Adaptive Predictive Expert Control

ADEX Methodology
User Manual

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Contents

About This Manual

The following sections describe ADEX control and optimization methodology, the ADEX controllers which are required to stabilize and precisely control critical variables of industrial processes, the interface with the desired optimization logic.

Related Documentation

The following documents contain information you might find helpful as you read this manual:

- *ADEX Configurator*

Principles of ADEX

ADEX is a new generation of advanced control combining adaptive predictive control (AP) [1-3] with expert control, and with each operating domain defined in an integrated control structure. The evolution of the input/ output variables (I/O) of the process determines whether AP or Expert control should be applied, depending on the corresponding operating domain.

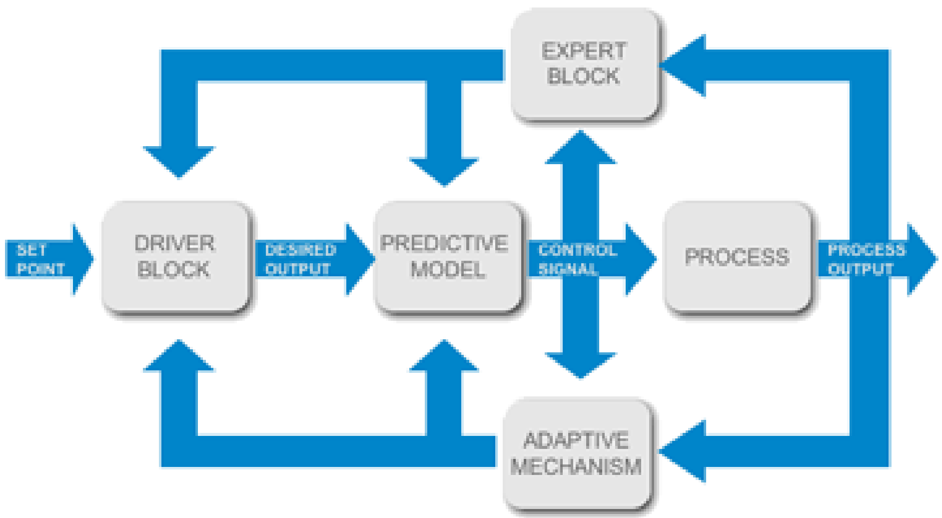

FIGURE 1 - GENERAL CONFIGURATION OF AN ADEX CONTROLLER

The general configuration of an ADEX controller is shown in Figure 1 and the operation of the different blocks, at each control instant, is described as follows:

- The *Expert Block* determines if AP or Expert control should be applied. When Expert control is applied, this block determines that the Control Block operates as an Expert system with rules which imitate the behavior of an operator. When AP control is applied, the Expert block interacts with other ADEX blocks as described in the following sections.

- The *Driver Block* generates a desired trajectory for each output variable of the process in order to drive the process output towards the set point in accordance with pre-defined performance criteria. The Expert block is able to modify that performance criterion in order to accommodate the desired action of ADEX within the various AP operating domains which will have already been defined.

- The *Control Block* uses an adaptive predictive model which defines a mathematical cause-effect relation between the process input and output variables to generate a sequence of future control actions at each control instant, and drive the predicted process outputs along a desired output trajectory generated by the Driver Block. The first control action of this sequence is applied at each control instant to the process. The expert block determines the initial values of the AP model parameters for each AP domain in question.

- The Adaptive Mechanism utilizes the input-output (I/O) variable measurements of the process in order to:

    - Adapt the AP model parameters to minimize the prediction error for each output variable of the process. The Expert block, nevertheless, determines when the adaptation should be carried out, taking into account operating conditions.

    - Enable the driver block to re-generate desired output trajectories taking into account the evolution of the process I/O variables.

In accordance with the functionality described above, when the I/O variables of the process evolve within an expert control domain, the expert block will determine the application of expert control. In this case, the control block will calculate the control vector according to rules which imitate human operator intelligence similar to the way that fuzzy logic or expert systems work. The control objective will be to drive the process towards AP domains where the operation can be optimized.

In addition, when the I/O variables of the process evolve in an adaptive predictive domain, the expert block determines the application of AP control. The adaptive mechanism will identify the cause-effect relation of the process variables, and the variations in this relation over time, inside the AP model. The control block will use this to predict and control the evolution of these variables. In this way, the prediction error will tend towards zero, in spite of possible changes in process dynamics, and the output variables will converge on desired output trajectories generated by the driver block, stabilizing at their set points.

