



First ELECON Workshop Towards Efficient European and Brazilian Electricity Markets

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Ancillary Services Market

- **Ancillary Services**
 - Concepts
- **Proposed methodologies**
 - Ancillary Services market
 - Energy and ancillary services joint market
- **Case Study**
- **Conclusions**

Ancillary services are **all services required** by the transmission or distribution **system operator** to enable them to **maintain** the integrity and **stability** of the transmission or distribution **system** as well as the **power quality**.

EURELECTRIC 2004

- **Ancillary Services market**

- Regulation Down
- Regulation Up
- Spinning Reserve
- Non-Spinning Reserve

- **Joint Market**

- Energy
- Ancillary Services

- **AS Cascading process**



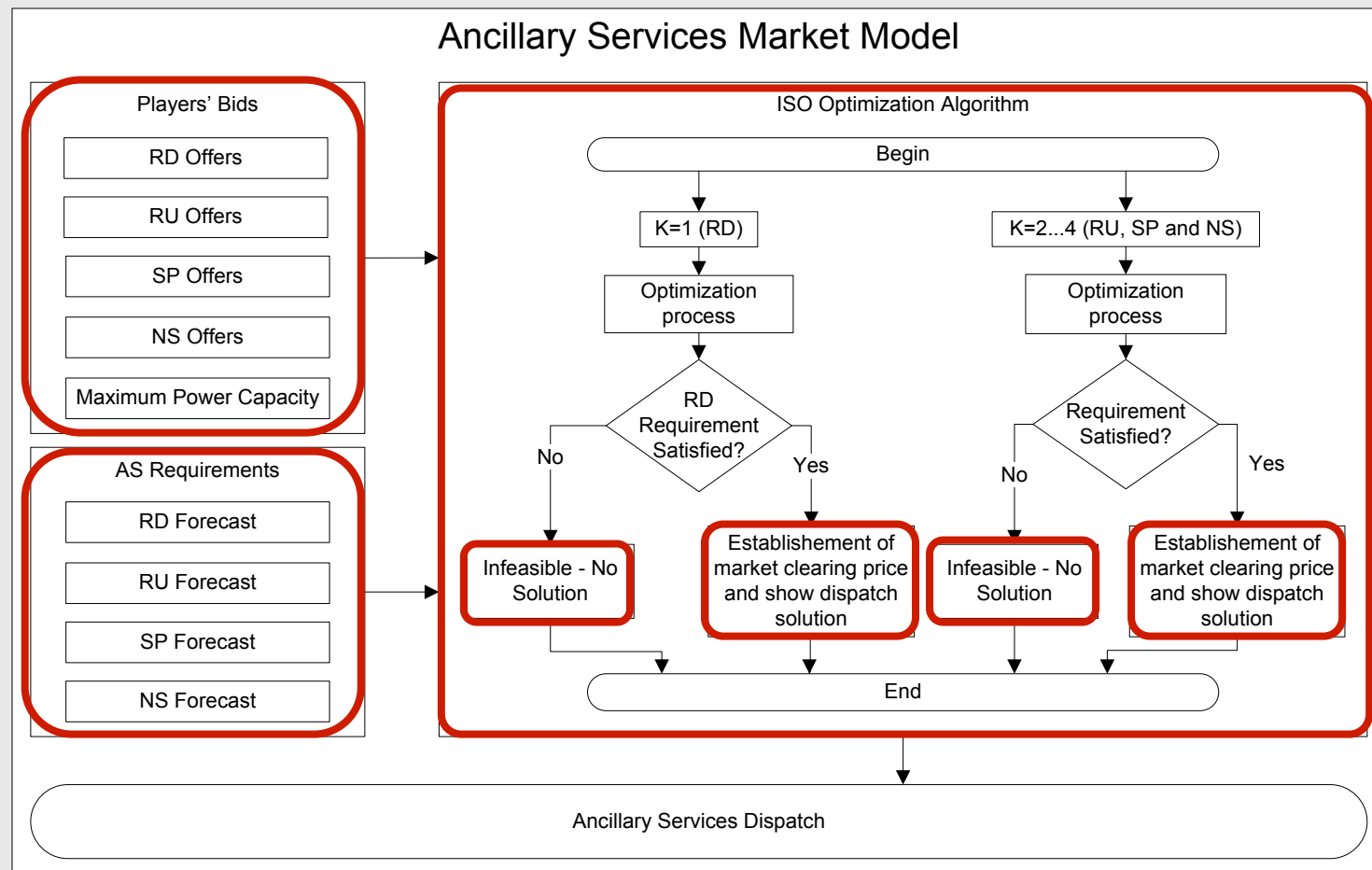
- **Relaxation Variables**

- RLXD – used when there is insufficient generation to meet the requirement
- RLXU – used when there is excess of generation

