Challenge ROADEF/EURO 2010 :
A large-scale energy management problem with varied constraints

Marc PORCHERON, Agnès GORGE, Olivier JUAN, Tomas SIMOVIC and Guillaume DEREU

EDF R&D

February 2010

1. Introduction

EDF power generation facilities in France stand for a total of 98.8 GW of installed capacity. The varied range of EDF facilities mixes all forms of energy: thermal (nuclear, coal, fuel oil and gas), hydraulic and other renewable energies. Most of the electricity EDF generates in France is produced by thermal power plants: 90% in 2008, among which 86% by nuclear power plants. This subject is focused on thermal power plants and especially on those that have to be repeatedly shut down for refueling and maintenance, e.g. nuclear ones. The scheduling of these outages has to comply with various constraints, regarding safety, maintenance, logistics and plant operation while it must lead to production programs with minimum costs.

The proposed subject consists of modeling the production assets and finding an optimal outage schedule and includes of two dependent sub problems:

1. determining a schedule of plant outages. The schedule must satisfy constraints in order to comply with limitations on resources which are necessary to perform refueling and maintenance operations.

2. determining an optimal production plan to satisfy demand, i.e. a quantity of energy to produce by each plant at each time step for each scenario. Production must satisfy some technical constraints. In medium-term electricity management numerous uncertainties have to be taken into account (demand, generation units availability, spot market prices, quantities that can be bought or sold,...), which leads to the need to consider multiple scenarios.

The objective is to minimize the expected cost of production.

2. Participation and planning

The web page of the challenge (http://challenge.roadef.org) contains the same information that is presented in this document. The participants are invited to consult the web page regularly for updates regarding data, updating of FAQ, etc.

2.1. Categories

This contest is **open** to anybody with the exception of people who have a professional relationship with the company that is providing the topic.

There are three categories:

- Junior: team composed entirely of students with a single thread being authorized
- Senior: no restriction on the composition of the team, a single thread is authorized
- Multi-thread: no restriction on the composition of the team, no restrictions on the number of threads

One team can participate in several categories at the same time. All junior teams are automatically enrolled in the senior category. Similarly, all single thread teams are automatically participating in the multithread category with the same executable.

2.2. Prizes

- Junior: 4000€ distributed among the three first finalist teams
- Senior: 4000€ for the winning team
- Multi-thread: 2000€ for the winning team

2.3. Program options

For our evaluation scripts, the participants are asked to provide an executable called energyManagement,

with the following options:

- -t TIME to stop the program execution after TIME seconds (caution: this is “real time", not cputime). The test machine will be totally dedicated and the tests will be done sequentially, therefore all the teams will have the same amount of CPU power.
- -n INSTANCE to load the data associated with the instance INSTANCE. The input file will be INSTANCE.
- -i to return the identifier of the team that is the author of the executable (if it is the only option the executable returns the team identifier and quits). The team identifier will be given to every team upon registration.
- -r SOLUTION to specify the name of the file containing the solution. The solution file has to be conform to the format specified in the section 4.2 of this document

Each data set or instance is contained in a single .txt file; therefore only one data file has to be read for each instance.

To summarize, the command:

energyManagement -t 1800 -n instance1 –r solution1

will load the data file instance1; run the program for at most 1800 seconds and generate an output file named solution1.

Warning: the tests will be run with -t 1800 (30 minutes) or -t 3600 (60 minutes).

2.4. Types of data sets and team rankings

EDF will provide several data sets to participants during the course of the contest. The sets will be provided in the following manner:

- The initial data set (Base A: 5 sets, 30 minutes per set) will be provided during the qualification phase between the beginning of the contest and the inscription deadline at the latest. This set will be used to select candidates for the final.
- The second data set (Base B: 5 sets, 60 minutes per set) will be made available at the conclusion of the qualification phase. It will contain more complex problems than the previous set and will allow participants to perfect their methods.

- The final data set (Base X: 5 set, 60 minutes per set) will not be disclosed to participants but will be used to establish a ranking of the finalists before the start of the EURO'11 congress. It will be released to participants after the announcements of final results.

At least one feasible solution will exist for each data set.

To rank participants at the end of the qualification phase, the objective function of every set will be normalized by the best solution found by a participating team with a sum being performed on all elements of the set A. The maximum execution time will be fixed to 1800 seconds (30 minutes).

$$scoreQualicationPhase = \sum_{i \in A} \frac{objective(i) - objective^*(i)}{objective^*(i)}$$

To rank participating teams at the end of the final phase, the objective function of every set will be normalized by the best solution found by a participating team with a sum being performed on all elements of the set B and X. The maximum execution time will be fixed to 3600 seconds (60 minutes).

$$scoreFinalPhase = \sum_{i \in B \cup X} \frac{objective(i) - objective^*(i)}{objective^*(i)}$$

If an executable fails to find a feasible solution, its score on this instance will be double the score obtained by the worst feasible solution found by a team.

The computer used for the evaluation of executables provided by participants will be a Bi-processor Intel Xeon 5420 2.5Ghz quad core (8GB of memory under Linux, 3GB under windows, 12MB of cache). The available java virtual machine, if needed, will be the Sun JRE (version 1.5.0_14-b03).

On Windows : `java version "1.5.0_14"`

```
Java(TM) 2 Runtime Environment, Standard Edition (build 1.5.0_14-b03)
Java HotSpot(TM) Client VM (build 1.5.0_14-b03, mixed mode)
```

On linux : `java version "1.5.0_14"`

```
Java(TM) 2 Runtime Environment, Standard Edition (build 1.5.0_14-b03)
Java HotSpot(TM) 64-Bit Server VM (build 1.5.0_14-b03, mixed mode)
```

The use of following software is allowed:

- ILOG CP Optimizer 2.3
- ILOG CPLEX 12.1.2.0 (Simplex, Mixed Integer & Barrier Optimizers)
- ILOG OPL 6.3 (cpp and java interfaces)
- XPRESS-Optimizer v18.10.10 (Hyper capacity, MIP, Barrier, QP/MIQP)
- CoinAll-1.2
- COMET

It will also be possible to use the following modeling languages:

- GAMS 23.1

2.5. Expected deliveries from candidates and planning

Expected deliveries are in bold in the planning below.

