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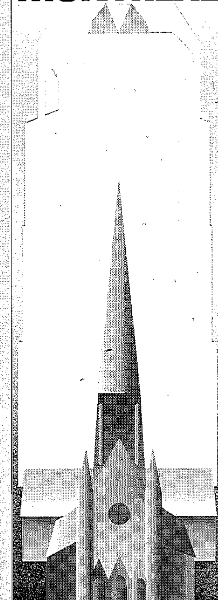

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OPERATIONS PLANNING OF HYDRO-QUEBEC GENERATION SYSTEM USING CHRONOLOGICAL SIMULATION

by

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HYDRO-QUÉBEC

SUMMARY

This article describes a Monte Carlo chronological simulation model used by Hydro-Quebec in operations planning to perform the peak power analysis of its generation system.

After the presentation of the different applications of the peak power analysis, it outlines the resolution approach. The uncertainties on load and supply are detailed along with the characteristics of the peak management means (peaking thermal plants, imports and exports, demand-side management, loss of load).

Finally, a discussion on the implementation of the model is provided along with a sample of results.

Key-words : Generation adequacy, reserve requirements, operations planning, Monte Carlo simulation, hourly chronological model, peak power analysis.

1. HYDRO-QUEBEC GENERATION SYSTEM

Hydro-Quebec operates a system of generation, transmission and distribution of electricity. Its main particularity is the large proportion of hydroelectric generation. From an installed capacity of about 26,000 MW at the end of the 1990, 93% is hydroelectric. In 1990, 95% of the energy generation of 115 TWh was from the 44 hydroelectric plants, another 3.5% being supplied by the Gentilly 2 nuclear plant.

The system is interconnected to neighbouring systems of Canadian provinces and American states. Import and export transactions take place with neighbouring systems for firm and interruptible power and energy.

2. THE OPERATIONS PLANNING PROCESS

At Hydro-Quebec, the operations planning process involves different time horizons. The long term horizon [1] looks into the next 15 years, the mid term horizon [2] the next year and the short term horizon, the next month.

In those horizons, the process may be seen as two interrelated problems. First, a peak power analysis is made by taking into account the hourly pattern of the components of load and supply. Second, an optimization model will distribute the energy on different periods and plants (or even units) in order to meet the load and to optimize the use of water in reservoirs. The approach used in such an optimization model may vary with each horizon. [1,3,4].

This paper deals with the first problem, the peak power analysis.

3. DESCRIPTION OF THE PROBLEM

Table 1 shows a typical forecasted power balance for the winter peak hour of an upcoming 12-month period. The demand side includes internal and export loads each comprising an interruptible portion. The supply side accounts for all possible sources of power: hydraulic and nuclear, peaking thermal and imports. The maximum capacity is reduced by hydraulic restrictions (reservoir levels, inflows to run-of-river plants, ice cover restrictions, water temperature,...), planned outages of units and locked-in capacity caused by transmission outages or limitations.

	(MW)
DEMAND	
Internal demand	30000
- Automatic peak shaving	- 1000
- Interruptible	- 1000
Exports	2700
- Interruptible	- 2300
	28400
SUPPLY	
Maximum capacity	27500
- Hydraulic restrictions	- 1200
- Planned outages	- 300
- Locked-in capacity	- 200
+ Imports	+ 6500
	32300
AVAILABLE MARGIN	3900

Table 1 - Typical power balance

This power balance allows the planner to assess the forecasted available margin for the next peak period. However, such a power balance contains many uncertainties as most of its components do. The internal load depends on climatic variations and economic parameters, the hydraulic restrictions depend on inflows (and to a lesser extent on energy demand) and unplanned outages of generation and transmission facilities may happen. All these uncertainties define the stochastic nature of the problem.

Moreover, such a power balance repeats continuously and thus the problem also has a chronological nature.