Proposed methodologies

| Characteristics | Model | |
|--------------------------|--|--|
| | Ancillary Service Market | Energy and AS joint market |
| Market model | AS market | Joint Market |
| AS cascading process | Yes | Yes |
| Network operation | No | No |
| Resource management goal | Minimization of ISO operation costs | Market clearing price |
| AS bidding regions | No | No |
| Relaxation variables | Ensured by ISO through bilateral contracts | Ensured by ISO through bilateral contracts |
| Complex Contracts | No | No |

Model diagram



■ Mathematical formulation

- Objective function

**Generation
resources**

**Relaxation
variables**

Minimize OC =

$$\sum_{t=1}^T \left[\sum_{k=1}^{N_K} \sum_{r=1}^{N_R} \left(P_{S(r,k,t)} \times C_{S(r,k,t)}^{\max} + RLXD_{(k,t)} \times W_{RLXD(k,t)} + RLXU_{(k,t)} \times W_{RLXU(k,t)} \right) \right]$$

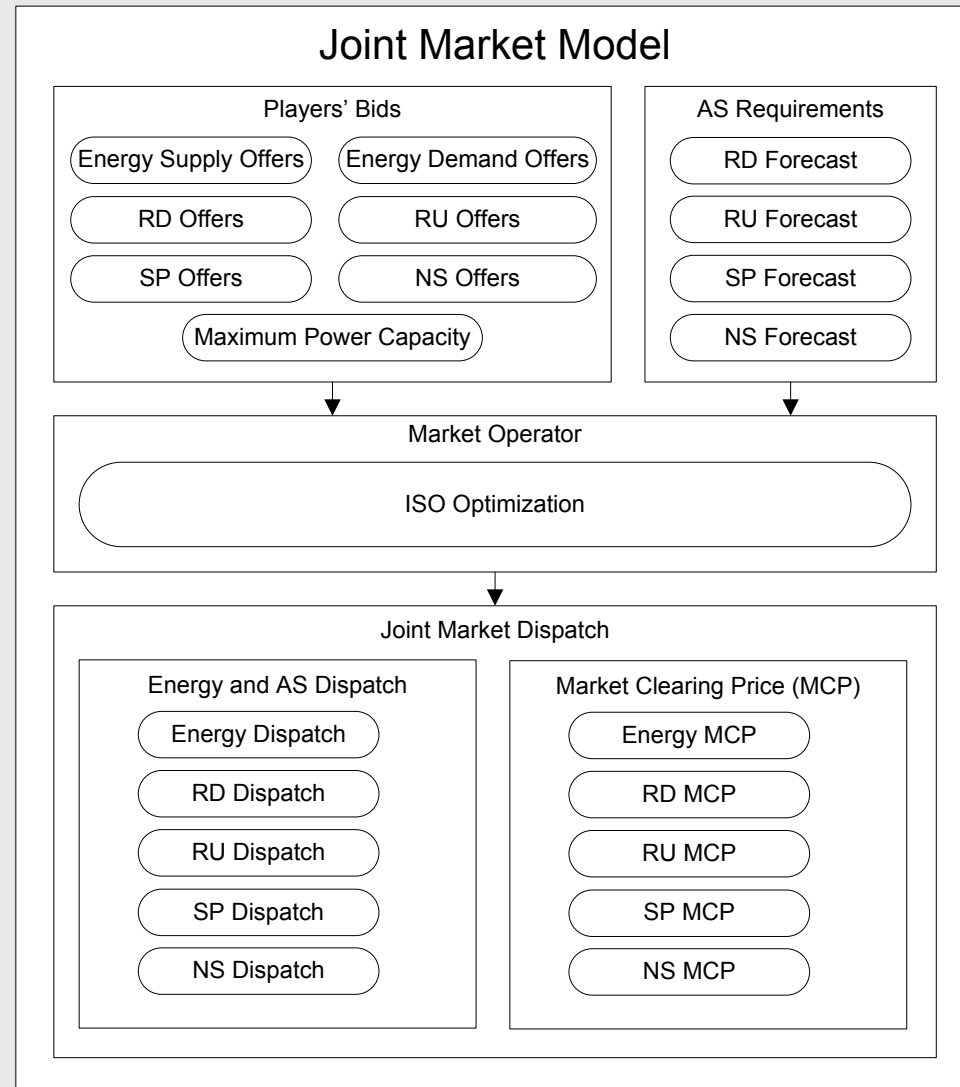
■ Problem constraints

- Minimum and maximum limits of active power for AS
- Maximum overall capacity
- Ancillary services power balance
- AS cascading mechanism
- Relaxation variables

Proposed methodologies

| Characteristics | Model | |
|--------------------------|--|--|
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| Complex Contracts | No | No |

■ Model diagram



■ Mathematical formulation

- Objective function

Generation resources

Relaxation variables

Minimize OC =

$$\sum_{t=1}^T \left[\sum_{k=1}^{N_K} \sum_{r=1}^{N_R} \left(P_{S(r,k,t)} \times C_{S(r,k,t)}^{\max} + RLXD_{(k,t)} \times W_{RLXD(k,t)} + RLXU_{(k,t)} \times W_{RLXU(k,t)} \right) - \sum_{l=1}^{N_L} P_{b(l,t)} \times C_{b(l,t)}^{\max} \right]$$

Demand bids

■ Problem constraints

- Demand bids limits

| Characteristics | Model | |
|--------------------------|--|--|
| | Ancillary Service Market (Case Study 1) | Energy and AS joint market (Case Study 2) |
| Market model | AS market | Joint Market |
| Bids | Asymmetric Market | Symmetric Market |
| AS cascading process | Yes | Yes |