- Beginning of July: publication of the subject and provision of a portion of Base A
- Beginning of September: divulgation of the rest of Base A and of an executable that will allow verification of the feasibility of a solution
- November 1: end of pre-enrollments, each team should send a **registration file** containing the names, status (student or researcher) and affiliations of persons comprising the applicant team. On this date, a list of registered teams will be published on the web site. Late registration will still be allowed.
- January 5: deadline for submission of **executables** for the qualification phase, team must also send **results files** with associate time of computation and a short description of the proposed method (1 page) including information on computer used for each set of base A.
- ROADEF February 2010: announcement of the finalists and release of Base B
- June 5: deadline for the submission of **executables** for the final phase, team must also send an **extended abstract** (5 pages) on the method proposed and **results files** with associate time of computation and the characteristics of computer used for each set of base B for information
- EURO July 2010: announcement of final results

3. Problem formulation

A production portfolio with two types of production units is considered:

- Type 1 power plants which can be supplied in fuel continuously
- Type 2 power plants, which have to be supplied in fuel at regular intervals. Whenever a Type 2 plant is supplied with new fuel, it has to be offline and cannot produce during the length of this outage period.

These production assets are used to satisfy a customer demand over a specific time horizon. This time horizon has been discretized with a homogeneous time step. Customer load is uncertain and known only through an available set of uncertainty scenarios. These scenarios are assumed to be the realization of some stochastic process. Production at a Type 1 plant incurs a cost that is proportional to the power output and also depends on the load scenario and the time step. Refueling of a Type 2 plants leads to costs proportional to the amount of loaded fuel. This cost depends also on the time step. The quantity of the fuel available for each Type 2 power plant at the beginning of the time horizon is known.

3.1. Decision variables

The following decision variables make up the problem:

- dates for outages to refuel Type 2 power plants

- the amount of fuel that is supplied whenever a Type 2 power plant is refueled
- production levels for Type 1 and Type 2 power plants for each time step and uncertainty scenario

NB: dates for outages to refuel Type 2 power plants and the amount of fuel that is supplied whenever a Type 2 power plant is refueled are decision variable which do not vary over scenarios.

3.2. Objective function

The sum of the following two terms needs to be minimized:

- cost of refueling of Type 2 power plants reduced by the expected value of remaining fuel at Type 2 power plants at the end of the time horizon for all scenarios.
- expected value of the production cost of Type 1 power plants for all scenarios

This objective function has to be minimized while satisfying customer load for all time steps in the time horizon and all production scenarios (see below).

3.3. Constraints

- For each scenario, the sum of production levels of all power plants has to be equal to the customer load
- Technical constraints for each plant
  - Type 1 power plants: Production levels have to be between MSG (minimum stable generation) and Full load, where the full load level depends on the scenario and time step
  - Type 2 power plants have the following constraints
    - Production levels have to be between MSG and Full load, where the latter depends on the available fuel levels at the current time step. This dependence might be non-linear
    - Fuel level dynamics, that couple fuel quantity and production output during the time horizon
    - Minimum and maximum amount of fuel that can be supplied during each outage.
    - Minimum and maximum bound on the amount of residual fuel at the time of an refueling outage
- Constraints on scheduling of outages:
  - Outages last for a certain amount of time steps (we will speak of overlapping outages whenever the outages of two power plants coincide partially)
  - Outages have to be spaced by a minimum amount of time steps
  - A maximum number of overlapping outages
  - A maximum number of outages that begin in a specific time frame

Order of magnitude of the problem:

- Number of Type 1 power plants: up to 100;
- Number of Type 2 power plants: up to 70;
- Time horizon: up to 300 weeks with 3 to 42 timesteps per week
- Number of scenarios: up to 500

- Number of outages to schedule for every Type 2 power plant: up to 8
- Number of constraints related to scheduling of outages: up to 200 .

3.4. Model formulation

3.4.1. Vocabulary

Time step: time period limited by two consecutive instants. In this document, the time interval [t, t+1] will be referred to as « *time step t* ». Time steps are numbered relative to the beginning of the time horizon, starting at 0.

Week: certain data and variables will be defined for a week. A week represents several time steps.

NB: In a data set, a week contains always the same number of time steps. Nevertheless, this number can vary between the data sets. The length of the time step will always be the same in a given data set.

3.4.1.1. Type 2 power plants

- **Production campaign**: a series of time steps during which the plant can produce
- **Outage**: a series of time steps during which no production is possible. A plant is refueled approximately one time for every outage. An outage can start only at the beginning of a week and ends at the end of a week. Therefore, possible outage starting dates are at the beginning of a week.
- **Cycle**: succession of an outage and a production campaign
- **Reload**: amount of energy provided to the plant during an outage
- **Coupling:** first week of a production campaign.
- **Decoupling:** first week of an outage
- **Modulation**: difference between the maximum power of a plant and the actual production.

3.4.2. Indices

- **s**: index of scenarios, varying between 0 and *S-1*
- **t**: index of time steps, varying between 0 and *T-1*
- **h**: index of weeks, varying between 0 and H-1
- **j**: index of Type 1 plant, varying between 0 and *J-1*
- **i**: index of Type 2 power plant, varying between 0 and *I-1*
- **k**: index of cycles of Type 2 power plants varying between -1 and *K-1*. *K-1* represents the *maximum* number of cycles that can start during the considered period. In the case where k=-1, it represents the campaign in progress at the beginning of the time horizon, before the first outage.

NB: The cycles must stay in the same order as the index. The last cycles can be outside the considered period and in this case there is no need to schedule the corresponding outages.