A portion of the power balance that takes more and more importance in Hydro-Quebec's operations planning process is what we define as peak management means such as thermal peaking plants, capacity imports, interruption of exports, demand-side management either automatic (customers switching to a back-up energy source when outside temperature is below a predetermined threshold) or controllable by the system operator (interruptible loads). In 1991, the sum of those means will total approximately 20% of the annual peak load. Reduction of minimum operating reserve and of firm load, although unwanted, may also be seen as peak management means in the simulation process for the evaluation of system adequacy.

The use of these means is restricted by physical and contractual constraints (e.g. minimum notice, bounds on number of hours per use, minimum number of hours between uses, annual use limitations, priority order) and by economic considerations.

During the normal course of the operations planning and decision-making process, many specific questions and preoccupations have to be answered such as:

- The generation adequacy, i.e. the capacity of the generation system to satisfy the load demand taking into account operational constraints, the measure of which may take different forms such as loss of load expectation (LOLE), loss of load probability (LOLP) and expected unserved energy (EUE).

- The reserve required to satisfy a predetermined adequacy criterion for each time horizon, the value of which may imply building new plants (long term), purchasing capacity power for the upcoming winter months (mid term) or committing means having a non-zero lead time (short term).

- Trade-off between reliability gains and additionnal cost of increasing the reserve.

- Expected use of interruptions allowed in internal and export contracts.

- Pricing of interruptible contracts according to their utilization constraints.

- Expected fuel needs.

- Expected use of capacity import contracts; expected capacity available for exports.

- Optimal ordering of the many peak management means depending on annual use limitations, priority constraints and cost.

- Maintenance scheduling and cost evaluation of an outage.

- Economic value of improving load forecast, of reducing the forced outage rate,...

- Input to the energy optimization model (impact of peak on energy such as minimum thermal energy generation per period).

All of the above applications are typical motivations that led to the development of the model described in this paper.

4. RESOLUTION APPROACH

To solve the problem addressed here, it is needed to model the system in many details.

The hydraulic restrictions, the duration of generating units outages and the constraints of use of the peak management means all have a chronological dependency and, as pointed out in [5], cannot easily be modelled with the probabilistic approach using load duration curves. Consequently, it was chosen here to use an hourly Monte Carlo simulation approach to cover both the chronological and stochastic nature of the problem and to allow flexibility in the representation of the system, especially from an operations planning point of view where questions are very specific.

Figure 1 shows the overall layout of the model. It is basically composed of a certain number of sub-models each depicting a particular uncertainty, and of the main part of the model that simulates the use of the peak management means.

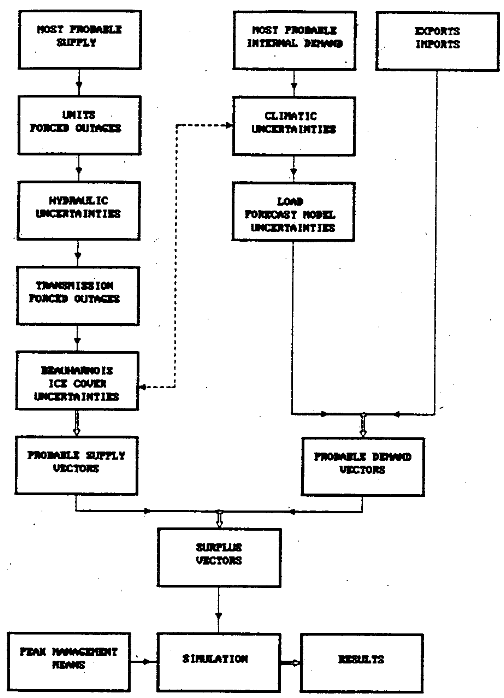

Figure 1 - General diagram of the model

For N simulations, each sub-model generates N random hourly vectors that reproduce N possible representations of a particular uncertainty for the study period (up to 8760 hours). One simulation consists of using one vector from each sub-model and building a "surplus" vector indicating for each hour the difference between supply and demand (before counting on the peak management means). This hourly surplus vector is then used for stacking the peak management means according to their characteristics.