| Network operation | No | No |
| Resource management goal | Minimization of ISO operation costs | Market Clearing Price |
| AS bidding regions | No | No |
| Relaxation variables | Ensured by ISO through bilateral contracts | Ensured by ISO through bilateral contracts |
| Complex Contracts | No | No |

■ Input data

| Regulation Down | | | Regulation Up | | | Spinning Reserve | | | Non-Spinning Reserve | | | Maximum Capacity | Minimum Requirement | Maximum Requirement |
|-----------------------|-----------------------|----------------------|-----------------------|-----------------------|----------------------|-----------------------|-----------------------|----------------------|-----------------------|-----------------------|----------------------|------------------|---------------------|---------------------|
| Minimum quantity (MW) | Maximum quantity (MW) | Bid price (m.u./MWh) | Minimum quantity (MW) | Maximum quantity (MW) | Bid price (m.u./MWh) | Minimum quantity (MW) | Maximum quantity (MW) | Bid price (m.u./MWh) | Minimum quantity (MW) | Maximum quantity (MW) | Bid price (m.u./MWh) | (MW) | (MW) | (MW) |
| 70 | 85 | 10.0 | 80 | 85 | 5.0 | 80 | 85 | 10.5 | 95 | 98 | 10.0 | 280 | 150 | 500 |
| 80 | 85 | 8.0 | 70 | 85 | 4.5 | 70 | 85 | 9.2 | 45 | 60 | 11.0 | 250 | 200 | 400 |
| 55 | 85 | 8.0 | 80 | 85 | 5.2 | 80 | 85 | 8.5 | 70 | 70 | 10.2 | 290 | 150 | 200 |
| 60 | 85 | 4.0 | 50 | 85 | 5.0 | 50 | 85 | 8.3 | 41 | 60 | 10.6 | 250 | 150 | 200 |
| 100 | 111 | 3.5 | 65 | 85 | 6.3 | 65 | 85 | 8.9 | 45 | 60 | 9.0 | 255 | | |
| 20 | 85 | 9.0 | 50 | 85 | 6.0 | 50 | 85 | 8.8 | 18 | 60 | 11.0 | 245 | | |
| 40 | 85 | 7.0 | 98 | 99 | 7.5 | 98 | 99 | 9.3 | 24 | 60 | 10.5 | 265 | | |
| 10 | 85 | 4.8 | 100 | 120 | 6.5 | 100 | 120 | 8.6 | 80 | 81 | 10.4 | 330 | | |
| 40 | 85 | 9.0 | 110 | 130 | 5.5 | 110 | 111 | 8.3 | 80 | 81 | 10.3 | 350 | | |
| 15 | 85 | 10.0 | 40 | 85 | 4.0 | 40 | 85 | 8.0 | 90 | 91 | 9.0 | 280 | | |