3.4.3. Data

- **$DEM^{t,s}$** : load to satisfy for the time step *t* and scenario *s*
- **D^t** : length of time step *t.*

3.4.3.1. For every unit *j* of Type 1 plant

- **$PMAX_j^{t,s}$** : maximum power during time step *t* for scenario *s* (see constraint [CT2])
- **$PMIN_j^{t,s}$** : minimum power during time step *t* for scenario *s* (see constraint [CT2])
- **$C_j^{t,s}$** : proportional production cost for time *t* and scenario *s*

3.4.3.2. For every unit *i* of Type 2 plant

- **XI_i** : initial fuel, i.e. at the beginning of the first time step
- **$DA_{i,k}$** : length of outage of cycle *k* in weeks
- **$MMAX_{i,k}$** : maximum modulation over the production campaign of cycle *k* (see constraint [CT12])
- **$RMAX_{i,k}$** : maximum load of fuel provided during the outage of cycle *k* (see constraint [CT7])
- **$RMIN_{i,k}$** : minimum load of fuel provided during the outage of cycle *k* (see constraint [CT7])
- **$Q_{i,k}$** : refueling coefficient during the outage of cycle *k* (see constraint [CT10])
- **$PMAX_i^t$** : maximum power during time step *t* (see constraints [CT5][CT6])
- **$BO_{i,k}$** : bound on stock of fuel that activates the constraint of imposition of power profile during cycle *k* (see constraint [CT5][CT6])
- **$PB_{i,k}$** : imposed decreasing production profile during the production campaign of cycle *k* (piece-wise linear function dependent on the level of fuel) (see constraint [CT6])
- **ε** : tolerance for tracking of the imposed decreasing production profile (see constraint [CT6])
- **$SMAX_{i,k}$** : maximum bound on stock of fuel during production campaign of cycle *k* (see constraint [CT11])
- **$AMAX_{i,k}$** : maximum bound on stock of fuel at the time of outage of cycle k. (see constraint [CT11])
  NB: these parameters have the following property : $SMAX_{i,k} > AMAX_{i,k} > BO_{i,k} > 0$
- **$C_{i,k}$** : proportional cost of fuel during cycle k
- **$C_{i,T+1}$** : proportional cost of fuel at the end of the time horizon [T,T+1]

The parameters used in constraints for scheduling outages of Type 2 power plants will be defined along with the constraints in which they appear.

3.4.4. Constraints

We shall use:

- ***ha(i,k)*** : week of cycle *k* during which the plant *i* goes offline (i.e. week of decoupling). In the case where the outage of cycle *k* at plant *i* is unscheduled, *h(i,k) = -1*;
- ***p(j,t,s)*** : production of Type 1 plant *j* during the time step *t* over scenario *s ;*
- ***p(i,t,s)*** : production of Type 2 plant *i* during the time step *t* over scenario *s ;*
- ***r(i,k)*** : reload performed during the outage of cycle *k* of Type 2 plant *i ;*
- ***x(i,t,s)*** : stock of fuel of Type 2 power plant *i* at instant *t* (at the beginning of time step *t)* over

scenario s *;*

- ***ec(i,k)*** : set of time steps composing the production campaign of cycle *k of* plant *i*
- ***ea(i,k)*** : set of weeks composing the outage of cycle *k* of plant *i* ;

For all constraints a numerical tolerance of 10^{-2} is considered.

[CT1] **Constraints coupling load and production**: during every time step *t* of every scenario *s*, the sum of production of Type 1 and Type 2 power plants has to be equal to the load:

$$\forall s,t \quad \sum_{j}^{J} p(j,t,s) + \sum_{i}^{I} p(i,t,s) = DEM^{t,s}$$

This is an equality constraint due to the fact that electricity production and demand have to be at an equilibrium at every instant. If this equilibrium is disturbed for whatever reason, a deviation from the system frequency of 50 Hz occurs. Any such deviation is undesirable for security reasons, actions have to be taken subsequently by the transmission system operator to restore the system frequency back to the set point.

3.4.4.1. Technical constraints of plants

3.4.4.1.1.Type 1 power plants

[CT2] **Bound on production.** During every time step *t* of every scenario s, production of plant *j* has to be between minimum and maximum bounds:

$$\forall s,t,j \quad PMIN_j^{t,s} \le p(j,t,s) \le PMAX_j^{t,s}$$

NB: The bounds on production include a random outage. That is why they change with scenario and time step.

3.4.4.1.2.Type 2 power plants

[CT3] **Offline power**

During every time step *t* of every scenario *s* where plant *i* is on outage, its production is equal to zero.

[CT4] **Minimum power**

During every time step *t* of every scenario *s* where plant *i* is online, its production is positive or equal to zero.

[CT5] **Maximum power before activation of imposition of power profile constraint**

During every scenario *s* and every time step *t* of the production campaign of cycle *k*, if the current fuel stock of plant *i* is greater than or equal to $BO_{i,k}$, the production level has to be equal or less than its maximum bound :

$$\forall s,t,i,k \quad \left(t \in ec(i,k)\right) \wedge \left(x(i,t,s) \geq BO_{i,k}\right) \Rightarrow p(i,t,s) \leq PMAX_i^t$$

