NOTE TECHNIQUE

HIERARCHICAL CONTROL FOR OPTIMISED OPERATION OF A GAS PLANT AT MOBIL OIL

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LA COMMANDE HIÉRARCHIQUE
POUR UNE CONDUITE OPTIMISÉE D'UNITÉ DE "GAS PLANT" *(MOBIL OIL FRANÇAISE)*

En s'appuyant sur une application exemplaire, cet article décrit l'intérêt et l'apport de la commande hiérarchique dans la conduite optimisée d'une unité. Après une description des principes de la hiérarchisation, la présentation de l'atelier *gas plant* met en évidence l'intérêt d'une telle approche.
L'architecture de commande fait intervenir des régulations classiques et deux algorithmes de commande prédictive mono et multivariable (MONOREG et IDCOM-HIECON) dont les fonctionnalités sont mises à profit dans l'application. La mise en oeuvre de ces algorithmes comprend plusieurs étapes qui exploitent les outils de CAO associés. Après implantation dans le calculateur du site, les performances sont évaluées dans les différents modes opératoires.

HIERARCHICAL CONTROL
FOR OPTIMISED OPERATION OF A GAS PLANT AT *MOBIL OIL*

This article shows the interest and the benefit of hierarchical control through a typical example as applied to a gas plant. After a description of the hierarchical control principles, the plant is presented to highlight the interest of such an approach.
The implemented control architecture consists of regular controllers and two Model Based Predictive Control algorithms (MONOREG and IDCOM-HIECON) whose capabilities were helpful in this application. The implementation of these algorithms follows several steps which make use of the corresponding CAD tools. The performance is evaluated in different operating conditions, once the designed controllers are installed on the process computer

EL CONTROL JERARQUICO PARA UNA GESTION CENTRALIZADA DE LA UNIDAD "GAS PLANT" *(MOBIL OIL FRANÇAISE)*

Fundándose en una aplicacion ejemplar, se describe en el presente articulo el interés y la aportacion del control jerárquico aplicado a la gestion optimizada de una unidad de produccion. Tras una descripcion de los principios de la jerarquizacion, la descripcion del taller *gas plant* evidencia claramente el interés de semejante enfoque.
En la arquitectura del control jerárquico intervienen las regulaciones convencionales y dos algoritmos de control

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predictivo mono y multivariable (MONOREG e IDCOM-HIECON) cuyas funcionalidades se aprovechan debidamente en la aplicaci6n preconizada. La implementación de estos algoritmos incluye varias etapas que se utilizan por las herramientas CAD asociadas. Tras implantación en el calculador de la planta, se avalúa la eficacia obtenida en los distintos modos operatorios.

This application is in keeping with the quality policy which led the refinery to introduce Model Based Predictive Control in 1989. This methodology applies to a specific level in the control architecture.

1 HIERARCHICAL CONTROL

Quite complex process operation problems can be solved efficiently by structuring the control.
The analysis of a production plant leads to splitting it down into hierarchical levels ranked from 0 to 3. Each level receives its set points from the upper level (Fig. 1).

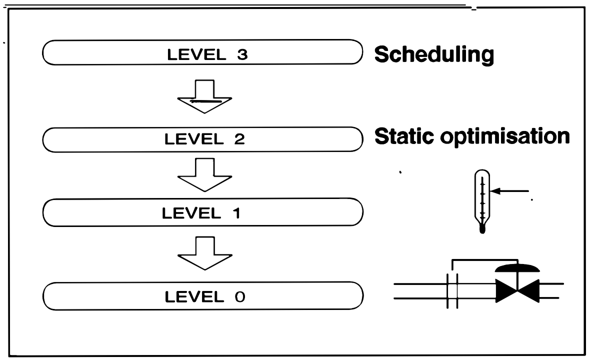
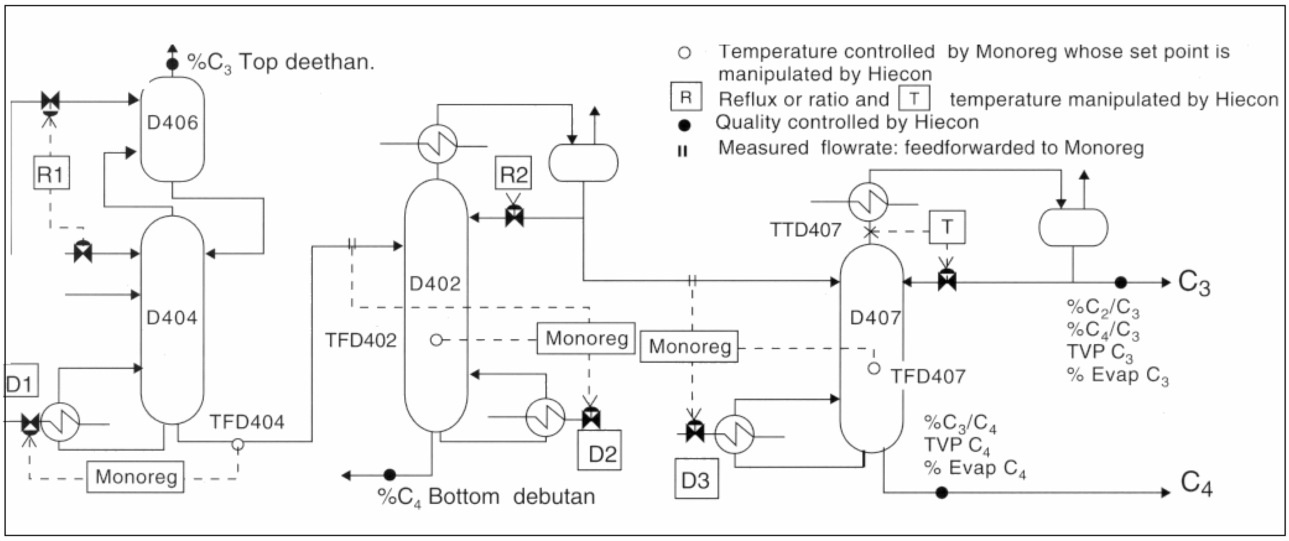


