Enhancing the flexibility in TIMES:
Introducing Ancillary Services Markets

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Aim of the research project

Extension of TIMES code capturing the impacts of short-term variability of electricity supply and demand on system adequacy and security of supply

The extension can be used together with the dispatching, grid or RLDC extensions and influences the investment and dispatch decisions of the power plants

It provides a market-based solution for flexibility required to integrate large share of variable renewable energy

It aims at giving a clear picture of the costs to electricity system including renumeration for new flexibility
## Current status

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Completion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>Mathematical specification of ancillary services in TIMES (PSI)</td>
<td>97%</td>
</tr>
<tr>
<td>Task 2</td>
<td>Revision of the specification and enhancements based on real-world applications (MAREI/UCC)</td>
<td>95%</td>
</tr>
<tr>
<td>Task 3</td>
<td>Review of the design, implementation and testing (VTT)</td>
<td>97%</td>
</tr>
<tr>
<td>Task 4</td>
<td>Documentation (PSI, VTT, MAREI/UCC)</td>
<td>95%</td>
</tr>
</tbody>
</table>

Overall budget: 38,500 EUR
1. BRIEF INTRODUCTION TO ANCILLARY SERVICES MARKETS
In the case of a power plant failure...

Positive (or upward) reserve: shortage of supply requiring additional units to be online

Negative (or downward) reserve: excess of supply requiring increased consumption

Legend
- Green: Power plant output
- Pink: Balancing service

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Balancing the energy & reserve markets

Two constraints are considered in the electricity system:

- Balance of energy demand and supply of electricity (EQ_COMBAL in TIMES)

- Balance of supply and demand of reserve capacity (this extension)

- The reserve capacity becomes endogenous to the decision mechanism, and the traditional peak constraint can be used to implement strategic reserves
### Ancillary services markets & products

ENTSO-E categorises operating reserves as:

<table>
<thead>
<tr>
<th>Reserve Type</th>
<th>Description</th>
<th>Response Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Containainment Reserve (FCR)</td>
<td>It is activated automatically upwards or downwards</td>
<td>Fast response</td>
</tr>
<tr>
<td>Automatic Frequency Restoration Reserve (aFRR)</td>
<td>It relieves the FCR, upwards or downwards</td>
<td>Fast response</td>
</tr>
<tr>
<td>Manual Frequency Restoration Reserve (mFRR) or tertiary</td>
<td>It relieves the aFRR, upwards or downwards</td>
<td>Fast response</td>
</tr>
<tr>
<td>Replacement Reserve (RR)</td>
<td>It relieves the mFRR, but not implemented in all countries</td>
<td>Slow response</td>
</tr>
</tbody>
</table>
Calculating the demand for ancillary markets

The calculation of operating reserves is complex and differs between countries.

Real world example based on the Belgian System Operator

Source: ELIA, 2017
The different types of reserves are provided independently from a process.

The supply of operating reserve from a process is constraint by:

- The minimum stable operating level
- The ramping rates for energy & reserve provision
Provision of reserve from a storage

A storage process that has been contracted to provide reserve of power $P$ for time $d$

- It is charged for time $t^{(1)}$ to increase stored energy to the power level of $P$
- It retains stored energy level to provide reserve power $P$ for time $d=t^{(2)}-t^{(1)}$

Brijs et al., 2016
2. TIMES EXTENSION MODELLING ANCILLARY SERVICES MARKETS
Reserve Demand in TIMES (components)

1. The TIMES extension allows for endogenous demand & trade for operating reserve.
2. Each reserve is a user-defined commodity with deterministic and/or probabilistic demand.

Abstraction followed in the TIMES extension for each reserve type:

- **Deterministic Component (e.g. loss of largest grid element)**:
  - Exogenous: Specified by the user as a constant amount
  - Endogenous: Calculated by TIMES from a set of processes

- **Probabilistic component (e.g. forecast errors)**:
  - Exogenous: Historical forecast errors
  - Endogenous: Dynamically adjusted forecast errors

The demand for a reserve can be:
- Deterministic (det) only
- Probabilistic (prob) only
- Weighted sum of prob & det
- Maximum of prob & det
- Difference of prob & det

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Deterministic demand calculation

1. Exogenously provided by the user as an absolute number for a timeslice
2. Endogenously calculated by TIMES, based on the largest capacity from a set of user-defined processes

Remarks:
- If the demand is provided exogenously from the user, then it consists a lower bound
- The contribution of the largest capacity (or, formally, grid element) can be weighted

\[
\begin{align*}
\text{VAR}_\text{BSD}^\text{deter} & \geq \text{dexog}^\text{deter} \\
\text{Variable for deterministic demand} & \\
\text{Exogenous demand provided by the user} & \\
\text{Weight of the largest grid element} & \\
\end{align*}
\]
Probabilistic demand calculation

1. The user needs to define the forecast errors of system imbalances, e.g. wind/solar production & demand.

2. The calculation is based on convolution, assuming the forecast errors independent random variables following the standard normal distribution with mean zero and standard deviation equal to the forecast error.