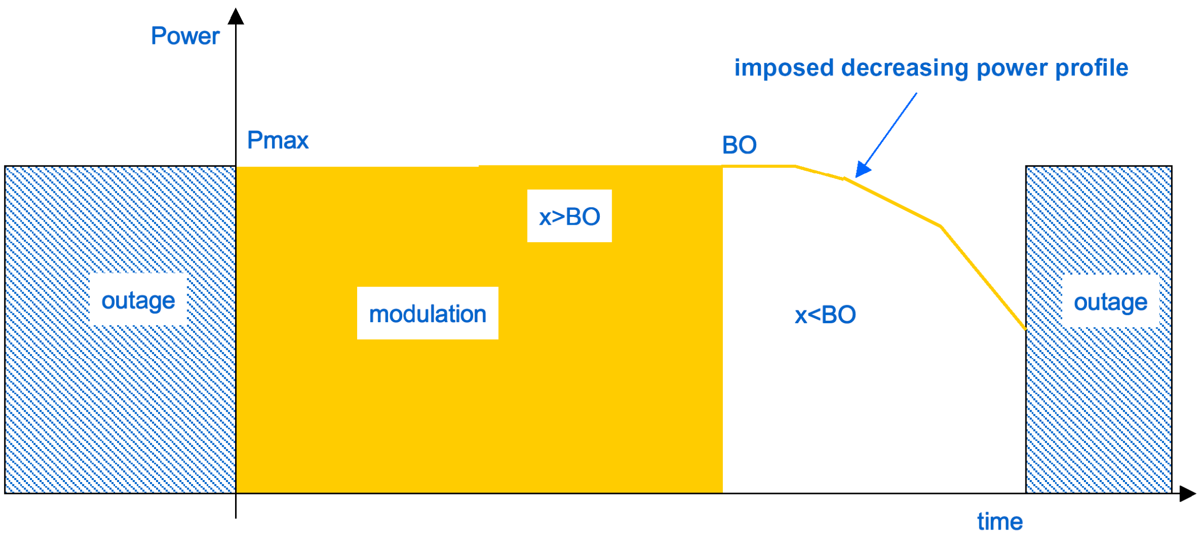
N.B. In the case where k=-1, it represents the campaign in progress at the beginning of the time horizon, before the first outage. The corresponding data in the data file is labeled as "current" (`current_campaign_max_modulus`, `current_campaign_stock_threshold`, etc.). This remark also applies to CT6, CT10 and CT12

[CT6] **Maximum power after activation of imposition of power level constraint**.

During every scenario *s* and every time step *t* of the production campaign of cycle *k*, if the current fuel stock of plant *i* is inferior to $BO_{i,k}$, production has to follow the power profile $PB_{i,k}$ with a tolerance ε :

$$\begin{array}{l}
\forall s,t,i,k \\
\text{if } \left(t \in ec(i,k)\right) \wedge \left(x(i,t,s) < BO_{i,k}\right) \\
\{ \\
\quad \text{if } x(i,t,s) \ \geq \ \left(PB_{i,k}(x(i,t,s)) \times PMAX_i^t\right) \times D^t \\
\quad\quad \text{then} \\
\quad\quad (1-\varepsilon)\left(PB_{i,k}(x(i,t,s)) \times PMAX_i^t\right) \leq p(i,t,s) \ \leq (1+\varepsilon)\left(PB_{i,k}(x(i,t,s)) \times PMAX_i^t\right) \\
\quad \text{else} \\
\quad\quad p(i,t,s) = 0 \\
\}
\end{array}$$

The following figure illustrates this principle:



An outage can start before, during or after the imposition of a decreasing power profile. If there is no longer enough fuel stock to produce, production is equal to zero ($p(i,t,s) = 0$). Production can stay at zero for an unlimited number of time steps before an outage is declared (as long as the constraint CT13 on the latest possible date of an outage is respected). There is no event that triggers an outage automatically.

[CT7] **Bounds on refueling**

The reload performed during cycle *k* of plant *i* has to be inside its minimum and maximum bounds :

$$\begin{array}{l}\forall i,k,\ ha(i,k)\ \neq\ -1\\ RMIN_{i,k}\ \leq r(i,k)\ \leq RMAX_{i,k}\end{array}$$

[CT8] **Initial fuel stock**

$$\forall s,i\ \ x(i,0,s)\ = XI_i$$

[CT9] **Fuel stock variation during a production campaign**

$$\forall s,t,i,k\ \ t\in ec(i,k)\Rightarrow x(i,t+1,s)\ = x(i,t,s)-p(i,t,s)\times D^t$$

[CT10] **Fuel stock variation during an outage**

$$\begin{array}{l}\forall s,t,i,k,\ (t\ is\ the\ first\ time\ step\ of\ ea(i,k))\\ \Rightarrow x(i,t+1,s)\ = \left((\mathrm{Q}_{\mathrm{i,k}}\text{-}1)/\mathrm{Q}_{\mathrm{i,k}}\right)\left(x(i,t,s)-BO_{i,k-1}\right)+r(i,k)\ +BO_{i,k}\end{array}$$

In the process of refueling a Type 2 power plant a certain amount of unspent fuel has to be removed to make the addition of new fuel possible. The refueling coefficient $Q_{i,k}$ helps to quantify this amount. Note that $BO_{i,k}$ is in reality part of the reload – r(i,k) and BO we separated in the formulation because one is a decision variable and the other is imposed (a technical parameter).

N.B: There is no fuel variation outside of the first time interval of an outage.

[CT11] **Bounds on fuel stock at the instant of outage and after refueling**

$$\begin{array}{l}\forall s,t,i,k,(t\ is\ the\ first\ time\ step\ of\ ea(i,k))\\ \Rightarrow\begin{cases}0\leq x(i,t,s)\ \leq AMAX_{i,k}\\ x(i,t+1,s)\ \leq SMAX_{i,k}\end{cases}\end{array}$$

Where $x(i,t+1,s)$ is given by [CT10].

The $AMAX_{i,k}$ and $SMAX_{i,k}$ bounds are important especially for security reasons.

N.B: We consider that refueling is performed entirely during the first time step of the outage.

[CT12] **Constraint on maximum modulation over a cycle**

$$\forall s,i,k \quad \sum_{t \in ec(i,k) \wedge x(i,t,s) \geq BO_{i,k}} \left[\left(PMAX_i^t - p(i,t,s) \right) \cdot D^t \right] \leq MMAX_{i,k}$$

Every modulation of the power output of a Type 2 power plant leads to a certain amount of wear of the equipment involved. Therefore frequent power modulations at Type 2 power plants are undesirable.

