Assessment on Scheduling Coal Power Station Maintenance

Pedro Sánchez-Martín, Santiago López-de-Haro
IIT, Universidad Pontificia Comillas, Alberto Aguilera 23, 28015-Madrid, Spain
pedro.sanchez@iit.upco.es http://www.iit.upco.es

Joaquín Fernández-Caro, Jorge E. delaHoz
ViesgoEnel S.A., Orense 11, 28003-Madrid, Spain

Abstract

A new mathematical model has been developed to assess on power station maintenance scheduling. Preventive and predictive maintenance decisions are evaluated jointly in a liberalized electric market context. A three-station case study is shown.

1. Introduction

Usually generating conditions of coal power stations are becoming degraded as station continuous on time increases. Main station components, such as boiler's tubes, burners and coal mills, are progresively deteriorated as they are used. This deterioration is more significant as the station is getting older. Stations unavailabilities are classified as follows: unscheduled unavailabilities, which take place due to critical component failures, and scheduled unavailabilities that are caused by predictive and preventive maintenance actions.

General management strategies for preventive and predictive maintenance of power units are described in [1]. On one hand, preventive maintenance consists of periodical checking and replacement actions of damaged components along station lifetime. After performing those actions, stations improve their reliability and operative conditions. Power stations should be off while preventive maintenance. On the other hand, predictive maintenance estimates the time to failure of main station components. This kind of maintenance tries to minimize its impact on energy production, so some times power stations are able to generate simultaneously. However, predictive maintenance actions usually improve availability station rate less than preventive ones do.

An achievement of this research consists of developing a mathematical programming model to schedule optimally preventive and predictive maintenance strategies together. Additionally this model considers variable station unavailability rates that depend on cumulative committed time and maintenance actions.

The main objective of maintenance management depends on the electric market regulation. In a centralized electric system planning, power station maintenance is

C. Spitzer et al. (eds.), *Probabilistic Safety Assessment and Management*
© Springer-Verlag London 2004

scheduled so that it minimizes system production cost [2], [3] and [4]. However, in a decentralised electric system planning, these maintenance decisions are focused on company profit maximization [5]. These profits are based on the combination of energy market price and production. Then, a maintenance scheduling in a liberalised energy market requires an energy price estimation along the study horizon.

2. Mathematical model description

The mathematical model is based on a mixed integer linear programming model that approximates station reliability using unavailability rates, Q, in a deterministic way. Those rates change their values depending on the production and maintenance schedule optimised by the model.

2.1. Notation

Indices

s : station index
p, p' : period indeces
l : demand level index

Data

$t_{p,l}$: period and level duration [h]
$\lambda_{p,l}$: market price estimation [€/MW]
$\overline{p}_s$: station maximum capacity [MW]
$\underline{p}_s$: station minimum capacity [MW]
$\overline{q}_s$: station maximum unavailability rate
$\underline{q}_s$: station minimum unavailabity rate
td_s :equivalent predict.maint.duration[h]
qi_s : station unavailab.increment [%/h]
$\overline{nd}_s$: predict. maint. maximum number
$\overline{nv}_s$: prevent. maint. maximum number
cs_s : station start cost [€]
b_s : station intercept generating cost [€/h]
a_s : station cost slope [€/MWh]
cd_s : predictive maintenance cost [€]
cv_s : preventive maintenance cost [€]
qd_s : station unavailab.reduction due to predictive maintenance [p.u.]
qv_s : station unavailab.reduction due to preventive maintenance [p.u.]
pv_s : prevent. maint. duration [periods]
ql_s : station predictive limit unavailability rate [p.u.]

Decision and state variables

$P_{s,p,l}$: station output [MW]

$C_{s,p}$: station commitment indicator [0/1]

$X_{s,p}$: station start indicator [0/1]

$V_{s,p}$: station preventive maintenance start indicator [0/1]

$D_{s,p}$: station predictive maintenance indicator [0/1]

$Q_{s,p}$: period station unavailability rate [p.u.]

$I_{s,p}$: station under limit unavailability rate indicator [0/1]

2.2. Objective Function

The objective function (1) maximizes global station profit subtracting generating, start and maintenance costs from market incomes assuming energy market price trayectory.

$$Max \sum_{s,p,l} t_{p,l} \cdot \lambda_{p,l} \cdot P_{s,p,l} - \sum_{s,p,l} t_{p,l} \cdot \left[b_s \cdot C_{s,p} + a_s \cdot P_{s,p,l} \right]$$
$$- \sum_{s,p} \left[cs_s \cdot X_{s,p} + cv_s \cdot V_{s,p} + cd_s \cdot D_{s,p} \right] \quad (1)$$

2.3. Constraints

Maximum and minimum generation limits are modeled on constraints (2) & (3). Station start indicator is assigned evaluating consecutive commitment indicators in constraint (4). Repetitive preventive and predictive actions are bounded with constraints (5) and (6) respectively. Constraint (7) cancels station commitment indicators out for the number of periods where preventive maintenance is performed. Constraint (8) avoids preventive and predictive maintenance time coincidence among stations.