Figure 1
Hierarchical levels

Level 0: this corresponds to basic control (most are flow control loops). At this level, the controllers do not depend on the considered process: the tuning will not be different if the product flow feeds a distillation column or a heater.
The control loops are quite fast (a few seconds). They concern SISO systems, satisfied by PI controllers which cover most of the needs on a given plant.

Level 1: at this level, the control loops are specific to the process. Temperature and quality control loops are typical examples whose tuning depends on the dynamics of each given physical process. These loops may concern MIMO systems (multiple inputs-multiple outputs) and may require feedforwarding. Their response times are roughly around one hour.



At the refinery, depending on the degree of complexity of the process, the controllers are of the PID type or predictive controllers (SISO or MIMO)[l]. At level l, the controllers may also be assigned some constraints to be respected on secondary process outputs.

The actions computed by level 1 controllers are set points that are applied to the level 0 controllers. Level l itself may also be split down into a cascade when it provides better handling of the process subparts.

Level 2: this level is not concerned with dynamic control but carries out static optimisation. This optimisation is based on a static physical model of the process, including non-linearities.

It yields the process operating conditions that will optimise a given economic function in order to satisfy a combination (qualities, quantities) specified by level 3 to this level2.

Level 3: this corresponds to the production scheduling, i.e. fixing production means in time and space according to the market requirements involved.

Hierarchical control is a chain whose every link is important and has to be adjusted step by step.

The advantage of building such a hierarchy is that it allows a global problem to be approached through successive phases; it also makes it possible to react against disturbances at the level where they appear and with the efficiency corresponding to that level.

Such an approach was implemented on several plants at the refinery and in particular on the gas plant, described below.

2 DESCRIPTION OF THE PROCESS

This plant processes gases coming from upstream units (atmospheric distillation, reforming, etc.). The purpose of the gas plant is to separate the different components -propane and butane- according to given specifications [1]. The gas plant processes the gases produced by the distillation of 3.2 million tons of crude oil per year.

The gas plant consists of three main columns; the first one, made of two parts, receives the load. These columns are successively (from left to right in Figure 2 above) the deethaniser, the debutaniser and the depropaniser.

For each of these columns, the qualities to be satisfied are correlated with the top and bottom temperatures.

As usual, these temperatures are controlled by acting on the top reflux and the bottom reboiler.

(I) *SISO:* Single input/single output.

MIMO: Multi-input/multi-output

The required energy comes from the topping column pumparounds.

The bottom part of the deethaniser is fed with liquid and gaseous load and heavy naphtha rises to its top part. This column is used to absorb the heavy components of gases and liquids (C5-C4-C3) and to limit the C2 concentration in the propane C3.

The debutaniser, fed by the deethaniser, separates the heavy naphtha from C4-C3-C2 and adjusts the C5 proportion in C4, The depropaniser, fed by the debutaniser, separates butane from propane with respect to specified concentrations.

The qualities of the products are given by analysers or are computed from measured values. A total of twelve qualities are available for control purposes.

Depending on the operating modes, subsets of these qualities are given specifications.

The gas plant is operated through four different operating modes, each of them corresponding to a specific control strategy.

Specified production and qualities correspond to each operating mode:

- commercial C3/C4, maxi C3: compliance with commercial specifications while maximising propane production;
- commercial C3/C4, maxi C4: compliance with commercial specifications while maximising butane production;
- C3 PDA : production of pure C3 for internal use;
- special C4 : production of specific C4 for petrochemical processes.

3 THE ADVANTAGES OF CONTROL ARCHITECTURE

There are six control actions used to adjust the specified qualities: a reflux rate or ratio and a reboiler duty for each of the three columns.

The following functional representation block diagram shows these actions and the final qualities as a single block, skipping the intermediate effects (Fig. 3).

