zampieri, “On the existence and linear approximation of the power flow solution in power distribution networks,” *IEEE Trans. on Power Systems*, no. 99, 2015
  - Bounded approximation error

Linearizing constraints

- Maximum power constraints
- Minium and maximum voltages constraints



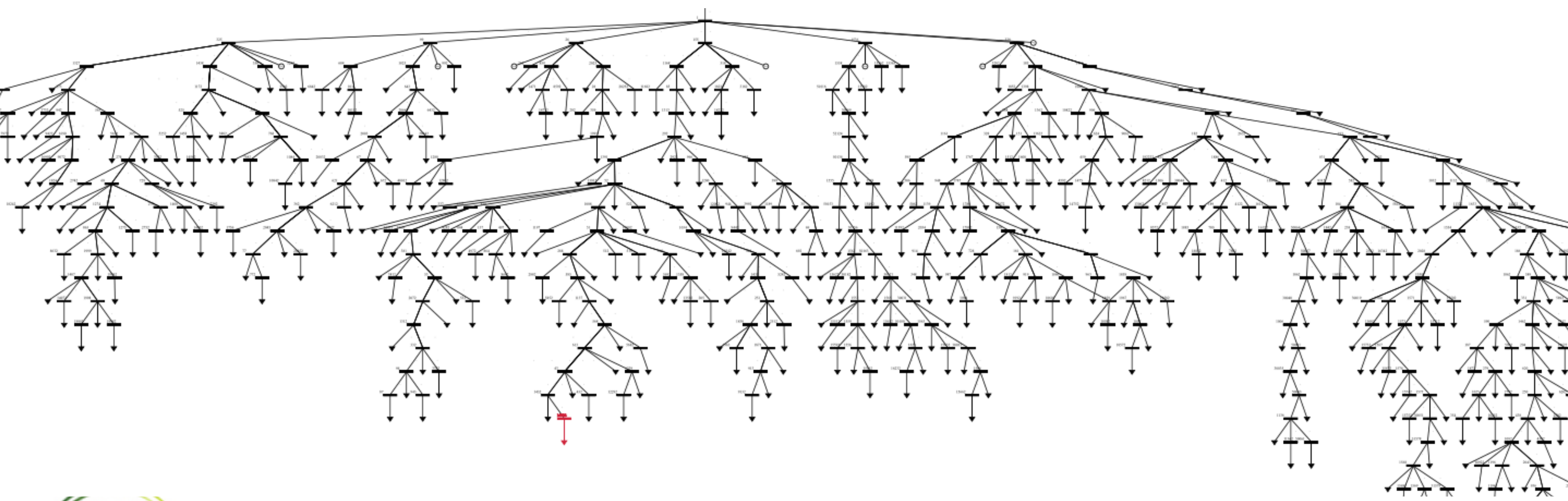
Conservative error of 1.92% with 4 cutting points



Conservative error of 3.5% with a voltage angle of 15°

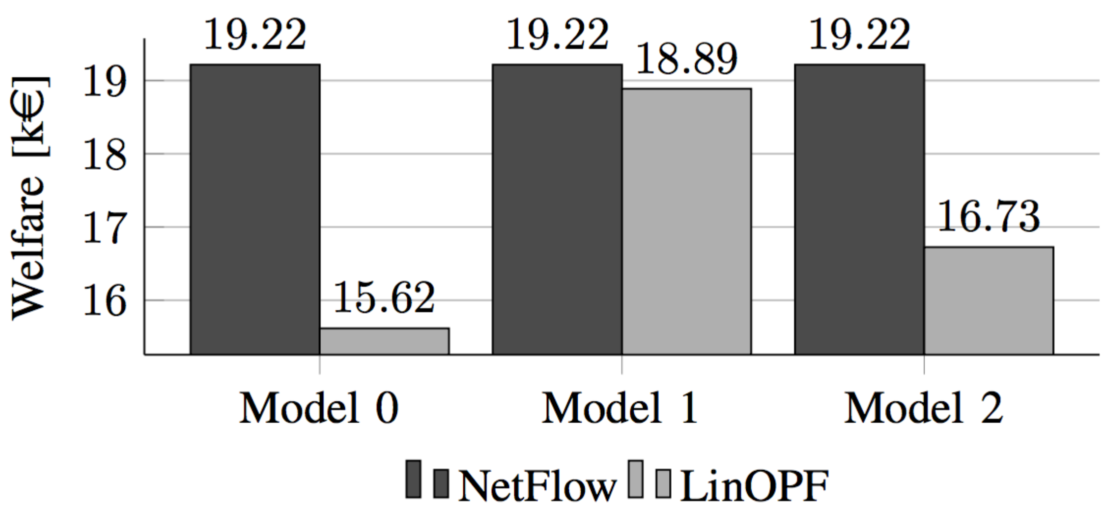
Test system

- Test system based on a real MV distribution network from ORES (Belgium DSO)
- 328 MV buses