Results – Baseline

| Bids | Regulation Down | | Regulation Up | | Spinning Reserve | | Non-Spinning Reserve | | Total (MW) |
|----------------------------------|-----------------|----------|---------------|----------|------------------|----------|----------------------|----------|--------------|
| | MW | m.u./MWh | MW | m.u./MWh | MW | m.u./MWh | MW | m.u./MWh | |
| 1 | 0 | 10.0 | 0 | 5.0 | 0 | 10.5 | 0 | 10.0 | 0 |
| 2 | 0 | 8.0 | 70 | 4.5 | 0 | 9.2 | 0 | 11.0 | 70 |
| 3 | 0 | 8.0 | 0 | 5.2 | 0 | 8.5 | 0 | 10.2 | 0 |
| 4 | 0 | 4.0 | 50 | 5.0 | 65 | 8.3 | 0 | 10.6 | 115 |
| 5 | 111 | 3.5 | 0 | 6.3 | 0 | 8.9 | 59 | 9.0 | 59 |
| 6 | 0 | 9.0 | 0 | 6.0 | 0 | 8.8 | 0 | 11.0 | 0 |
| 7 | 0 | 7.0 | 0 | 7.5 | 0 | 9.3 | 0 | 10.5 | 0 |
| 8 | 39 | 4.8 | 0 | 6.5 | 0 | 8.6 | 0 | 10.4 | 0 |
| 9 | 0 | 9.0 | 0 | 5.5 | 0 | 8.3 | 0 | 10.3 | 0 |
| 10 | 0 | 10.0 | 80 | 4.0 | 85 | 8.0 | 91 | 9.0 | 256 |
| Contracted Service (MW) | 150 | | 200 | | 150 | | 150 | | 650 |
| Service Requirement (MW) | 150 | | 200 | | 150 | | 150 | | 650 |
| Market Clearing Price (m.u./MWh) | 4.8 | | 5.0 | | 8.3 | | 9.0 | | Total (m.u.) |
| Total Cost (m.u.) | 720 | | 1000 | | 1245 | | 1350 | | 4315 |

Results – With Cascade

| Bids | Regulation Down | | Regulation Up | | Spinning Reserve | | Non-Spinning Reserve | | Total (MW) |
|----------------------------------|-----------------|----------|---|----------|-----------------------------|----------|----------------------|----------|--------------|
| | MW | m.u./MWh | MW | m.u./MWh | MW | m.u./MWh | MW | m.u./MWh | |
| 1 | 0 | 10.0 | 80 | 5.0 | 0 | 10.5 | 0 | 10.0 | 80 |
| 2 | 0 | 8.0 | 85 | 4.5 | 0 | 9.2 | 0 | 11.0 | 85 |
| 3 | 0 | 8.0 | 80 | 5.2 | 0 | 8.5 | 0 | 10.2 | 80 |
| 4 | 0 | 4.0 | 70 | 5.0 | 50 | 8.3 | 0 | 10.6 | 120 |
| 5 | 111 | 3.5 | 0 | 6.3 | 0 | 8.9 | 0 | 9.0 | 0 |
| 6 | 0 | 9.0 | 0 | 6.0 | 0 | 8.8 | 0 | 11.0 | 0 |
| 7 | 0 | 7.0 | 0 | 7.5 | 0 | 9.3 | 0 | 10.5 | 0 |
| 8 | 39 | 4.8 | 0 | 6.5 | 0 | 8.6 | 0 | 10.4 | 0 |
| 9 | 0 | 9.0 | 0 | 5.5 | 0 | 8.3 | 0 | 10.3 | 0 |
| 10 | 0 | 10.0 | 85 | 4.0 | 50 | 8.0 | 0 | 9.0 | 135 |
| Contracted Service (MW) | 150 | | 400 | | 100 | | 0 | | 650 |
| AS Cascading (Slacks) | - | | RU to SP 50 5.2 RU to NS 150 5.2 | | SP to NS 0 8.3 - | | - | | - |
| Service Used (MW) | 150 | | 200 | | 150 | | 150 | | 650 |
| Market Clearing Price (m.u./MWh) | 4.8 | | 5.2 | | 8.3 | | 0.0 | | Total (m.u.) |
| Total Cost (m.u.) | 720 | | 2080 | | 830 | | 0 | | 3630 |