This system was structured, with respect to the hierarchical control principle, as two separated functional blocks:

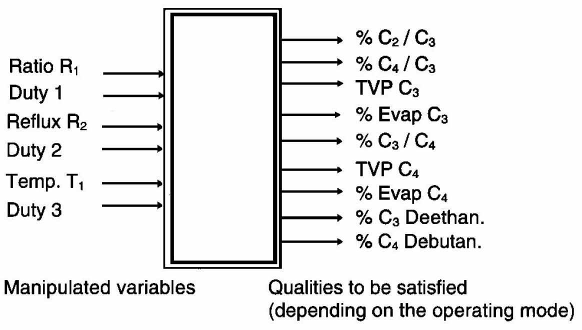


Figure 3 Global functional representation

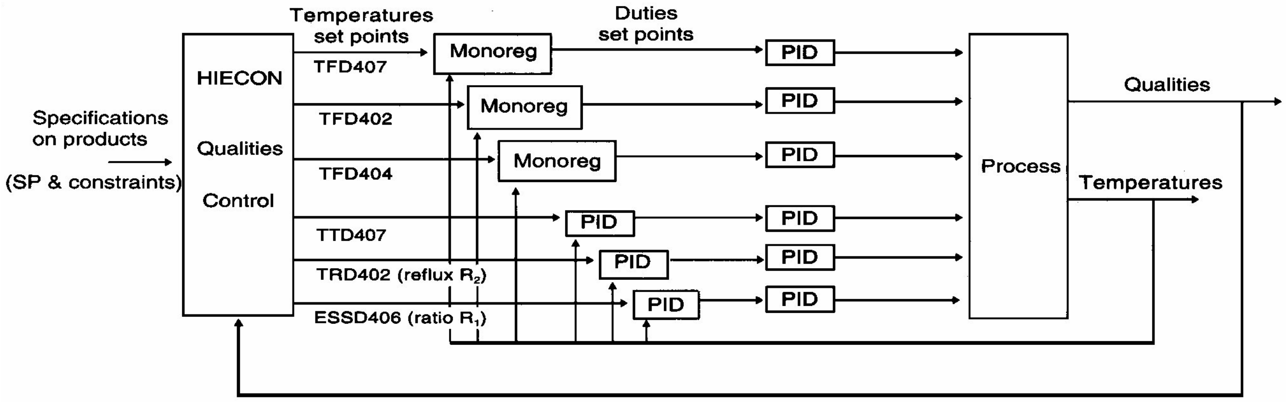


Figure 4

Hierarchical architecture of the gas plant control one controls the temperatures (top and bottom) of each tower, the other satisfies the qualities. This splitting is justified by the following reasons.

The temperature control structure of a column does not depend on the operating mode; each column may have its temperatures controlled separately.

With the provision of certain dynamic precautions (smooth closed loop behaviour), each temperature loop was considered as a SISO system.

On the other hand, product quality control appears to be a more complex problem.

Some of the qualities are a result of a temperature combination (multivariable effects) and therefore require a suitable control algorithm.

The qualities are measured with substantial delay times: stabilisation of the temperatures through their own controllers avoids the propagation of disturbances, whose effects are delayed on the measured qualities.

Added to that, analysers are known to be less reliable than thermocouples; intermediate temperature control at least allows keeping the unit under control in case of analyser failures.

The splitting of the system into hierarchical levels makes it possible to dissociate two functional tasks of plant operation:

- SISO temperature control achieves stable behaviour of the columns;
- the MIMO quality controller defines their positions with regard to their set points and constraints.

The operating modes, defined in terms of specified qualities, can be taken into account by the MIMO controller alone.

The selected architecture (Fig. 4) makes understanding, implementation and maintenance of the system easier.

4 CONTROL ALGORITHMS

Considering the selected control architecture, three controllers, of different complexities, were used:

Temperatures:

-simple loops for which PI controllers are suitable;

-systems whose response shapes require advanced controllers and feedforwarding.

Qualities:

-their global control is performed by a MIMO control algorithm.

The "complex" temperature loops are processed by MONOREG controllers and the MIMO quality control is provided by the IDCOM-HIECON[2].

Both control algorithms, developed by *Adersa*, belong to the Model Based Predictive Control family [2, 3, 7]; i.e. they work in real time from a model of the process (step response representation) for process output prediction on a given horizon [6] and for the computation of the actions to be applied.

The time needed by the process outputs to reach their set points is specified by the user in terms of a desired closed loop response time for each of them.

MONOREG (Fig. 5) is suitable at level 1 for simple structure systems with one process output to be controlled and one manipulated variable.

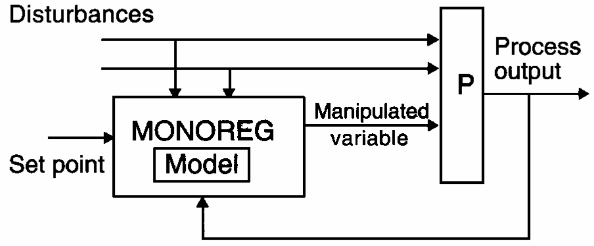


Figure 5

Typical control loop using the MONOREG controller

The controller takes measured disturbances into account as feedforward variables, thanks to the identified model linking these disturbances and the process output to be controlled.