Remarks:
° The system imbalances are defined via GR_GENMAP(r,p,item), where processes are mapped to imbalances.
° Because of linear approximation of the non-linear function of convolution, a scaling factor is provided to the user.

$$\text{VAR}_\text{BSD}^{\text{Prob}}_{r,t,s,c} = 3 \cdot \sqrt{\sum_k \left( \sigma_{r,t,c,k,s}^2 \cdot \text{VAR}_{RLD_{r,t,s,k}}^2 \right)}$$

$$\approx \delta_{r,t,c,s} \cdot 3 \cdot \sum_k \left( \sigma_{r,t,c,k,s} \cdot \text{VAR}_{RLD_{r,t,s,k}} \right)$$

Original formulation

Linear approximation
Reserve demand in TIMES (dependencies)

The demands for different types of reserves are not entirely independent

e.g. based on the probability distribution:
- aFRR-type can be the 60% quantile
- mFRR-type can be the 90% quantile
- RR-type can be the 99% quantile

\[
\frac{aFRR}{FRR} = \frac{\mu + \sigma \cdot \Phi^{-1}(0.6)}{\mu + \sigma \cdot \Phi^{-1}(0.99)} = \mu + \sigma \cdot 0.253 = \lambda \in (0,1)
\]

TIMES input parameter to define the relationship between e.g. aFRR and FRR, or negative and positive reserve

Brijs et al., 2016
Provision of reserve supply in TIMES (concept)

Operating reserve can be provided by supply processes*, storages*, and demand processes

For a process that can potentially provide reserve, the following parameters need to be defined:

1. Minimum stable operating level and ramping-up/down for supply processes
2. **New**: percentage of capacity available for reserve provision, both for supply & demand processes
3. **New**: Ramping rates and duration of contracted reserve (depends on the reserve type) for storages
4. **New**: Optionally, absolute bounds on reserve provision

* Supply processes include also storages for which NCAP_AFC is defined for the output commodity and electricity is not both an input and an output commodity

* Storages refers to storage processes with energy bounded by capacity and can also have electricity as both an input and output commodity
Additional features, related to Ancillary Services markets

1. Continuous maintenance of power plant, endogenous or exogenous
   - The **1-NCAP_AFS** is used to define the max. capacity under maintenance, and the user also specifies the **duration** of the maintenance; **start-ups** at the process timeslice should also be defined.
   - If maintenance is set at a level above the process timeslice level, then TIMES optimally schedules the maintenance period; otherwise it can be exogenously defined by the user at a user-defined timeslice.
   - The capacity under maintenance remains offline over the whole maintenance period.

2. Both cycle- and calendar- lifetime for storage processes
   - A targeted annual number of cycles **max_cycles/tlife** is defined by the user.
   - A cycle in TIMES would be a discharging followed by a charging (it follows that for 1 kWh storage, the annual energy discharged is equal to the number of cycles).
   - If the number of cycles in a year exceeds the targeted number of cycles per year, then a replacement of storage has been occurred.
   - The «additional capacity to support the excessive cycling» is then multiplied by the annualised capital and fixed operating costs to form the «cost of excessive cycling» that enters in the objective function.

3. Demand load shifts, forward or backward, are already supported from TIMES version 4.3.6.
3. NEW TIMES INPUT PARAMETERS SUPPORTING THE EXTENSION
## Reserve demand formulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS_RTYPE (r, b)</td>
<td>Type of reserve b in region r. Supported types are:</td>
</tr>
<tr>
<td></td>
<td>± 1 , FCR-type of reserve (positive or negative)</td>
</tr>
<tr>
<td></td>
<td>± 2 , aFRR-type of reserve (positive or negative)</td>
</tr>
<tr>
<td></td>
<td>± 3 , mFRR-type of reserve (positive or negative)</td>
</tr>
<tr>
<td></td>
<td>± 4 , RR-type of reserve (positive or negative)</td>
</tr>
<tr>
<td>BS_OMEGA (r, y, b, s)</td>
<td>Parameter denoting if the demand for reserve b is:</td>
</tr>
<tr>
<td></td>
<td>=1 the maximum of deterministic and probabilistic components</td>
</tr>
<tr>
<td></td>
<td>=2 the weighted sum of deterministic and probabilistic components</td>
</tr>
<tr>
<td></td>
<td>=3 the difference of deterministic and probabilistic components</td>
</tr>
<tr>
<td>BS_DETWT (r, y, b)</td>
<td>Weight of the deterministic component in the demand for reserve b</td>
</tr>
</tbody>
</table>
## Reserve balance equation