ADEX Systems

Generally, the optimized control of a process or industrial plant with a complex dynamic requires the development and application of a control and optimization strategy (COS). These strategies generally combine the use of ADEX controllers with complementary optimization logic (COL), the purpose of which is to minimize the consumption of energy and other resources, maximize production both in quality and quantity while at the same time, guaranteeing the safety and stability of the process and hence, prolong its useful life.

As has been previously indicated, 'ADEX system' is the term applied to any control and optimization control system software which is based upon one or more COS using ADEX controllers.

The COS can be developed according to the following procedure:

1. For each plant or process operating scenario, a COS can be developed in which the COL will carry out the following:

    a. Determine the inputs which have to be applied to the ADEX controllers integrated in the COS based on measured process variables, and then determine the control signals which must be applied to the process based on the outputs produced by the ADEX controllers.

    b. Find the operating or set points for the process variables which optimize its function, benefiting from the precise and stable control provided by the ADEX controllers.

2. The ADEX controllers will operate in expert and AP domains in the following manner:

    a. Whilst in the expert domain, the ADEX controllers will drive the variables towards the AP domain.

    b. Once in the AP domain, the process outputs will be driven via desired trajectories towards set points and stabilized close to them.

3. In the context of ADEX optimization, the function of ADEX controllers will guarantee stabilization of the process variables close to the set points and enable the COL to find the points of optimum functionality

within this stable environment, thereby optimizing the process overall in real time.

Implementation of ADEX Controllers in the Multivariable Case

As has been mentioned previously, ADEX is multivariable. Consequently, it can be applied to MIMO (*Multi-Input Multi Output*) with 'm' inputs and 'n' outputs. In the present implementation of ADEX COP, it is assumed that:

1. The number of inputs m will always be greater than or equal to the number of outputs n (m ≥ n)..

2. There is a sub-group of inputs (m* = n) within the m variables, whose values can be manipulated by the control system to control the n variables of the process output.

3. The remainder of the input variables (l*=m-n) are considered as perturbations which act on the process output variables and whose effects are taken into account by the ADEX controller in the calculation of the control vector.

4. The maximum number of output variables is 3 (3 ≥ n) while the number of inputs can amount to 9 (9 ≥ m).

A practical method of applying ADEX methodology is to divide the multi variable ADEX controller into a set of n multi input, single output ADEX controllers (MISO). Each one of these ADEX MISO controllers calculates an output value which is adjusted subsequently to take into account interactions with the other MISO controllers and so determine the final control signals (vector) to be applied.

For example, a 3 x 2 ADEX controller can control two output variables manipulating two components of the control vector, and taking into account the effect of one perturbation. The ADEX 3 x 2 controller internally considers two 3 x 1 controllers. The calculations, in relation to the internal function of these two controllers, are carried out separately taking into account their own operating domains, but the calculation of the final control vector also takes into account the interactions between the controllers.

Description of ADEX Operators

ADEX COP includes a set of ADEX controllers which can be integrated into the COL of the COS's. Figure 2 shows operators which represent a subset (from 1 x 1 to 3 x 3) of these controllers. A multivariable ADEX controller comprises one set of one or more ADEX MISO controllers which are dynamically related since the outputs (control actions on the process) can affect the control variables of the set (outputs of the process).

The operators shown in Figure 2 have pins located on the left hand side for connecting the COL to the input variables of the controller while those on the right hand side are used to connect the controller outputs.