The CAD[3] toolbox attached to MONOREG contains the necessary modules for model identification and controller tuning and testing.

IDCOM-HIECON (Fig. 6) is designed for MIMO systems and takes complex control strategies into account. Besides the regular set point control and the respect for constraints on actions and process outputs, the IDCOM-HIECON algorithm makes a local dynamic optimisation of the unit.

(2) These algorithms are the results of the experience acquired by ADERSA since the design and the applications of IDCOM in the early seventies [4] and [5].

(3) CAD: Computer aided design

As a matter of fact, it moves the operating point of some variables according to the specifications, while respecting both constraints and control objectives.

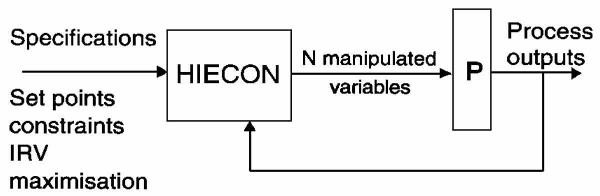


Figure 6

The multivariable controller is given control and optimisation specifications

The optimisation objectives are called "secondary" because they are taken into consideration insofar as the main objectives (set points and constraints) are met.

These secondary objectives may be defined on manipulated variables and/or on process outputs and are of two types:

- Ideal Resting Value: a variable is moved to this target as long as it is not required for the main objectives to be met.
- Maximisation/Minimisation: the variable concerned is moved, with a specified rate of change, until certain constraints stop its slip.

These two secondary objectives can be taken into account as soon as there are some extra degrees of freedom (more available manipulated variables than specified set points).

All these objectives and specifications representing the control strategy can be easily defined in a list: i.e. the control structure. The IDCOM-HIECON may switch automatically in real time between several pre-defined control structures. The switching may be performed either on operator request (in order to change from one operating mode to another), or to use a back- up control structure corresponding to a sensor failure or to non-availability of an actuator.

The IDCOM-HIECON CAD toolbox is integrated under Windows ^{TM} and makes implementation easy, from model identification up to controller testing on simulation.

5 SYSTEMATIC IMPLEMENTATION

The major implementation steps are model identification and simulated control testing.

The process analysis showed eight functional input variables (6 actions and 2 feedforward variables), which implies the application of an equivalent number of plant tests in order to obtain the information necessary for model identification. It was considered preferable to apply the plant tests considering the inputs one by one rather than grouping all the moves within a single run for practical reasons and in order to make test validation easier.

After validation, the collected data can be processed by the identification tools attached to IDCOM- HIECON.

These tools display the results with plotted step responses and compared process and model behaviours (Fig. 7).

The significant relationships were identified and made up the model, which is part of the controller.

The other part of the controller is the set of control structures. Each of them is built from the CAD user interface which helps the user define the control strategy directly in terms of objectives to be met by IDCOM-HIECON.

One of them, corresponding to the mode "C3 PDA" is given in Figure 8 as an example.

The designed controller can then be tested, using a simulated process; the simulation is made from a model that may be different from the one used in the controller in case of robustness tests.

The closed loop tests (Fig. 9) highlight the satisfaction of the objectives defined in a control structure: the variables to be optimised are moving as expected and the primary objectives are satisfied.