In fact, each simulation faces a given scenario describing, for the studied period, a possible sequence of events.

5. MODELLING OF UNCERTAINTIES

Each sub-model is unique as it describes a particular phenomenon. The Hydro-Quebec system is presently defined using 7 different sub-models.

5.1 Export and import markets

Firm and interruptible contracts were chosen to be expressed as a deterministic demand. The hourly variation is modelled by dividing each week in time zones. For example, instead of providing 168 different values for a market for a week, one may choose to supply only 6 values, the first tied to predetermined peak hours and the last to low-load hours. Both exports and imports may be represented, the latter being seen as a negative demand.

In some cases, this flexible framework is useful to model other deterministic characteristics such as average forced outage or loss of hydraulic capability during off-peak hours.

5.2 Climatic uncertainty

The internal load is highly sensitive to weather conditions such as temperature, wind and sunlight. For instance, a decrease of 1°C during winter may lead to a load increase of about 350 MW mainly due to electrical heating.

The climatic uncertainty is modelled by "reliving" each hour of the last 26 years of historical climatic data in the new context of the forecasted load conditions of the study period. Moreover, each year of historic data is shifted plus and minus 3 days to gain information on extreme conditions that occurred during a weekend for example. Such an exercise constitutes a set of 182 different demand scenarios for a mid term horizon. Each time the mid term forecast changes, these 182 vectors are updated.

For the short term horizon (less than a week), the weather forecasts and their distribution of error are used to generate any given number of hourly variations.

5.3 Load forecast model uncertainty

Even perfectly knowing the weather conditions, the load forecast carries a "structural" uncertainty caused mainly by demographic and economic parameters that affect the total energy in the study period. Such an uncertainty on total energy may be seen as having a normal distribution and affecting each hour of a scenario in the same direction, with greater magnitude the further we get from time zero.

Once the structural scenario is set, its distribution on an hourly scale still leads to uncertainties which are modelled by normally distributed hourly errors.

5.4 Units forced outages

In addition to a maintenance schedule of the generating units, the system will encounter forced outages. During the study period, each unit will go through a succession of available states and unavailable states (in addition to maintenance periods). To simulate the behaviour of each unit, the durations of available and unavailable periods must be studied. One approach is to fit these with their statistical distribution (usually exponential) and draw random occurrences from it.

Our approach is rather to randomly draw directly from the historical data of availability and unavailability durations of the last 10 years.

Many refinements may be adopted to improve the representation of the forced outage uncertainty. Some factors may influence the availability of units, e.g. the time of year, the type, size and age of units, and the extension of a planned outage. Any such refinement may be easily taken into account with our approach.

5.5 Hydraulic uncertainty

At first, hydraulic restrictions of plants are computed from the forecasted evolution of reservoirs storage and flows through run-of-river plants. However, the uncertainty of inflows has an impact on these restrictions.

A weekly hydraulic energy simulation model, taking into account the variability of inflows, is used in the operations planning process to monitor the risks of spilling, of draining or of violating certain hydraulic constraints. Some results of that model are used as inputs here to express the variations of the parameters that influence the hydraulic restrictions.

Special attention must be paid to the interrelations between this sub-model and the forced outages in order to always maintain an accurate counting of available capacity (for example, by not assessing an hydraulic restriction to a unit that is already on forced outage).

5.6 Transmission forced outages

In Hydro-Quebec transmission system, outages of certain strategic components may significantly limit the total generation of a subset of plants. These limitations must be taken into account (again tying this calculation to outages of units and hydraulic restrictions already deducted). Moreover forced outages of the components of the transmission system that have a known effect on generation may be simulated.

5.7 An example of other uncertainties

With the Monte Carlo simulation approach, about any characteristic of the system may be modelled by adding a module to the diagram shown in figure 1. An example of such a particular uncertainty is found in the Hydro-Quebec system.