Results – Comparison

| Market Dispatch | Regulation Down | | Regulation Up | | Spinning Reserve | | Non-Spinning Reserve | | Total | |
|----------------------------------|-----------------|------------|---------------|------------|------------------|------------|----------------------|------------|-------------|-------------|
| | Cascade | No Cascade | Cascade | No Cascade | Cascade | No Cascade | Cascade | No Cascade | Cascade | No Cascade |
| Contracted Service (MW) | 150 | 150 | 400 | 200 | 100 | 150 | 0 | 150 | 650 | 650 |
| Market Clearing Price (m.u./MWh) | 4.8 | 4.8 | 5.2 | 5.0 | 8.3 | 8.3 | 0.0 | 9.0 | - | |
| Total Cost (m.u.) | 720 | 720 | 2080 | 1000 | 830 | 1245 | 0 | 1350 | 3630 | 4315 |

| Characteristics | Model | |
|--------------------------|--|--|
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| AS cascading process | Yes | Yes |
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| Resource management goal | Minimization of ISO operation costs | Market Clearing Price |
| AS bidding regions | No | No |
| Relaxation variables | Ensured by ISO through bilateral contracts | Ensured by ISO through bilateral contracts |
| Complex Contracts | No | No |

Input data

| Energy and Ancillary Services Joint Market | | | | | | | | | | | | | | |
|--|-----------------|------------------|---------------|------------------|--------------|------------------|------------------|------------------|--------------------------|------------------|-----------|----------------------|------------------|--|
| Bids | Regulation Down | | Regulation Up | | Spin Reserve | | Non-Spin Reserve | | Energy | | Max Power | Loads | | |
| | Qt (MW) | Pe (m.u./MWh) | Qt (MW) | Pe (m.u./MWh) | Qt (MW) | Pe (m.u./MWh) | Qt (MW) | Pe (m.u./MWh) | Qt (MW) | Pe (m.u./MWh) | | Qt (MW) | Pe (m.u./MWh) | |
| 1 | 70 | 10 | 80 | 15 | 10 | 5 | 95 | 7 | 430 | 2.1 | 450 | 300 | 7 | |
| 2 | 80 | 8 | 70 | 8.1 | 55 | 9 | 45 | 4 | 350 | 3.6 | 400 | 100 | 5 | |
| 3 | 55 | 8 | 80 | 7.1 | 88 | 8.5 | 70 | 6 | 480 | 5.2 | 500 | 80 | 4.1 | |
| 4 | 60 | 4 | 50 | 5 | 30 | 7.2 | 41 | 4.6 | 450 | 5.8 | 480 | 300 | 7.7 | |
| 5 | 100 | 3.5 | 65 | 7 | 24 | 4 | 45 | 9 | 250 | 6.3 | 300 | 350 | 8.8 | |
| 6 | 20 | 9 | 50 | 14.6 | 80 | 8 | 18 | 11 | 270 | 3.5 | 280 | 350 | 9.9 | |
| 7 | 40 | 7 | 98 | 7.2 | 50 | 7.3 | 24 | 4 | 299 | 2.8 | 320 | 105 | 4.5 | |
| 8 | 10 | 4.8 | 100 | 8.3 | 60 | 6.6 | 80 | 10.5 | 399 | 9.2 | 405 | 80 | 3.9 | |
| 9 | 40 | 9 | 100 | 6.5 | 10 | 4.3 | 80 | 5.3 | 345 | 4.5 | 400 | 300 | 7.5 | |
| 10 | 15 | 10 | 40 | 4 | 49 | 9 | 90 | 5 | 369 | 3.9 | 400 | 100 | 5.5 | |
| Req | Min 250 | Max 300 | Min 200 | Max 300 | Min 150 | Max 200 | Min 150 | Max 200 | Forecastes Losses 160 | | - | Rigid Demand 1300 | | |