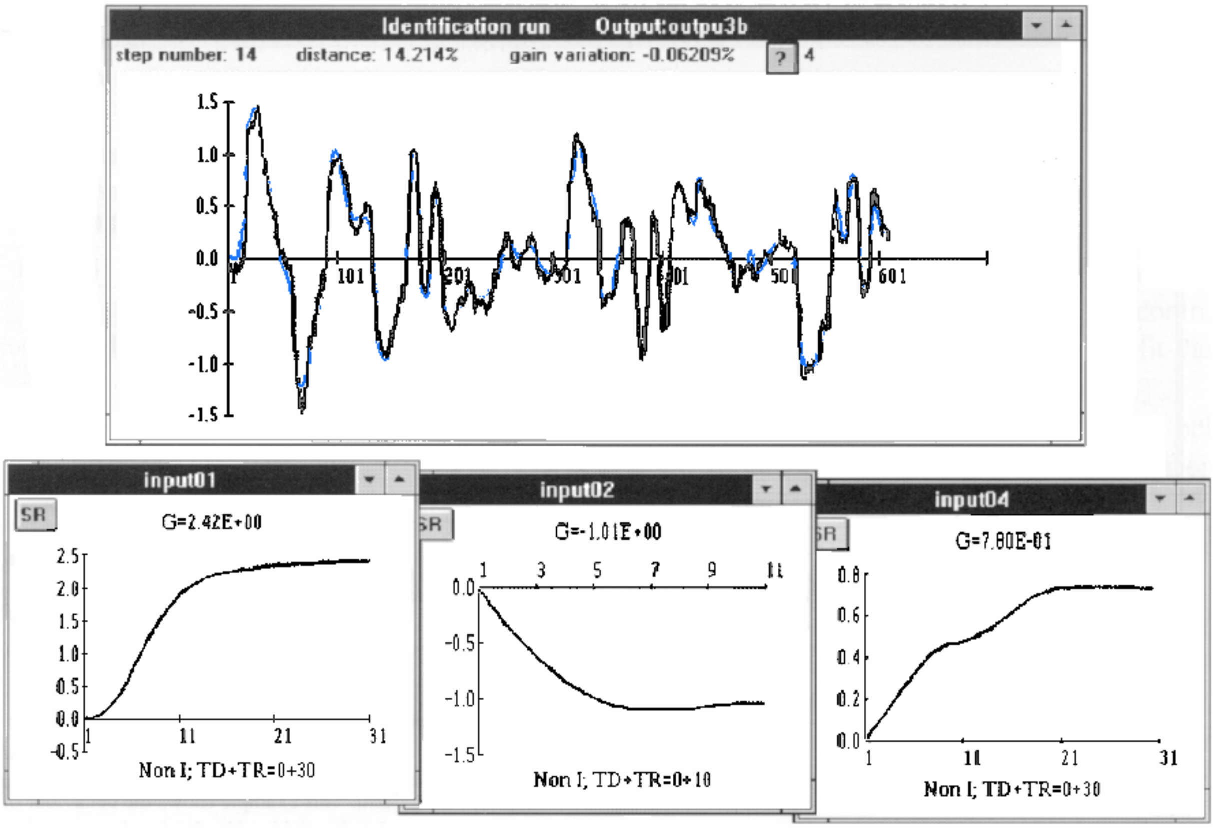
Each of the control structures is validated the same way in different disturbed and noisy conditions and with model mismatch.

These risk free tests applied on a PC with the CAD toolbox are the best way to ensure safe, successful on-site implementation.

Once designed and tested, the controller may be transferred onto the process computer with the model and the control structures.

6 TRANSFER TO THE PROCESS COMPUTER

The control algorithms (MONOREG and IDCOM-HIECON), in Fortran language, had already been implemented on the computer (IBM 9221) for previous projects. Then, only the specific statements accessing the real time database had to be adapted.



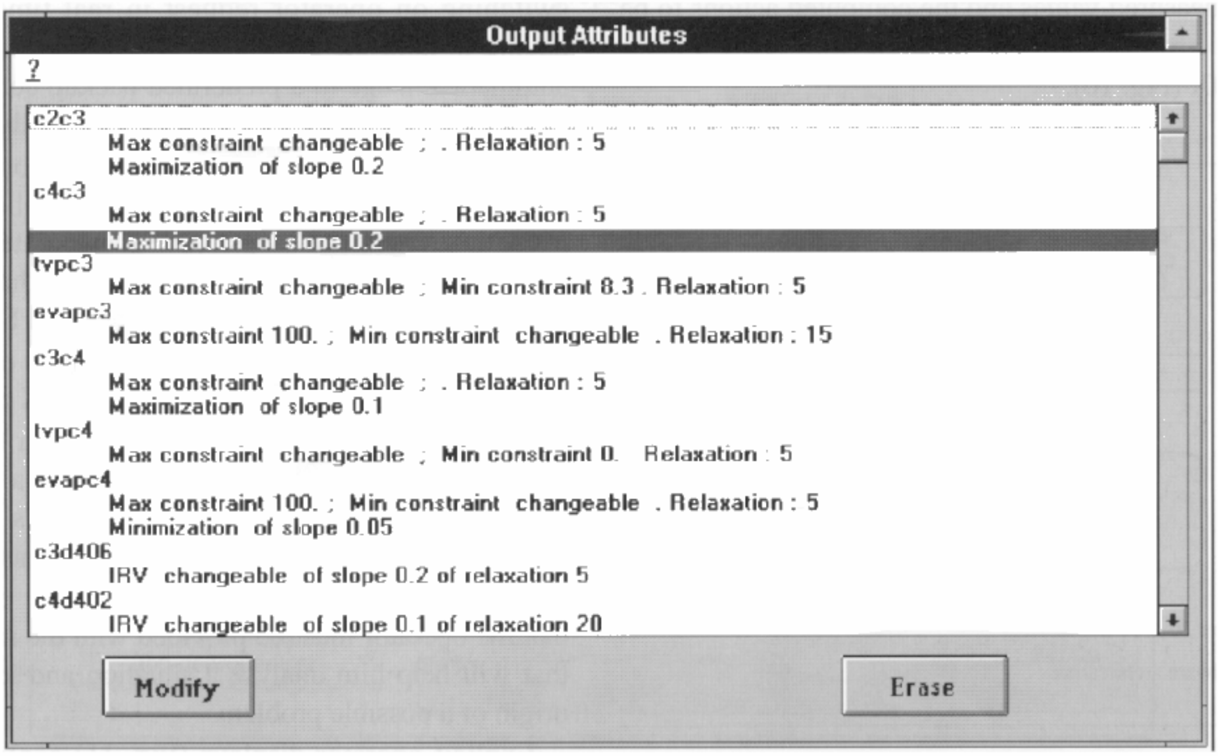
step number: 14 distance: 14.214% gain variation: -0.06209%