NB: The maximum modulation constraint does not apply if $x(i,t,s) < BO_{i,k}$. In this case, constraint CT6 defines the power profile.

3.4.4.2. Constraints on the scheduling of outages of Type 2 power plants

All the constraints that follow apply only to Type 2 power plants.

[CT13] **Constraint on the date of outage at the earliest and the latest**

Outage of cycle *k i* has to start during a given interval.

Data:

- **TO$_{i,k}$** *: first possible* week of the start of an outage (i.e. decoupling)
- **TA$_{i,k}$** *: last possible* week of the start of an outage (i.e. decoupling)

Constraint:

$$\begin{array}{ll} \forall (i,k) & TO_{i,k} \leq ha(i,k) \leq TA_{i,k} \\ \forall (i,\ k>0) & ha(i,k) \geq ha(i,k-1) + DA(i,k-1) \end{array}$$

NB: If one of the sides of the inequality is undefined , this side does not have to hold. The side that is defined must hold. The

[CT13bis] Constraint on the date of outage at the latest

Outage of cycle *k i* has to be scheduled if a last possible week of an outage **TA$_{i,k}$** is defined.

Data:

- **TA$_{i,k}$** *: last possible* week of the start of an outage (i.e. decoupling)

Constraint:

$$TA_{i,k} \neq -1 \Rightarrow ha(i,k) \neq -1$$

NB This constraint applies only for the final phase of the challenge.

[CT14] **Constraints on the minimum spacing/maximum overlapping between outages:**

Outages of a set **A$_m$** have to be spaced by at least **Se$_m$** weeks, with m being the index of constraints CT14 varying from one to M$_{14}$.

.

Data:

- **A_m** : a set of considered outages
- **Se_m** : duration in weeks of minimum authorized spacing. A negative value will be interpreted as maximum authorized overlapping

Constraint:

$$\forall i, i' \in A_m, i \neq i', \forall k, k',$$
$$\left(ha(i,k) \neq -1 \ \wedge \ ha(i',k') \neq -1\right)$$
$$\Rightarrow \quad \left(ha(i,k) - ha(i',k') - DA_{i',k'} \geq Se_m\right) \vee \left(ha(i',k') - ha(i,k) - DA_{i,k} \geq Se_m\right)$$

Constraints CT14 to CT18 represent the limited amount of human resources that is available to perform necessary refueling and maintenance operations during each outage or to assure safe coupling or decoupling of a Type 2 power plant. In constraints CT14 to CT20, the sets of outages A_m typically represent outages of power plants that are located in the same geographical region.

N.B In the data, A_m is defined by a set C_m of Type 2 power plants – A_m contains all the outages of power plants in C_m.

[CT15] **Minimum spacing/maximum overlapping between outages during a specific period**

Outages of a set **A_m** that intersect an interval [**ID, IF**] have to be spaced by at least or can overlap by at most **Se_m** weeks, with m being the index of constraints CT15 varying from one to M_{15}.

Data:

- **A_m** : a set of considered outages
- **Se_m** : length of minimum authorized spacing in weeks. A negative value will be interpreted as maximum authorized overlapping
- **ID_m** : week of the start of the specific period
- **IF_m** : week of the end of the specific period

Constraint:

$$\forall i, i' \in A_m, i \neq i', \forall k, k',$$
$$\left(ha(i,k) \neq -1 \ \wedge \ ha(i',k') \neq -1\right) \wedge$$
$$\wedge \left(ID_m - DA_{i,k} + 1 \leq ha(i,k) \leq IF_m\right) \wedge \left(ID_m - DA_{i',k'} + 1 \leq ha(i',k') \leq IF_m\right)$$
$$\Rightarrow \left(ha(i,k) - ha(i',k') - DA_{i',k'} \geq Se_m\right) \vee \left(ha(i',k') - ha(i,k) - DA_{i,k} \geq Se_m\right)$$

[CT16] **Minimum spacing constraint between decoupling dates**

Dates of decoupling of outages of a set **A_m** have to be spaced by at least **Se_m** weeks, with m being the index of constraints CT16 varying from one to M_{16}.

Data:

- $\mathbf{A_m}$: a set of considered outages
- $\mathbf{Se_m}$: length of minimum authorized spacing in weeks, with $\mathbf{Se_m} > 0$

Constraint:

$$\forall i, i' \in A_m, i \neq i', \forall k, k',$$
$$\left(ha(i,k) \neq -1 \ \wedge \ ha(i',k') \neq -1\right)$$
$$\Rightarrow \quad \left|ha(i,k) - ha(i',k')\right| \geq Se_m$$

[CT17] **Minimum spacing constraints between dates of coupling**

Coupling dates of outages of a set $\mathbf{A_m}$ have to be spaced by at least $\mathbf{Se_m}$ weeks, with m being the index of constraints CT17 varying from one to M_{17}.

Data:

- $\mathbf{A_m}$: set of considered outages
- $\mathbf{Se_m}$: length in weeks of minimum authorized spacing, with $\mathbf{Se_m} > 0$

Constraint :

$$\forall i, i' \in A_m, i \neq i', \forall k, k',$$
$$\left(ha(i,k) \neq -1 \ \wedge \ ha(i',k') \neq -1\right)$$
$$\Rightarrow \quad \left|ha(i,k) + DA_{i,k} - ha(i',k') - DA_{i',k'}\right| \geq Se_m$$

[CT18] **Minimum spacing constraints between coupling and decoupling dates**

Dates of coupling and decoupling of outages of a set $\mathbf{A_m}$ have to be spaced by at least $\mathbf{Se_m}$ weeks, with m being the index of constraints CT18 varying from one to M_{18}.