Generating capacity per period is updated bearing in mind, in an additive way, the current unavailability rate, Q, and when predictive maintenance is scheduled, the proportion of equivalent predictive duration to the period time (9). Combined effects of unavailability rate and predictive maintenance duration are not evaluated.

Depending on the current unavailability rate value, it is possible to choose between preventive or predictive maintenance action or only be able to perform preventive actions. Constraint (10) establishes those rate limit indicators to choose the

kind of maintenance and constraint (11) cancels predictive options when those rate limits are exceeded.

Finally, unavailability rates grow as station commitment time increases and diminishes as maintenance actions are taken (12). These rates are updated each period and predictive maintenance duration are discounted from the period duration.

$P_{s,p,l} \le \overline{p}_s \cdot C_{s,p} \quad \forall s,p,l$ (2)	$P_{s,p,l} \ge \underline{p}_s \cdot C_{s,p} \quad \forall s,p,l$ (3)
$X_{s,p} \ge C_{s,p} - C_{s,p-1} \quad \forall s, p>1$ (4)	$\sum_p V_{s,p} \le \overline{nv}_s \quad \forall s$ (5)
$\sum_p D_{s,p} \le \overline{nd}_s \quad \forall s$ (6)	$\sum_{p'=p}^{p+pv_s-1} C_{s,p'} \le (1-V_{s,p}) \cdot pv_s \quad \forall s,p$ (7)
$\sum_{s',p'=p}^{p+pv_s-1} D_{s',p'} + \sum_{\substack{s' \ne s \\ p'=p}}^{p+pv_s-1} V_{s',p'} \le 1-V_{s,p}; \forall s,p$ (8)	$P_{s,p,l} \le \overline{p}_s (1-Q_{s,p} - \frac{td_s}{\sum_l t_{p,l}} D_{s,p}); \forall s,p,l$ (9)
$Q_{s,p} \le \overline{q}_s \cdot (1-I_{s,p}) + ql_s \cdot I_{s,p} \quad \forall s,p$ (10)	$D_{s,p} \le I_{s,p} \quad \forall s,p$ (11)
$Q_{s,p} \ge Q_{s,p-1} - qv_s \cdot V_{s,p-1} - qd_s \cdot D_{s,p-1} + qi_s \cdot \left(C_{s,p} \cdot \sum_l t_{p,l} - D_{s,p} \cdot td_s \right) \quad \forall s,p$ (12)	

3. A Case Study

A three coal power stations maintenance has been optimised for a 52-period horizon. Economic and technical characteristics of these stations are shown at Table 1. Reliability characteristics and energy price evolution are included in Table 2. On the right hand side of Table 2 the energy price evolution is shown.

Station's name	$\underline{p}_s$ [MW]	$\overline{p}_s$ [MW]	a_s [€/MWh]	b_s [€/h]	pv_s	td_u [h]	cs_s [€]	cd_s [€]	cv_s [€]	$\overline{nd}_s$	$\overline{nv}_s$
Alpha	166	400	2.2	100	2	48	700	2000	4000	1	2
Beta	100	350	2.5	70	2	24	500	1500	4000	1	2
Gamma	200	500	2.0	125	2	48	800	2500	7000	1	2

Table 1. Economic and technical and characteristics

	$\underline{q}_g$ [pu]	$\overline{q}_g$ [pu]	qd_s [pu]	qv_s [pu]	qi_s [pu/h]	ql_s [pu]
Alpha	0.05	0.3	0.1	0.25	7e-5	0.15
Beta	0.1	0.25	0.05	0.15	5e-5	0.15
Gamma	0.1	0.35	0.1	0.25	8e-5	0.20

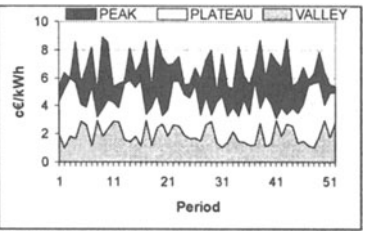

Table 2. Reliability characteristics and Energy Price Evolution

Figure 1, 2 & 3 show unavailability rate evolutions on each station as operation and maintenance decisions are taken. Every station's unavailability rate starts with an initial value and itgrows in a stairwise case as its operation time increases. After performing a maintenance action, unavailability rate is reduced in an amount that depends on the kind of maintenance, preventive or predictive. Figure 2 show that unavailability rate reduction is higher performing preventive maintenance actions than performing predictive ones. Figure 4 shows maintenance actions sparsity for the whole horizon. No simultaneous maintenance among three stations is allowed due to technical limits.