input01: G=2.42E+00, Non I; TD+TR=0+30

input02: G=-1.01E+00, Non I; TD+TR=0+10

input04: G=7.80E-01, Non I; TD+TR=0+30

Figure 7 The model identification tools display the identified step responses and compare process and model behaviours.



```
c2c3
        Max constraint  changeable  ;  . Relaxation : 5
        Maximization  of slope 0.2
c4c3
        Max constraint  changeable  ;  . Relaxation : 5
        Maximization  of slope 0.2
tvpc3
        Max constraint  changeable  ;  Min constraint 8.3 . Relaxation : 5
evapc3
        Max constraint 100. ;  Min constraint  changeable  . Relaxation : 15
c3c4
        Max constraint  changeable  ;  . Relaxation : 5
        Maximization  of slope 0.1
tvpc4
        Max constraint  changeable  ;  Min constraint 0.  Relaxation : 5
evapc4
        Max constraint 100. ;  Min constraint  changeable  . Relaxation : 5
        Minimization  of slope 0.05
c3d406
        IRV  changeable  of slope 0.2 of relaxation 5
c4d402
        IRV  changeable  of slope 0.1 of relaxation 20
```

Figure 8

A control structure contains the specifications relative to the manipulated variables and to the process variables. Above, the qualities given constraints and dynamic optimisation objectives (maximisation, minimisation and Ideal Resting Values).

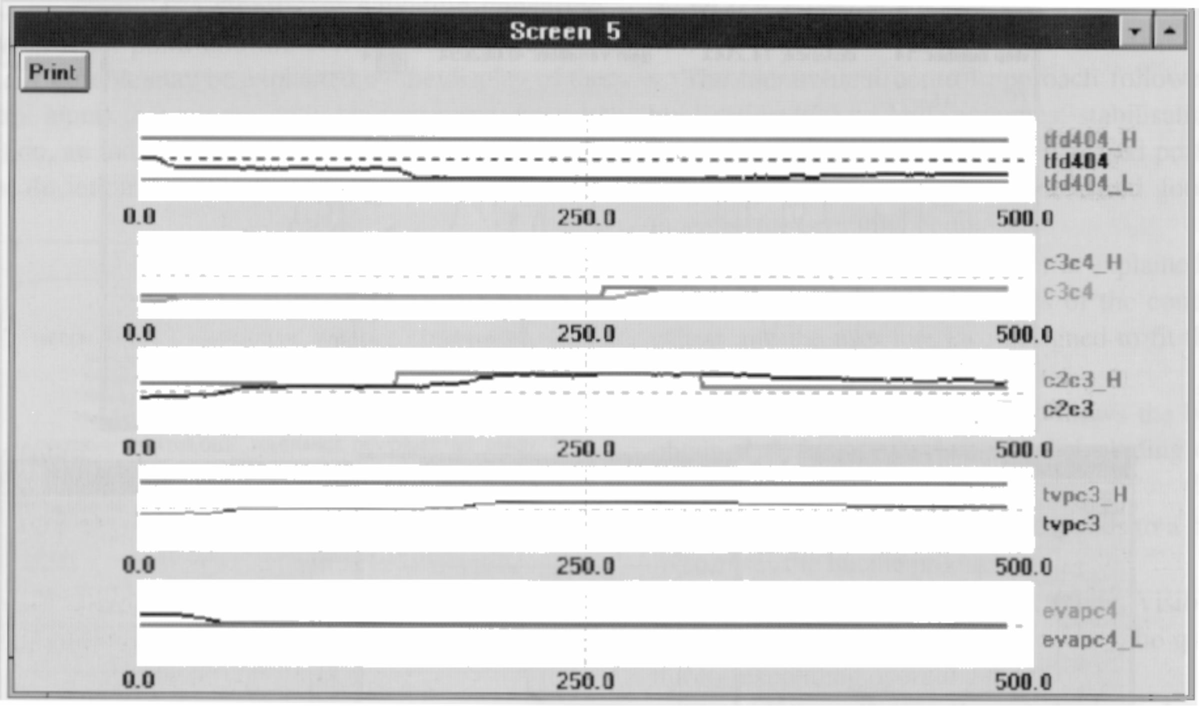


Figure 9

The IDCOM-HIECON development tools are used here to test the simulated closed loop system. This example shows the behaviour of some of the qualities when their constraints are changed. The first axis displays one of the manipulated variables (deethaniser bottom temperature set point) which acts within its constraints.

The measured values and the computed actions to be applied are transmitted through the DCS Fisher PROVOX (Fig. 10).