Data:

- $\mathbf{A_m}$: a set of considered outages
- $\mathbf{Se_m}$: length in weeks of minimum authorized spacing, with $\mathbf{Se_m} > 0$

Constraint:

$$\forall i, i' \in A_m, i \neq i', \forall k, k',$$
$$\left(ha(i,k) \neq -1 \ \wedge \ ha(i',k') \neq -1\right)$$
$$\Rightarrow \quad \left|ha(i,k) + DA_{i,k} - ha(i',k')\right| \geq Se_m$$

[CT19] **Resource constraints**

Use of resources on a given set of outages A_m is subject to constraints due to their limited availability, with m being the index of constraints CT19 varying from one to M_{19}.

Data:

- $\mathbf{A_m}$: a set of considered outages, with m being the index of constraints CT19 varying from one to M_{19}.
- $\mathbf{L_{i,k,m}}$: number of weeks after the start of the outage *(i,k)* that defines the start of the period of use of a certain resource. $L_{i,k}$ is included in the interval $[0 , DA_{i,k}[$.
- $\mathbf{TU_{i,k,m}}$: time of use of resource (superior to 1), in weeks, that includes the length of possible use of this resource as well as a period of possible unavailability between two successive utilizations of this resource.
- $\mathbf{Q_m}$ **:** available quantity of resource (the quantity of a resource used for every outage is equal to one)

Constraint: The outages of set $\mathbf{A_m}$ given by the solution must satisfy the following conditions:

- available quantity of Q_m is not exceeded
- usage period $TU_{i,k,m}$ of the resource is respected.

$$\forall h \quad \sum_{(i,k)\in A_m \wedge ha(i,k)\neq -1} \mathbf{1}_{\left[ha(i,k)+L_{i,k,m};ha(i,k)+L_{i,k,m}+TU_{i,k,m}\right[}(h) \leq Q_m$$

Where:

$$\mathbf{1}_A(x) = \begin{cases} 1 \text{ if } x \in A \\ 0 \text{ if } x \notin A \end{cases}$$

is the indicator function

N.B: In all cases $L_{i,k,m} + TU_{i,k,m} \leq DA_{i,k,m}$

During every outage a certain amount of material resources is used. This constraint represents their limited availability.

[CT20] **Constraint on the maximum number of overlapping outages during a given week**

The number of overlapping outages during a given week is limited.

- Data: for a week *h*, $\mathbf{A_m(h)}$: a set of outages (a set varying with *h*)
- $\mathbf{N_m(h)}$: a maximum number of outages in parallel during a week *h*

Constraint: For every solution, for every *h*, at most $N_m(h)$ outages of $A_m(h)$ can overlap during the week *h;* with m being the index of constraints CT20 varying from one to M_{20}.

$$\forall h \sum_{(i,k)\in A_m(h) \wedge ha(i,k)\neq -1} \mathbf{1}_{[ha(i,k);ha(i,k)+DA_{i,k}[}(h) \leq N_m(h)$$

Where:

$$\mathbf{1}_A(x) = \begin{cases} 1 \text{ if } x \in A \\ 0 \text{ if } x \notin A \end{cases}$$

is the indicator function

For a variety of reasons, it is undesirable to have more than a certain number of Type 2 power plants offline during the same time period. Therefore, the number of plants that can be on outage simultaneously is limited.

[CT21] **Constraint on the offline power capacity of a set of power plants during a time period**

For a given period, the power capacity of the set of plants C_m that are on outage has to be inferior to a maximum bound, with m being the index of constraints CT21 varying from one to M_{21}.

Data:

- $\mathbf{C}_m$: a set of considered plants
- $\mathbf{IT}_m$: a time period in weeks
- $\mathbf{IMAX}_m$: bound on maximum offline power capacity

Constraint:

$$\forall t \in h \backslash h \in IT \left(\sum_{i \in \mathbf{C}_m \backslash (\exists k \backslash h \in ea(i,k))} PMAX_i^t \right) \leq IMAX_m$$

The set of considered powerplants $\mathbf{C}_m$ represents typically a certain number of power plants located in the same geographical region. It is undesirable to have a large power generating capacity of Type 2 power plants in the same region on outage simultaneously.

3.4.5. Objective function

$$\sum_i \sum_k C_{i,k} \cdot r_i(k) + \frac{1}{|S|} \sum_s \left[\sum_t \left[\sum_j C_j(t,s) \cdot p_j(t,s) \cdot D^t \right] - \sum_i C_{i,T+1} \cdot x_i(T,s) \right]$$

NB:

- All of Type 2 power plants are assumed online during the initial time step
- *T* is the final time step. $x_i(T,s)$ represents the quantity of residual fuel of plant *i* at the end of the last time step [T-1,T], on scenario s

4. Formats of input/output files

The following sections show the structure of the input and output files. There is a single input file and a single output file for each data set. All text in the `Courrier New` font represents content of the files. All plain text in this font represents keywords, italicized text represents data and bold text represents notation of the corresponding parameters in constraints. The data is in non integer format, with the exception of indices and cardinalities.

4.1. Input file

The input file is structured in sections. Each section is delimited by the pair of keyword *begin/end*.

4.1.1. Main information section

`begin main`

`timesteps` *`number_of_timesteps`* `=`**`T`**

```
weeks number_of_weeks =H
campaigns number_of_campaign =K
scenario number_of_scenario =S
epsilon value_of_epsilon =ε
powerplant1 number_of_power_plant_of_type1 =J
powerplant2 number_of_power_plant_of_type2 =I
constraint13 number_of_constraint_of_type13 =M13
…
constraint21 number_of_constraint_of_type21 =M21
durations … =D^t
demand demand_1_1 demand_2_1 … demand_T_1 =DEM^{1…T,1}
…
demand demand_1_S demand_2_S … demand_T_S =DEM^{1…T,S}
end main
```

The duration field represents the duration of all the time steps, separated by tabulation.