<table>
<thead>
<tr>
<th>Commodity balance sense COM_LIM</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO (default)</td>
<td>Demands for reserve must be met and can even be exceeded; the balance is required at the commodity timeslices only</td>
</tr>
<tr>
<td>FX</td>
<td>Demands must be met and cannot be exceeded; the balance is required at the commodity timeslices only</td>
</tr>
<tr>
<td>N</td>
<td>Demands must be met and can even be exceeded; the balance is required at the finest level, such that the demand on the timeslices below the commodity timeslices are all the same and equal to the maximum imbalance</td>
</tr>
</tbody>
</table>
### Deterministic component of demand

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
</table>
| BS_DEMDET (r, dpar, b)   | Parameter for defining deterministic reserve demand  
  dpar=EXOGEN → amount of reserve b is provided exogenous  
  dpar=WMAXSI → weight of contribution of largest element in demand for b |
| BS_CAPACT(r)             | Conversion factor of reserve commodities from capacity units to commodity flow units Adequate for planning purposes |
| GR_GENMAP (r, p, item)   | Used to map processes p in item=WMAXSI which is the set of processes from which the largest element will be calculated by TIMES for determining the reserve demand |
# Probabilistic component of demand

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS_DELTA ((r, y, b, s))</td>
<td>Calibration parameter for the probabilistic demand for reserve (b)</td>
</tr>
<tr>
<td>BS_LAMBDA((r, y, b))</td>
<td>Dependence factor used in the calculations of the reserve requirements for reserve (b); it can be used to define dependencies between positive and negative reserves, as well as between reserves belonging to the same type, e.g. aFRR and FRR or aFRR and mFRR or mFRR and FRR</td>
</tr>
<tr>
<td>BS_SIGMA((r, y, b, k, s))</td>
<td>Standard deviation if the forecast error regarding the unpredictable variation (k) used for the calculation of the demand for reserve (b)</td>
</tr>
</tbody>
</table>
| GR_GENMAP \((r, p, k)\)  | Used to map processes \(p\) to unpredictable variations \(k\)  
Positive number: imbalance \(k\) is caused by supply processes  
Negative number: imbalance \(k\) is caused by demand processes |
Suppy of reserve demand

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS_BNDPRS (r, ty p, b, s, bd)</td>
<td>Absolute bound on the reserve provision (b)</td>
</tr>
<tr>
<td>BS_RMAX(r, y, p, b, s)</td>
<td>Maximum contribution of process (p) for the provision of reserve (b) If the parameter is set then the supply or demand process, or storage process with NCAP_AFC can provide reserves</td>
</tr>
<tr>
<td>BS_STIME(r, v, p, b)</td>
<td>Defines the time in hours for reserve provision from storage process (p) (bd=LO) time required for a storage process to ramp up to provide reserve (b) (bd=UP) duration of the provision of reserve (b) if the parameter is set, then a standard storage process can provide reserve</td>
</tr>
</tbody>
</table>
### Other features

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS_MAINT(r, v, p)</td>
<td>For endogenous maintenance scheduling, defines the minimum continuous maintenance time of process p in hours; if s is above the process timeslice then the maintenance period is optimised</td>
</tr>
<tr>
<td>STG_MAXCYC (r, y p)</td>
<td>Maximum number of cycles for storage process p</td>
</tr>
</tbody>
</table>
4. DEMONSTRATION
A simple RES for testing purposes