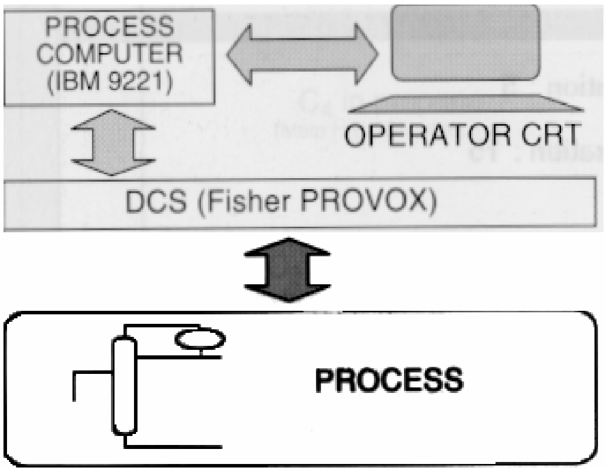


Figure 10 Hardware architecture

Regarding multivariable control of the qualities, four control structures were defined, corresponding to the operating modes. A module allows control structure switching on operator request in real time, without having to hold the controller. This module also allows automatic change to a predefined backup control structure depending on the availability of the analysers.

Another aspect of implementation concerns the design of the operator displays. The simplicity of the MONOREG control loops (one manipulated variable and only one control structure) is such that the user interface can be reduced to a simple ON/OFF indicator.

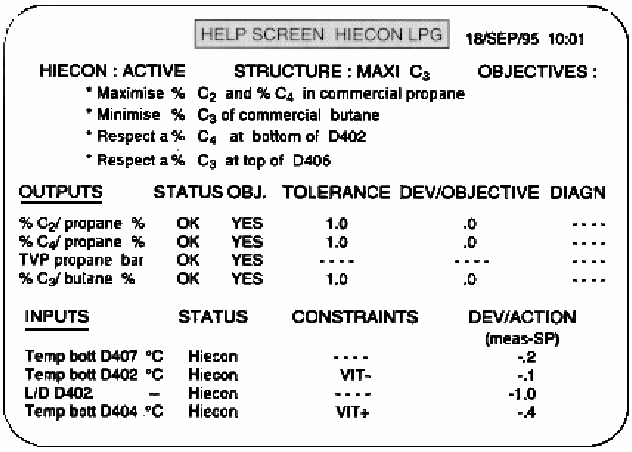
A more complete set of information to be displayed is justified in the case of the IDCOM-HIECON controller.

It does not appear simple for the operator to evaluate the validity of the actions computed by a controller which includes many process variables, different control structures and a number of constraints.

It is obvious and indeed confirmed by experience that the operator must be provided with the information that will help him analyse a situation and identify the origin of a possible problem.

Explicit operator displays (Fig. 11) contribute to a high operation rate because they obviate the need to switch off the controller as soon as any unexpected behaviour looks strange at first glance.

As an example, a significant deviation appearing between a set point and the corresponding measured process variable may be explained by the display of the control inputs that are presently on their constraints. In addition, an indication given about the future evolution of the deviation makes it easier to take a decision.



```
                    HELP SCREEN  HIECON LPG   18/SEP/95  10:01

 HIECON : ACTIVE      STRUCTURE : MAXI  C3       OBJECTIVES :
          * Maximise  %  C2  and % C4  in commercial propane
          * Minimise  %  C3 of commercial  butane
          * Respect a %  C4   at  bottom of  D402
          * Respect a %  C3  at top of  D406

OUTPUTS          STATUS OBJ.  TOLERANCE  DEV/OBJECTIVE  DIAGN

% C2/ propane  %   OK    YES      1.0           .0          - - - -
% C4/ propane  %   OK    YES      1.0           .0          - - - -
TVP propane  bar   OK    YES     - - - -       - - - -      - - - -
% C3/ butane  %    OK    YES      1.0           .0          - - - -

 INPUTS             STATUS     CONSTRAINTS      DEV/ACTION
                                                 (meas-SP)
 Temp bott D407  °C   Hiecon       - - - -          -.2
 Temp bott D402  °C   Hiecon        VIT-            -.1
 L/D D402        --   Hiecon       - - - -         -1.0
 Temp bott D404  °C   Hiecon        VIT+            -.4
```

Figure 11 IDCOM-HIECON help screen

7 NOTICEABLE RESULTS

The hierarchical control approach followed in this application had several outcomes: stabilisation of the units closer to their constraints, increased profit thanks to quality specifications being met, and good acceptance by the operating people.

The high operation rate (98%) is explained by both the performances and robustness of the control algorithms and the user interface designed to fit the operator's needs.

The trend given in Figure 12 shows the behaviour obtained during a two-day period, including operating mode changes.

The first part of the plots corresponds to a mode that maximises the butane production.

The selection of the C3PDA mode, visible in the middle of the displayed period, moves the qualities to the corresponding operating point.