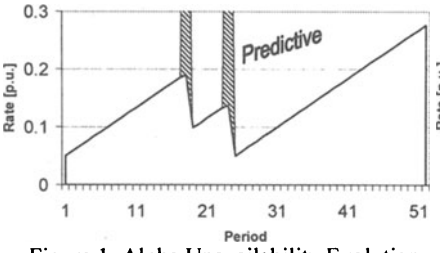

Figure.1. Alpha Unavailability Evolution

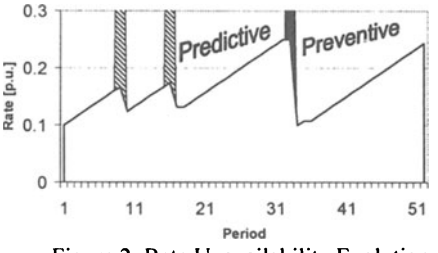

Figure.2. Beta Unavailability Evolution

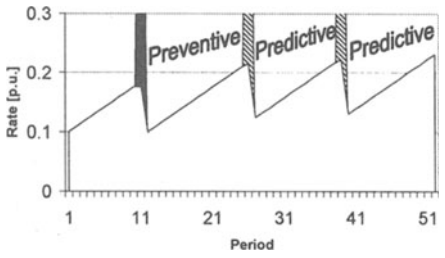

Figure.3. Gamma Unavailability Evolution

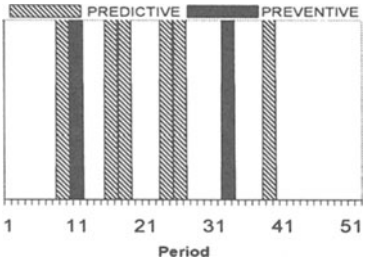

Figure.4. Global maintenance schedule

Figure 5, 6 & 7 show up and down station outputs due to energy market price changes at different demand levels. Additionally, in order to cope with preventive maintenance schedule, it is necessary to shut Beta & Gamma stations down for a couple of consecutive periods. Derated maximum capacity is shown at Alpha generation evolution, Figure 5. At the middle of the same figure there are two maximum production increments due to predictive maintenance actions.

At Figure 6 three stops are assigned to Beta station, one of them is due to preventive maintenance and the other two due to predictive derated capacity and low energy prices.

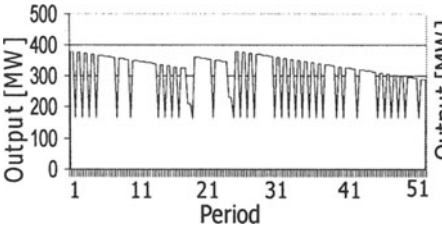

Figure.5. Alpha Output Profile

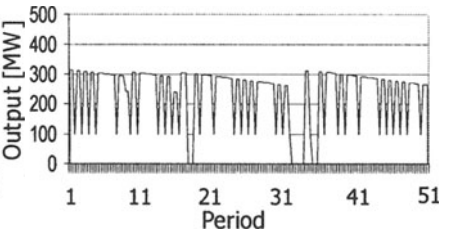

Figure.6. Beta Output Profile

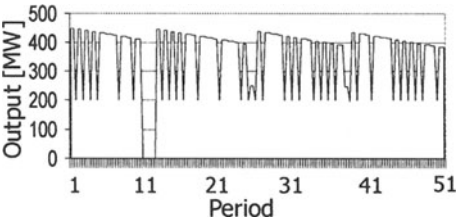

Figure.7. Gamma Output Profile

References

[1] Risk and Probability Applications Subcommittee, "The Present Status of Maintenance Strategies and the Impact of Maintenance on Reliability", *IEEE Transactions on Power Systems, 16, 4 , November 2001 pg 638-646*

[2] Leou, Rong-Ceng, "A Flexible Unit Maintenance Scheduling Considering Uncertainties", *IEEE Transactions on Power Systems, 16, 3, August 2001, pg 552-559*

[3] M.K.C. Marwali et. al. "Long-Term transmission and generation maintenance scheduling with network, fuel and emission constraints" IEEE Transactions on power systems, Vol. 14, No. 3 August 1999

[4] Muñoz, L. and Ramos, A., " Goal programming approach to maintenance scheduling of generating units in large scale power systems*" IEEE PES Summer Meeting. Berlin, 1997*

[5] Centeno, E., Vitoriano, B., et all, "A goal programming model for rescheduling of generation power in deregulated markets*" Annals of Operations Research, No.120, May, 2003*