The Beauharnois hydraulic plant has a significant capacity reduction during ice cover formation (up to 800 MW unavailable during a week) and thereafter. The time period of such restriction is variable and dependent on temperature. This uncertainty is modelled by applying the historical weather conditions to today's ice formation process. But because of the temperature dependency, this uncertainty is highly correlated to the internal load (see 5.2). Therefore, one simulation must use the same year's historical data for both.

6. MODELLING OF PEAK MANAGEMENT MEANS

Choosing a simulation approach was strongly guided by the ever increasing number and variety of peak management means in the Hydro-Quebec system. The parameters of the model for each peak management means are:

- available capacity for each period;
- priority order;
- minimum and maximum hours of continuous use;
- minimum hours between uses;
- incremental MW use (to reflect means that are used by block);
- minimum acceptable level of surplus to avoid the use of this means (means with long lead times will be given a higher level);
- cost per MWh.

These different parameters allow all the flexibility needed to model the peak management means. A means may also be identified as the reduction of an export market already mentionned in 5.1.

7. MONTE CARLO SIMULATION PROCESS

Once all the different sub-models have generated different scenarios, these are merged to obtain different surplus vectors each representing a plausible outcome of events. These vectors are input into the main simulation process along with the characteristics of the peak management means that need to be studied. Figure 2 illustrates the process for one scenario of 48 hours.

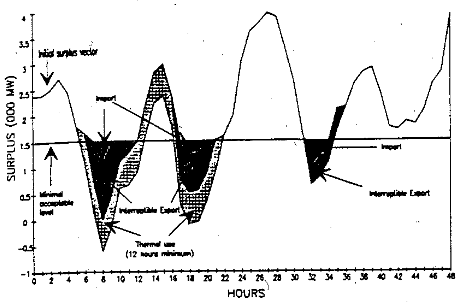

Figure 2 – EXAMPLE OF PEAK MANAGEMENT MEANS UTILIZATION

The algorithm must examine all the hourly surpluses and assess the need for each peak management means taking into account its constraints. This process may be time-consuming and affect the success of the Monte Carlo approach. Thus, throughout the implementation, special attention must be paid to such an algorithm. For example, by keeping track of results from preceding peak management means, improvements can be achieved. By the same token, flexibility and modularity are important aspects of the model. An important feature is the conservation of results of sub-models and the possibility of not re-running some of them. For example, the mid term load forecast is changed 3 or 4 times a year; so the sub-models related to load need only to be executed a few times a year, thus saving much computer time. It is also a way to keep all uncertainties constant and run many scenarios by only varying the peak management means characteristics, or to achieve sensitivity analyses. Another feature is the possibility to select which uncertainties and reports are active for a certain study.

8. EXAMPLE OF RESULTS

The model presently implemented allows Hydro-Quebec to fulfil many needs in the use of the peak management means by providing, for any period, the frequency, the number of hours, the total energy, the cost and different statistical distributions. An example for such results, for a 12-month period is shown in table 2.

Peak Management Means	Expected use			15 % exceed. probab.
	freq. (%)	hours	energy (GWh)	energy (GWh)
Thermal 1	100	700	350	700
Import 1	90	100	5	10
Interruptible Exports	98	200	75	150
Import 2	92	125	40	70
Thermal 2	68	45	15	30
Interruptible Internal load 1	57	25	2	4
Import 3	56	30	10	20
Interruptible Internal load 2	48	20	20	50
Thermal 3	44	5	2	3
Reduction, firm exports	24	2	1	1
Reduction, firm internal load	4	0.3	0	1

Table 2 - Example of results

Sensitivity studies have shown that although all modelled uncertainties have an influence on the adequacy of the system, the climatic, load forecast and units forced outages uncertainties were the most significant.