The stability of the units comes from the intermediate temperature controllers (PI and MONOREG):

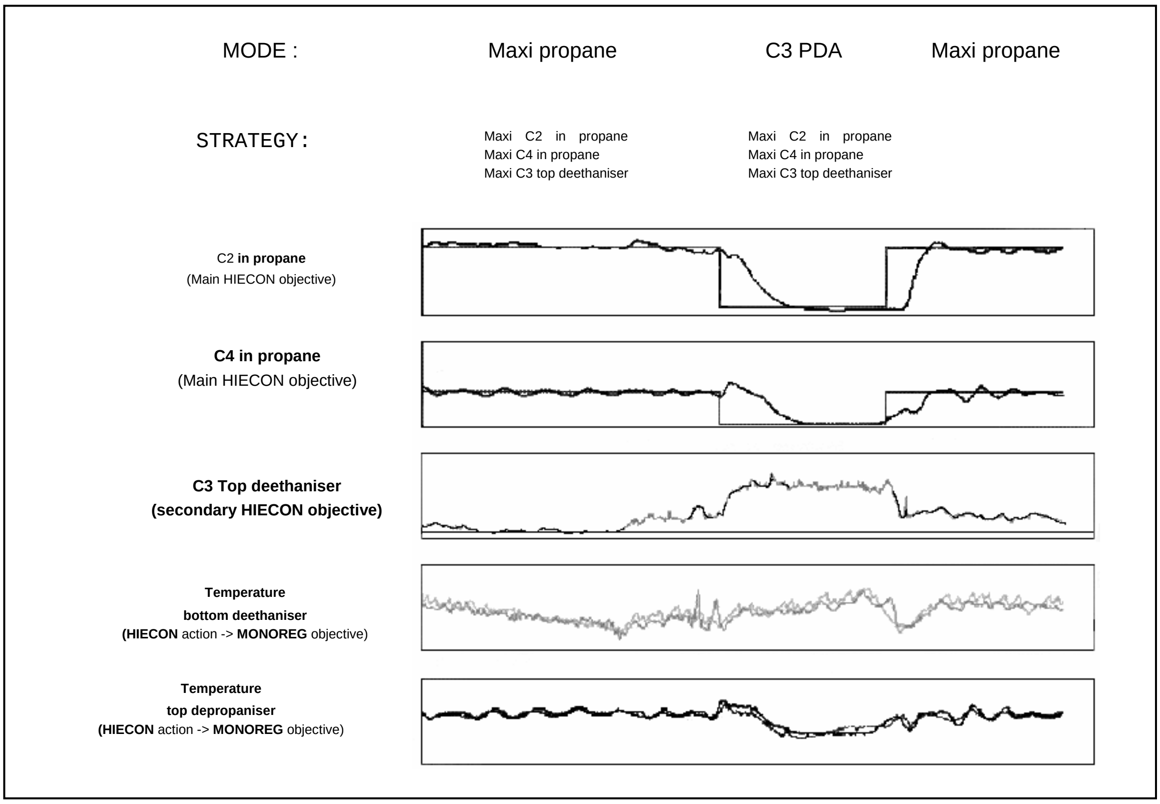


Figure 12 Plant trends during changes of operating modes

The positioning of the qualities while respecting the constraints, plus the local dynamic optimisation, both provided by the multivariable IDCOM-HIECON controller, significantly shortened operating mode switching.

The following statistics (Table 1) compare the performances obtained by temperature control alone and those obtained by full hierarchical control.

These statistics show a significant reduction of quality fluctuations by an average factor of six.

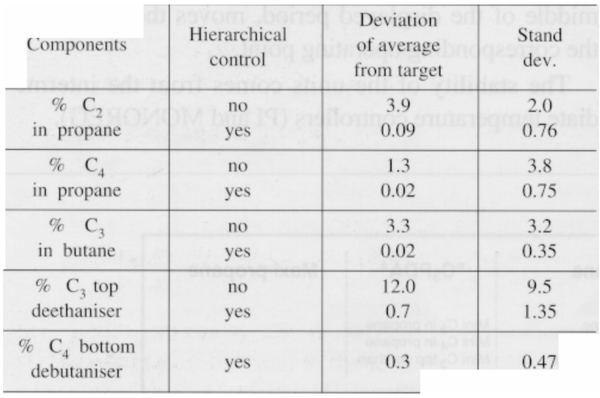
The application to the gas plant gives a clear example of the advantages of hierarchical control:

-progressiveness of implementation,

-better understanding of the process structure,

-discrimination between stabilisation and positioning aspects.

TABLE 1
Compared statistics



Components	Hierarchical control	Deviation of average from target	Stand dev.
% C_2 in propane	no yes	3.9 0.09	2.0 0.76
% C_4 in propane	no yes	1.3 0.02	3.8 0.75
% C_3 in butane	no yes	3.3 0.02	3.2 0.35
% C_3 top deethaniser	no yes	12.0 0.7	9.5 1.35
% C_4 bottom debutaniser	yes	0.3	0.47

The economical gain is a result of the better positioning of the qualities close to their constraints; this reduces the give-away [8].The quite important decrease in the deviation of the qualities from their specifications made it possible for the refinery to estimate the pay-out time at less than one year.

This result is similar to those obtained on previous predictive control applications implemented in the refinery.

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