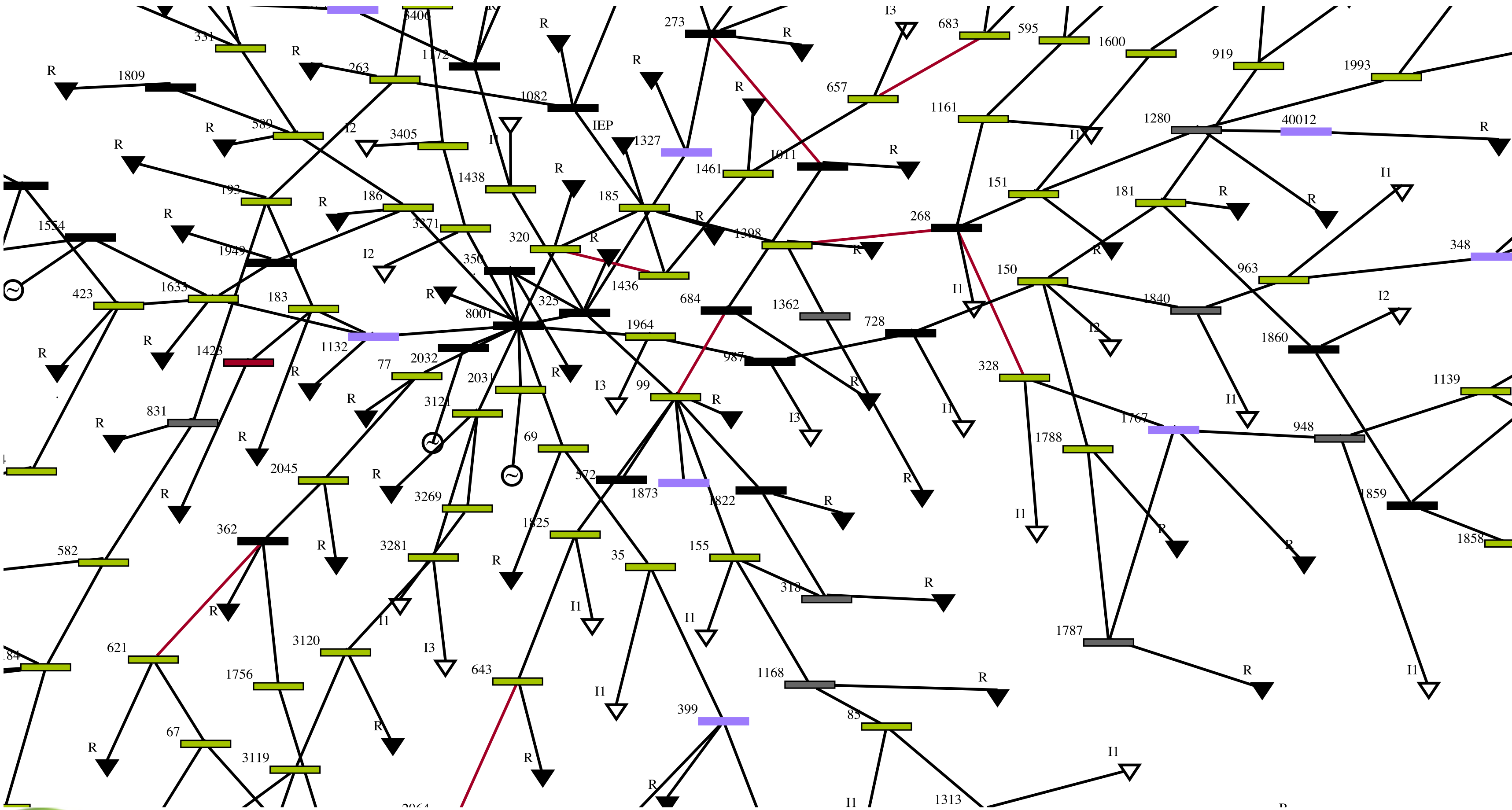


Results – Welfare

Sum of the benefits and costs of each actor with their sign, and a protection cost
(penalty for under and over-voltages, cost of shedding)



Results



331
1809
263
1172
1082
273
683
595
1600
919
1993
589
3405
IEP
1327
657
1161
1280
40012
193
186
1438
1461
1011
151
181
1554
3371
185
268
1949
320
1398
348
963
423
1633
183
350
1436
150
1840
8001
325
684
1362
728
1860
1423
1132
1964
2032
77
2031
987
328
1139
831
3121
99
1767
948
1788
69
2045
3269
372
1873
1822
1859
362
1825
582
3281
35
155
1858
318
3120
621
1787
1756
643
1168
67
399
3119
1313

Conclusion

- With voltage constraints
  - Weaknesses in model 0 and 2 (restricted and unrestricted)
  - Model 0 is too restrictive
  - Model 2 is too permissive
- Motivates the use of model 1 (dynamic) as a solution in-between
  - All problems are not solved using flexibility
  - Some reinforcement necessary
  - Can be identified with the simulations

Results breakdown

	Model 0		Model 1		Model 2		
	Netflow	*LinOPF*	*Netflow*	*LinOPF*	*Netflow*	*LinOPF*	
Welfare	19216	15616	19216	18888	19216	16725	€
Protections cost	0	318	0	283	0	2393	€
DSOs costs	0	0	0	0	0	0	€
TSOs surplus	-2349	-2492	-2349	-2376	-2349	-2349	€
Producers surplus	19010.6	15891.8	19010.6	19007.7	19010.6	19059.7	€
Retailers surplus	2554.06	2534.31	2554.06	2535.32	2554.06	2407.57	€
Total production	633.14	501.1	633.14	624.22	633.14	629.05	MWh
Total consumption	-1142.74	-1141.4	-1142.74	-1141.53	-1142.74	-1133.44	MWh
Total imbalance	0	0.32	0	0.28	0	1.58	MWh
Max. imbalance	0	0.03	0	0.03	0	0.29	MW
Total usage of flex.	29.63	26.82	29.63	27.42	29.63	29.63	MWh
Total energy shed	0	-0.32	0	-0.28	0	-1.3	MWh

Protection cost and quality of service

- Shedding of MV buses
  - Value of Lost Load (VOLL)
  - VOLL: 1000 €/MWh
- Under- and Over-voltages
  - Base power: Sb: 100 MVA
  - Base voltage: Vb: 10 kV
  - VOLL*Sb/Vb = 10 000 €/kV
  - ± 5% voltage variations