INTRODUCING ANCILLARY SERVICES MARKETS IN TIMES

<table>
<thead>
<tr>
<th>Technology</th>
<th>Installed capacity GW</th>
<th>Minimum operating level</th>
<th>Hourly ramping rate up and down</th>
<th>Minimum online and offline times</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUCLEAR</td>
<td>3.2</td>
<td>60%</td>
<td>5%</td>
<td>24/24</td>
</tr>
<tr>
<td>GAS-CC</td>
<td>1.9</td>
<td>50%</td>
<td>50%</td>
<td>4/2</td>
</tr>
<tr>
<td>GAS-OC</td>
<td>0.1</td>
<td>20%</td>
<td>100%</td>
<td>1/1</td>
</tr>
<tr>
<td>HYDDAM</td>
<td>13.4</td>
<td>n/a</td>
<td>80%</td>
<td>1/1</td>
</tr>
<tr>
<td>PHS</td>
<td>3.2</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demand</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>TWh</td>
<td>60</td>
</tr>
<tr>
<td>Demand</td>
<td>GWp</td>
<td>10.7</td>
</tr>
<tr>
<td>FCR</td>
<td>min</td>
<td>0.5</td>
</tr>
<tr>
<td>AFRR</td>
<td>min</td>
<td>7.5</td>
</tr>
<tr>
<td>MFRR</td>
<td>min</td>
<td>15</td>
</tr>
</tbody>
</table>
Demand for operational reserves

Reserve requirements:

FCR-type of reserve : exogenously given @ 90 MW
aFRR type of reserve : loss of largest grid element + probabilistic assessment @ 70% quantile
mFRR type of reserve : loss of largest grid element + probabilistic assessment @ 99% quantile

Symmetry in positive and negative reserves

Probabilistic assessment:

The whole FRR-type of reserve (aFRR + mFRR):
  ◦ Solar production forecast error: 1.5%
  ◦ Wind production forecast error: 0.8%
  ◦ Demand forecast error: 1.7%

The dependency factor between aFRR and FRR is $\lambda = 0.8$
Input parameters to model the example

Existing TIMES parameters to model dispatch features:

**NCAP_PASTI** to set existing capacities

**ACT_TIME** to set minimum online/offline times

**ACT_UPS** to set ramping rates and minimum stable operating level

NEW TIMES parameters to model ancillary markets:

**BS_RTYPE** to define the reserve commodities

**BS_OMEGA** to specify the reserve demand functions

**BS_DEMDET** to specify the deterministic component of the demands of the different reserves

**BS_SIGMA** to specify the probabilistic component of the demands of aFRR and mFRR, based on FRR

**BS_LAMBDA** to set the relationships between aFRR and FRR, as well as between mFRR and FRR

**BS_RMAX** to specify the contribution of each technology in reserves
Results on investment decisions – 3 scenarios

- **Base**
  - No peak constraint
  - No ancillary markets

- **Peak 30%**
  - No ancillary markets
  - Peak constraint 30%

- **Ancillary Markets**
  - No peak constraint
  - Ancillary markets

For the Peak 30% scenario:
The contribution to peak reserve from hydropower is 60%, from pump storage 50%.
No contribution to peak reserve from solar & wind
Results on operational decisions

**Base and Peak 30% scenario**

Electricity production in Winter (GWh/h)

- Pump Hydro
- Hydropower
- Oil OC
- Solar
- Wind
- Gas CC
- Nuclear

**Ancillary markets scenario**

Electricity production in Winter (GWh/h)

- Pump Hydro
- Hydropower
- Gas OC
- Solar
- Wind
- Gas CC
- Nuclear

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Feature: Capacity under maintenance

We force maintenance of up 30% of installed Gas-CC capacity for 5h

- NCAP_AFS(‘GAS-CC’, ‘SUM’, ‘UP’) = 0.7
- BS_MAINT(‘GAS-CC’) = 5
Feature: Storage cycle & calendar lifetime

Example of practical application: batteries in electric cars, when the battery and the car body are modelled as separate processes.

Input Data:
- NCAP_PASTI('BAT') = 1 GWh
- NCAP_TLIFE('BAT') = 10
- STG_MAXCYC('BAT') = 4000

**Table: Storage of 1 PJ capacity cycle**

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAR_SIN</td>
<td>1.8 PJ = 500 GWh</td>
</tr>
<tr>
<td>VAR_SOUT</td>
<td>1.62 PJ = 450 GWh</td>
</tr>
<tr>
<td>Targeted cycles per year</td>
<td>4000/10*1 = 40 GWh per year output</td>
</tr>
<tr>
<td>Current cycling per year</td>
<td>500 GWh/10 = 50 GWh</td>
</tr>
<tr>
<td>Excess cycling</td>
<td>50 / 40 = 1.25</td>
</tr>
<tr>
<td>Additional capacity to support excess cycling</td>
<td>1.25 – 1 = 0.25</td>
</tr>
</tbody>
</table>

**Seasons:**
- **Season 1**
- **Season 2**

**Notes:**
- Season 2 timeslices have four times the duration of the timeslices in Season 1.
Thank you for your attention!