The demand field represents the energy demand per time step, separated by tabulation, for one scenario. Each scenario has its own demand and a *demand* line is given for each scenario

4.1.2. Power plant section

The structure of a power plant section is organized in a common part and a specialized part:

```
begin powerplant
name name_of_the_power_plant
type 1 or 2
index power_plant_index
…
end powerplant
```

Depending on the type of power plant, the remaining fields differ. The next two subsections describe the variations. Note that the **K**, **T** ans **S** parameters are repeated but they are the same as in the main information section.

4.1.2.1. Power plant of type 1

```
begin powerplant
name name_of_the_power_plant
type 1
index power_plant_index =j
scenario number_of_scenario =S
timesteps number_of_timesteps =T
pmin pmin_1_1 pmin_2_1 … pmin_T_1 =PMIN_j^{1…T,1}
```

```
pmax pmax_1_1 pmax_2_1 … pmax_T_1 =PMAX_j^{1…T,1}
cost cost_1_1 cost_2_1 … cost_T_1 =C_j^{1…T,1}
…
pmin pmin_1_S pmin_2_S … pmin_T_S =PMIN_j^{1…T,S}
pmax pmax_1_S pmax_2_S … pmax_T_S =PMAX_j^{1…T,S}
cost cost_1_S cost_2_S … cost_T_S =C_j^{1…T,S}
end powerplant
```

The *pmin* field represents the minimal power produced by the plant if the power plant is started.
The *pmax* field represents the maximal power produced by the plant.
The *cost* field is the production cost of the plant.
The value of these three fields is provided for all timesteps on the same line separated by tabulation.
Each triplet of lines (*pmin*, *pmax*, *cost*) describes a scenario. A triplet is given for each scenario.

4.1.2.2. Power plant type 2

```
begin powerplant
name name_of_the_power_plant
type 2
index power_plant_index =i
stock initial_stock =XI_i
campaigns number_of_campaign =K
durations … =DA_i,k
current_campaign_max_modulus … =MMAX_i,-1
max_modulus … =MMAX_i,k
max_refuel … =RMAX_i,k
min_refuel … =RMIN_i,k
refuel_ratio … =Q_i,k
current_campaign_stock_threshold … =BO_i,-1
stock_threshold … =BO_i,k
pmax … =PMAX_i^{1..T}
max_stock_before_refueling … =AMAX_i,k
max_stock_after_refueling … =SMAX_i,k
refueling_cost … =C_i,k
fuel_price price_of_the_remaining_fuel_at_end =C_i,T
begin current_campaign_profile
profile_points number_of points = Np
decrease_profile f1 c1 f2 c2 … f_Np c_Np  =PB i,-1
```



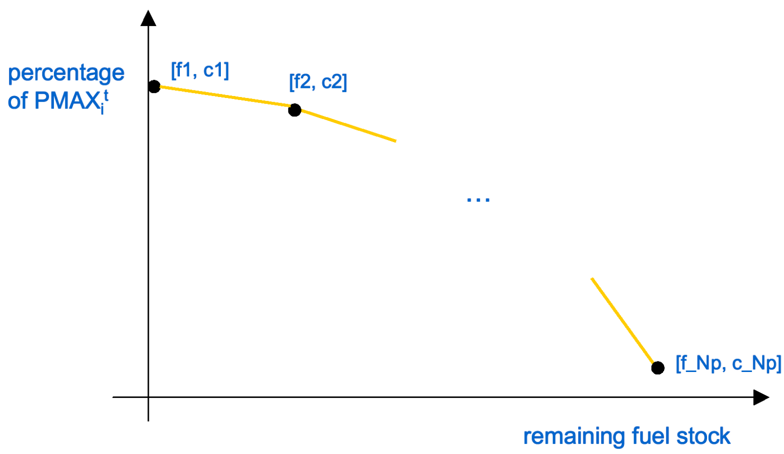
```
end current_campaign_profile
begin profile
campaign_profile index_of_the_campaign
profile_points number_of points = Np_i,0
decrease_profile f1 c1 f2 c2 … f_Np c_Np   =PB_i,0
end profile
…
begin profile
campaign_profile index_of_the_campaign
profile_points number_of points = Np_i,K-1
decrease_profile f1 c1 f2 c2 … f_Np c_Np   =PB_i,K-1
end profile
end powerplant
```

N.B.1 Certain parameters in the input file may appear K+1 times even though only K values are needed.

The current campaign data refer to parameters of the production campaign that is underway at the beginning of the considered time horizon. The rest of the data applies to subsequent production campaigns with outages to be scheduled.

N.B.2 The imposed decreasing power profile is defined by Np points (fuel, percentage of PMAX) coupling the stock of remaining fuel to percentage of maximum power output:

N.B.3. If BO>f1, the imposed decreasing power profile has an additional point [f0,c0]=[B0,1]:



4.1.3. Constraint section

For all the constraints that are applied on a set of outages A_m the input file will contain only Type 2 power plants. If no applicable information exist for a certain parameter in a given data set, the data file will contain a –1 in the place of this parameter. Also note that sets Am are defined by sets of C_mType 2 power plants.

```
begin constraint
type 13 to 21
index index_of_the_constraint
…
end constraint
```

4.1.3.1. CT13

```
begin constraint
type 13
index index_of_the_constraint
powerplant index_of_the_power_plant_of_type2 =i
campaign index_of_the_campaign =k
earliest_stop_time earliest_stop_time =TOi,k
latest_stop_time latest_stop_time =TAi,k
end constraint
```

N.B. The formulation of CT13 refers to earlierst and the latest start of the outage. The earliest_stop_time and latest stop time refer to the cessation (stop of) production of the power plant (start of an outage = cessation of production)

4.1.3.2. CT14

```
begin constraint
type 14
index index_of_the_constraint =m
set … =Cm
spacing spacing =Sem
end constraint
```

N.B. This constraint impacts only a subsetC_m of type 2 power plants. A_m is the set of all outages of type 2 power plants in C_m.