Joint market results

| Bids | Regulation Down | | Regulation Up | | Spinning Reserve | | Non-Spinning Reserve | | Energy | | Loads | | Total (MW) |
|---------------------------------|-----------------|----------|---------------|----------|------------------|----------|----------------------|----------|--------|----------|-------|----------|--------------|
| | MW | m.u./MWh | MW | m.u./MWh | MW | m.u./MWh | MW | m.u./MWh | MW | m.u./MWh | MW | m.u./MWh | |
| 1 | 0 | 10.0 | 0 | 15.0 | 10 | 5.0 | 0 | 7.0 | 430 | 2.1 | 300 | 7.0 | 440 |
| 2 | 40 | 8.0 | 5 | 8.1 | 0 | 9.0 | 45 | 4.0 | 350 | 3.6 | 0 | 5.0 | 400 |
| 3 | 0 | 8.0 | 44 | 7.1 | 0 | 8.5 | 0 | 6.0 | 456 | 5.2 | 0 | 4.1 | 500 |
| 4 | 60 | 4.0 | 50 | 5.0 | 30 | 7.2 | 41 | 4.6 | 359 | 5.8 | 300 | 7.7 | 480 |
| 5 | 100 | 3.5 | 65 | 7.0 | 24 | 4.0 | 0 | 9.0 | 191 | 6.3 | 350 | 8.8 | 280 |
| 6 | 0 | 9.0 | 0 | 14.6 | 10 | 8.0 | 0 | 11.0 | 270 | 3.5 | 350 | 9.9 | 280 |
| 7 | 40 | 7.0 | 0 | 7.2 | 0 | 7.3 | 21 | 4.0 | 299 | 2.8 | 0 | 4.5 | 320 |
| 8 | 10 | 4.8 | 0 | 8.3 | 60 | 6.6 | 0 | 10.5 | 0 | 9.2 | 0 | 3.9 | 60 |
| 9 | 0 | 9.0 | 2 | 6.5 | 10 | 4.3 | 43 | 5.3 | 345 | 4.5 | 300 | 7.5 | 400 |
| 10 | 0 | 10.0 | 40 | 4.0 | 0 | 9.0 | 0 | 5.0 | 360 | 3.9 | 0 | 5.5 | 400 |
| Contracted Service (MW) | 250 | | 206 | | 144 | | 150 | | 3060 | | 1600 | | 2210 |
| Slacks | - | | RU to SP | | SP to NS | | - | | - | | - | | - |
| | | | 6 | 8.1 | 0 | 8.0 | | | | | | | |
| | | | RU to NS | | - | | | | | | | | |
| | | | 0 | 8.1 | | | | | | | | | |
| Market Clearing Price (m.u./MW) | 8.0 | | 8.1 | | 8.0 | | 5.3 | | 6.3 | | 6.3 | | Total (m.u.) |
| Total Cost (m.u.) | 2000 | | 1668.6 | | 1152 | | 795 | | 19278 | | 10080 | | 14813.6 |

- **Results – Comparison between separated and joint market**
 - Joint market improve a economic efficiency around 4%

| Service | Market Price (m.u./MWh) | | | | Balance |
|----------------------|-------------------------|---------|---------------|-------------|---------|
| | AS Market | | Energy Market | Join Market | |
| | No Cascade | Cascade | | | |
| Regulation Down | 8.0 | 8.0 | - | 8.0 | 0.0 |
| Regulation Up | 8.3 | 8.3 | - | 8.1 | 0.2 |
| Spinning Reserve | 9.0 | 8.0 | - | 8.0 | 0.0 |
| Non-Spinning Reserve | 9.0 | 9.0 | - | 5.3 | 3.7 |
| Energy | - | - | 6.3 | 6.3 | 0.0 |
| Total Cost (m.u.) | 6360.0 | 6220.8 | 9198.0 | 14813.6 | 605.2 |
| | | 15418.8 | | | |

Economic Efficiency

Separated Market

Joint market

- **Ancillary services in competitive market environment**
- **The possibility of using the ancillary services cascading mechanism allows economic efficiency**
- **Relaxation variables ensures the feasibility of the solution**
- **Joint market improve economic efficiency**
- **The deterministic optimization guarantees the best solution**



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