PROGRAM CEP: POWER ERROR

INTRODUCTION

Of all RRS, it is the CEP module that presents the most difficulties of design. The internal logic of the actual program is very complicated, which makes it very difficult to explain things exactly as they are. The following description is thus really extremely simplified.

The main functions of CEP are:

- determine the power setpoint, and the maneuvering rate of this setpoint
- determine the power error, which plays an important role in the modules CBL, CBC, CBS, and EBA.
- determine if gadolinium addition is required
- maintain or change the control mode of the plant

The details of each of these functions will be explained in the following sections.

CONTROL MODES

In order to simplify our description of CEP, we will describe only aspects related to reactor-leading-turbine mode. It is interesting to mention here the main characteristics of the two control modes.

Reactor-Leading-Turbine mode

When the power plant is operated in Reactor-Leading-Turbine mode, the power to be produced by the reactor and the power maneuvering rate are specified by the operator from keyboard inputs going through the man-machine interface of the control computers. In this control mode, the reactor furnishes a constant power to the steam generators (except, of course during power maneuvers). The pressure control algorithm of the steam generators (RPG) will see that a constant steam flow rate on the secondary side is maintained. Therefore, the power transmitted to the electric grid by the turbo-alternator will also be constant. Thus in this case, the electric power is dictated by the reactor,

Turbine-Leading-Reactor mode

When the plant is in Turbine-Leading-Reactor mode, the power to be produced by the reactor is dictated by the electric grid. Essentially, the variable load applied to the turbo-alternator is translated into a rotational speed change. The speed control of the turbine (the electro-hydraulic control, CEH) is set-up to maintain a constant rotational speed (1800 rpm at Gentilly-2) by opening or closing the steam valves of the turbine. This will have an effect on the pressure of the steam on the secondary side of the steam generators. The pressure regulation program will then adjust the power of the reactor in order to reduce the pressure increase. The reactor power is thus modulated to respond to electric grid power load variations. In this control mode, the reactor power and power change rates are modified by RPG and by the overall plant power control program, RPC. These two programs have outputs which are treated in CEP.

In practice, the G2 plant is maintained in Reactor-Leading-Turbine mode, which is called the "normal" mode at G2. It is easier for the operator of the plant to furnish a fixed power to the electric grid.

If a reactor setback or a reactor stepback is in progress, the CEP will automatically change the control mode to Reactor-Leading-Turbine mode in order to prevent unwanted power increases when these conditions disappear.

FUNCTIONS OF CEP

As we have said, we consider only the Reactor-Leading-Turbine control mode. This simplifies the description of CEP, and makes it much easier to understand the contents of the module.

It is important to note at this point that the variables used to describe the powers in the control programs such as this one. They are all logarithmic (log_{10}), with units the decade. This is because the power behaves characteristically as an exponential, and consequently, the logarithm of the power will vary more slowly and linearly. However, human operators think in linear terms when power is concerned. Therefore, linear powers are used mainly for annunciation on displays. The equivalent internal variables are all in decades. Furthermore, when a power setpoint is specified by an operator in FPP or in %PP, it will be transformed into decades by RRS.

Target Power and Maneuvering Rate

In the normal mode of control, a power setpoint is available and specified by a variable called PRA, the "Required Power in normal control mode". This is usually obtained by a numerical entry to a keyboard made by the plant operator. PRA is a variable read in %PP and transformed internally into decades by RRS.

In the same fashion, a maneuvering rate is always available. This is variable DPLIM, also entered via a keyboard. The variable DPLIM is an index, which can take the values 0, 1, 2, 3 or 4. The power maneuvering rate itself is obtained from the following table:

DPLIM	Rate (decades/sec)	Rate (%FP/sec)	Description
0	0	0	maintain power
1	0.000434	0.1	slow rate
2	0.00108	0.25	normal rate
3	0.00217	0.50	fast rate
4	0.00434	1.0	fast startup rate

We now define another variable, the intermediate power setpoint by the statement

$$SPT = PRA$$

If a power setback is in progress, the following logic is applied to SPT:

If SPT > 2% (i.e. -1.7 decades), then

$$SPT = CPLOG$$

(CPLOG is a variable that we will introduce shortly), and $PRA \leq SPT$
The required power decreases during a power setback.