4.1.3.3. CT15

```
begin constraint
type 15
index index_of_the_constraint =m
set … =Cm
spacing spacing =Sem
start first_week_of_the_constraint =IDm
end last_week_of_the_constraint =IFm
end constraint
```

N.B. This constraint impacts only a subset $\mathbf{C_m}$ of type 2 power plants. $\mathbf{A_m}$ is the set of all outages of type 2 power plants in $\mathbf{C_m}$.

4.1.3.4. CT16

```
begin constraint
type 16
index index_of_the_constraint =m
set … =Cm
      spacing spacing =Sem
end constraint
```

N.B. This constraint impacts only a subset $\mathbf{C_m}$ of type 2 power plants. $\mathbf{A_m}$ is the set of all outages of type 2 power plants in $\mathbf{C_m}$.

4.1.3.5. CT17

```
begin constraint
type 17
index index_of_the_constraint =m
set … =Cm
spacing spacing =Sem
end constraint
```

N.B. This constraint impacts only a subset $\mathbf{C_m}$ of type 2 power plants. $\mathbf{A_m}$ is the set of all outages of type 2 power plants in $\mathbf{C_m}$.

4.1.3.6. CT18

```
begin constraint
type 18
index index_of_the_constraint =m
set … =Cm
spacing spacing =Sem
end constraint
```

N.B. This constraint impacts only a subset $\mathbf{C_m}$ of type 2 power plants. $\mathbf{A_m}$ is the set of all outages of type 2 power plants in $\mathbf{C_m}$.

4.1.3.7. CT19

```
begin constraint
type 19
index index_of_the_constraint =m
quantity quantity_of_available_resources =Qm
set … =Cm
begin period
powerplant index_of_the_power_plant=i
```



```
start … =L^m_i,k
duration … =TU^m_i,k
end period
…
begin period
powerplant index_of_the_power_plant=i
start … =L^m_i,k
duration … =TU^m_i,k
end period
end constraint
```

N.B. This constraint impacts only a subset C_m of type 2 power plants. A_m is the set of all outages of type 2 power plants in C_m.

4.1.3.8. CT20

```
begin constraint
type 20
index index_of_the_constraint =m
week week =h_m
set … =C_m
max maximum_allowed =N^m
end constraint
```

N.B. This constraint impacts only a subset C_m of type 2 power plants. A_m is the set of all outages of type 2 power plants in C_m.

4.1.3.9. CT21

```
begin constraint
type 21
index index_of_the_constraint =m
set … =C_m
startend interval_of_time =IT_m
max maximum_unavailable_power =IMAX_m
end constraint
```

4.2. Output file

The output file contains information about the dates of outages, quantity of reloaded fuel, overall costs and output level of each power plant for every time step.

```
begin main
team_identifier identifier_of_the_participating_team
solution_time_date dd/mm/yy hh:mm:ss
```

```
solution_running_time hh:mm:ss
data_set name_of_data_set_used_for_solution
cost total_cost
end main
begin outages
name name_of_power_plant
index power_plant_index
outage_dates outage_start_week outage_start_week outage_start_week
reloaded_fuel fuel1 fuel2 fuel3
name name_of_power_plant
index power_plant_index
outage_dates outage_start_week outage_start_week outage_start_week
reloaded_fuel fuel1 fuel2 fuel3 =r(i,0), r(i,k), … r(i,K-1)
…
name name_of_power_plant
index power_plant_index
outage_dates outage_start_week outage_start_week outage_start_week
reloaded_fuel fuel1 fuel2 fuel3 =r(i,0), r(i,k), … r(i,K-1)
end outages
begin power_output
scenario scenario_number
begin type1_plants
name  name_of_power_plant  power_plant_index=p(j,0,s),  p(j,t,s),…p(j,T-1,s)
name name_of_power_plant power_plant_index =p(j,0,s), p(j,t,s),…p(j,T-1,s)
…
name name_of_power_plant power_plant_index =p(j,0,s), p(j,t,s),…p(j,T-1,s)
end type1_plants
begin type2_plants
name name_of_power_plant power_plant_index =p(i,0,s), p(j,t,s),…p(i,T-1,s)
fuel_variation fuel_t1 fuel_t2 … fuel_T = x(i,0,s), x(i,t,s), … x(i,T-1,s)
remaining_fuel_at_the_end fuel =x(i,T,s)
name name_of_power_plant power_plant_index =p(i,0,s), p(i,t,s),…p(i,T-1,s)
fuel_variation fuel_t1 fuel_t2 … fuel_T =x(i,0,s), x(i,t,s), … x(i,T-1,s)
remaining_fuel_at_the_end fuel =x(i,T,s)
…
name name_of_power_plant power_plant_index =p(i,0,s), p(i,t,s),…p(i,T-1,s)
fuel_variation fuel_t1 fuel_t2 … fuel_T =x(i,0,s), x(i,t,s), … x(i,T-1,s)
remaining_fuel_at_the_end fuel =x(i,T,s)
end type2_plants
scenario scenario_number
```

```
begin type1_plants
name name_of_power_plant power_plant_index =p(j,0,s), p(j,t,s),…p(j,T-1,s)
…
end type1_plants
begin type2_plants
name name_of_power_plant power_plant_index =p(i,0,s), p(i,t,s),…p(i,T-1,s)
fuel_variation fuel_t1 fuel_t2 … fuel_T =x(i,0,s), x(i,t,s), … x(i,T-1,s)
remaining_fuel_at_the_end fuel =x(i,T,s)
…end type2_plants
end power_output
```

If some outages are unnecessary and unscheduled, one should set its *outage_start_week* to -1. All next outages must also be set to -1.

EDF and the challenge organizers reserve the possibility to introduce some minor modifications in the subject or in data sets, if needed. The official version on the subject will be available on the website. A log of updates will be also available online.