The model was used to determine a probabilistic mid term required reserve policy that depends on desired risk. For the short term problem (the next days), studies will be made to use the model for the assessment of risk associated to decisions. One concern of this horizon is to maintain an acceptable risk without unduly using costly or limited means having a significant lead time. The main uncertainty of that horizon is the climatic one which decreases significantly as it approches time zero. It will be fast to simulate thousands of scenarios of 48 hours to monitor the risk and obtain frequent gains in the decision-making process.

Future improvements of the model that are of interest include a better representation of outages and of hydroelectric units with short term limited generation capability. The computer time can be reduced by the implementation of faster algorithms in the crucial parts of the model and parallel processing [6,7] may be a good research avenue.

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SOMMAIRE

À Hydro-Québec, le processus de planification de la production peut-être perçu comme deux problèmes inter-reliés, quel que soit l'horizon d'étude (long, moyen ou court terme). Premièrement, une analyse de puissance doit être effectuée pour s'assurer qu'à tout instant, et particulièrement aux pointes, l'entreprise peut satisfaire la demande avec ses équipements disponibles et en tenant compte des moyens de gestion existants. Deuxièmement, une répartition temporelle et spatiale de l'énergie hydroélectrique (qui constitue 95% de la production) doit être réalisée, en optimisant l'utilisation de l'eau des réservoirs.

Cet article se concentre sur le premier problème, soit l'analyse de puissance. Plusieurs applications doivent y être traitées, notamment:
- la fiabilité du système;
- la réserve requise en puissance pour chacun des horizons de planification;
- l'utilisation espérée des divers moyens de gestion de pointe:
  - . production des centrales thermiques (et besoins de combustible);
  - . interruption de charges internes et externes (ventes aux réseaux canadiens et américains interconnectés) en vertu de contrats;
  - . achat auprès des réseaux voisins interconnectés;
- l'ordonnancement optimal des moyens de gestion de pointe;
- l'évaluation d'un nouveau moyen de gestion en fonction du service rendu, considérant toutes ses contraintes d'utilisation;
- la planification de la maintenance.

Dans toutes ces applications, la stochasticité des éléments de l'offre et de la demande doit être prise en compte.

L'approche classique utilisant des courbes de puissances classées n'a pas été jugée satisfaisante pour répondre aux précédentes préoccupations. En effet, les contraintes d'utilisation des moyens de gestion de pointe (minimum et maximum d'heures consécutives, minimum d'heures entre deux utilisations,...), la durée des pannes d'équipement ou encore les restrictions hydrauliques ont toutes une nature chronologique et l'omission de cette caractéristique a beaucoup d'impact sur l'évaluation de la fiabilité du système.

Nous avons donc développé un modèle de puissance horaire et chronologique basé sur des simulations Monte Carlo. Celui-ci reproduit d'abord les aléas qui surviennent en exploitation, par exemple:

- les aléas météorologiques et économiques ayant une forte influence sur la demande;
- les pannes de groupes et d'éléments de transport;
- l'aléa hydraulique qui affecte la production de pointe de certaines centrales.

Ceci détermine un certain nombre (au choix) de cas probables d'offre et de demande. L'utilisation des divers moyens de gestion est ensuite simulée horairement pour combler, au besoin, l'écart entre l'offre et la demande. De l'analyse de ces différents cas probables, on obtient une évaluation probabiliste de l'utilisation des moyens de gestion et de la fiabilité en puissance du scénario étudié.

La simulation Monte Carlo permet toute la souplesse requise pour bien représenter l'exploitation d'un système complexe avec des caractéristiques variées. L'inconvénient d'une telle méthode réside souvent dans le temps de calcul; par conséquent, un effort particulier doit être mis dans l'optimisation des algorithmes. Des résultats satisfaisants ont été obtenus sur des problèmes annuels (8760 heures). Le modèle est très flexible et permet des changements rapides de scénarios pour des besoins d'étude.