Computation of Setpoint Change (DPD)

Once the variable SPT is calculated, it becomes possible to calculate the power setpoint change, in the following way:

1. Calculate the required change:
   DELTA = (SPT - CPLOG)/ 8

2. Calculate the KC gain, (see graph on Fig. 4.1)

   KC = 1/ PLNCA   if PLNCA $\geq$ 0.25

   KC = 4   if PLNCA < 0.25

3. Calculate the term   LIM =
   KC * RATE(DPLIM)

4. IF DELTA > 0 then
   DELTA = minimum(DELTA, LIM)

5. IF DELTA < 0 then
   DELTA = maximum(DELTA, -LIM)

6. If a power setback is occurring, the maneuvering rate is specified by DPDSB (which is negative)
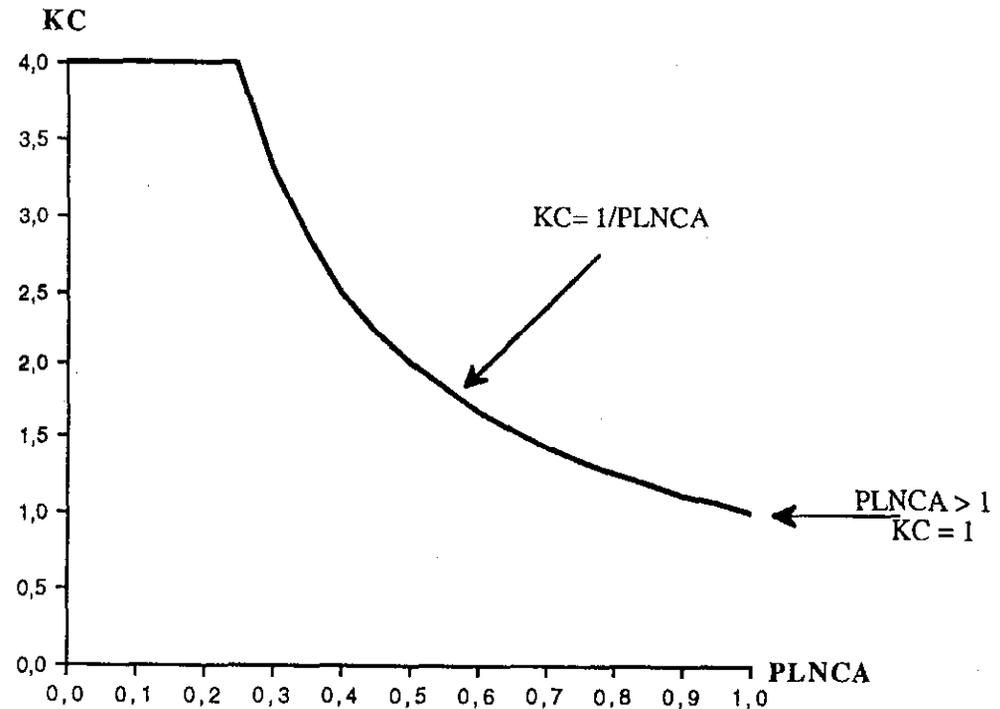
7. and finally DPD = maximum(DELTA, KC * DPDSB)

Figure 4.1: KC versus PLNCA

Note: The KC gain has been chosen such that the maneuvering rate when power is >25% PP becomes linear, i.e. the linear power will change by a constant value each second.

Calculation of Target Power

The first step consists of calculating the KB gain, which will be used to establish a superior limit
for the logarithmic power setpoint:

KLG   = 1.14

KLGB = 1.68

KB   = KLG * PLGCA + KLGB

KB   = minimum(KB, 1.0)

KB   = maximum(KB, 0.2)

The graph of KB is shown on Fig. 4.2.

At each execution of the fast part of CEP, a new
power setpoint of logarithmic power is calculated
from the last value it held (in the previous execution
of CEP) and of DPD, by a simple sum:

$CPLOG_{new} = CPLOG_{old} + DPD$

The condition that if $CPLOG_{new} > 0$, then $CPLOG_{new} = 0$

Figure 4.2: KB versusPLGCA

is imposed. Also if for more than 4 consecutive executions of this part of CEP (fast part), i.e. for
more than 2 seconds, the condition $CPLOG_{new} > PLGCA + 0.0212/KB$
holds true, the following limit is applied to $CPLOG_{new}$: $CPLOG_{new} = PLGCA + 0.0212/KB$
and the flag "deviation limiter" will be set to "ON", and a message is sent to the control room.
This limit is there to prevent too large a difference between the demanded power and the
measured power. In terms of linear powers, a difference of more than 5% at high power
($\geq 25\%$ PP), and of more than 28% at low power ($\leq 5\%$ FP) is prevented. As we will see in the next
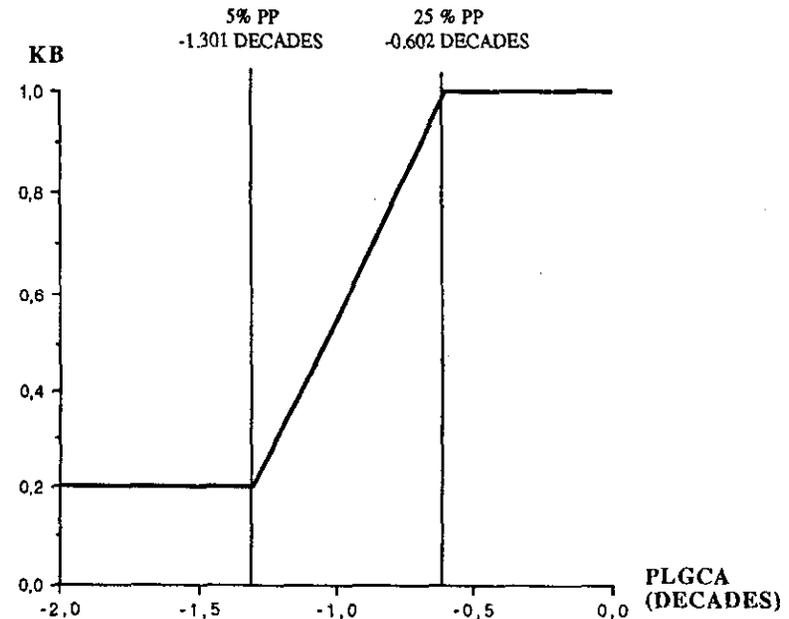section, $CPLOG_{new}$ is used in the evaluation of the power error. In other chapters, we will see that

reactivity devices are moved with speeds depending on this power error. If the power error is very large, the devices would be moved very fast, causing unwanted perturbations.

Power Error Calculation

The power error is a measure of the difference between the measured power and the demanded power of the reactor. It plays a fundamental role in the parts of RRS which govern the movements of reactivity devices. The sign of the power error determines whether to increase or decrease the levels of the zone controllers, as well as removing or inserting adjuster rods and the mechanical control absorbers. When the power error is zero, no movement of devices will be ordered, although device movements ordered before will be completed. A zero power error during a given time interval implies that the reactor is critical. No reactivity balance is compiled for reactor control.

However, the design of the devices themselves could be made using considerations on individual and bank reactivities. If a device is too absorbing or not absorbing enough to accomplish its assigned mission, difficulties will certainly appear in the control process, which will be too fast or too slow. It will have to be compensated in other ways. Thus there is an important interaction between device design and control algorithms during the design stage. Fine tuning of the different parts of the control system will be done throughout the life of the reactor, to reflect changes in aging components and also as new knowledge, especially relating to safety, is obtained.

The power error is made up of two terms, a power term and a rate term, which we will now describe in turn.

Power Term

The power term component of the power error is given by

$$KB * (PLGCA - CPLOG)$$

This term takes into account the fact that the power is not at the demanded level. This difference is taken between the measured power and the demanded power. When this difference is positive, the measured power is too high, and it will have to be reduced. If the difference is positive, it will have to be increased. Note that by CPLOG in the power error formula, we mean $CPLOG_{new}$.

Rate Term

The rate term component of the power error is given by

$$0.5 * (TLOGI - CTMAN)$$

This term is made of the difference between the TLOGI variable, the logarithmic rate of the ion chambers, defined in the MCP module, and the "power rate setpoint" CTMAN=DPD 0.5 decades/second. The 0.5 second factor of this expression comes from the execution interval of this part of CEP. The multiplier gain of 0.5 in the rate term has been chosen on stability grounds.

Power Error

Finally, the power error itself is given by

$$ERPU = KB * (PLGCA - CPLOG) + 0.5 * (TLOGI - CTMAN)$$

Automatic Gadolinium Addition

The last function of CEP is to annihilate slow excursions of power due to uncompensated positive reactivity increases, such as a decrease of Xenon concentration for example. If the condition

$$ERPU > 10\% \text{ (i.e.. } ERPU > 0.0414 \text{ decades)}$$

persists for 2 seconds or more, and that TLOGI > 0 during this interval of time, then a valve of the Gadolinium addition system (not of the injection system!) will open until these conditions disappear. In terms of reactivity, about 0.75mk/minute is added. An alarm is obviously sent when this happens.