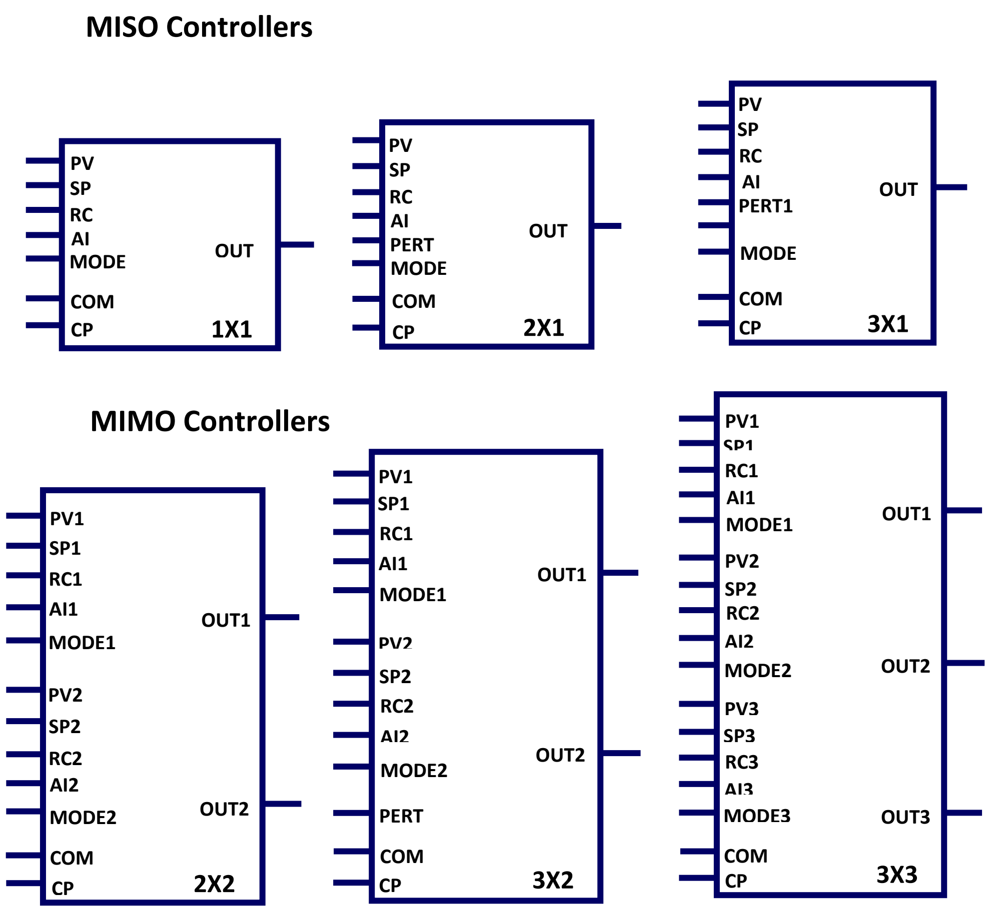

FIGURE 2 – ADEX OPERATORS

The acronyms associated with the pins on the left hand side of the 2 x 1 operator, representing the analog inputs of the controller are:

- **PV -** Output variable of the process which the ADEX controller must control.

- **SP -** Set point or desired value of the PV.

- **RC -** Rate of Change. Maximum increment desired between two control instants of the process variable PV under control when approaching a set point. This parameter can be calculated for the COL or determined internally for controller configuration.

- **AI -** Actual Input. The last actual control action taken by the controller which may be different to the calculated one due to control limitations or other causes.

- **PERT -** Perturbation variable which affects the evolution of the PV.

- **CP -** Control Period which can be calculated by the COL or determined internally by controller configuration. Determines the time between control actions generated by the ADEX controller. It is a multiple of the sampling time.

The only analogue operator output is:

- **OUT -** Control action produced by the controller.

Digital only inputs are:

- **MODE -** This is an input variable which determines the operating mode of the controller. When it has a value of 1, the controller enters into AUTOMATIC mode (**AUTO**) which means that it calculates the control action **OUT** to be applied to the process. When **MODE** has the value 0, the controller enters into **EXTERNAL** mode which means that the control action is determined by the COL of the COS or from outside the COS.

- **COM -** This variable has the value ‘1’ when the connection with the COS, in which the ADEX controller is integrated with the process variables, is functioning correctly. If not, the variable will have a value of ‘0’.

It can be seen from Figure 2 that, for example, there are two input pins on the 3 x 1 operator PERT1 and PERT2 since, in this case, there are two different perturbation variables. The number of perturbations in the set of controllers can vary between 0 and 6. When the ADEX controller is MIMO, a number is assigned to each variable by adding it to the acronym on the corresponding PV, SP, RC, AI, MODE and OUT pins (e.g. PV1, SP2 etc). The 'OUT' pins which have a number different to that of the PV are treated informally as ADEX MISO controller perturbations of the PV in question but this does not rule out the possibility of considering an additional number of perturbations between 0 and 6. This implies that an input/ output structure of ADEX controllers could be up to 7 x 1, 8 x 2, and 9 x 3 depending on the process variables to be controlled.

The various ADEX MISO controllers within the same multivariable ADEX controller can function under different operating modes

References

[1] J.M. Martín Sánchez, “Adaptive Predictive Expert Control System”, International Patent Application. Application Nº: PCT/US00/17836, Filling Date: June 28, 2000.

[2] J.M. Martín Sánchez, “Adaptive Predictive Control System”, USA Patent Nº 4.197.576, 1976.

[3] J.M. Martín Sánchez, “Adaptive Predictive Control System” (CIP), European Patent, Nº 0037579, 1980.

[4] J.M. Martín Sánchez y J. Rodellar, “Adaptive Predictive Control: From de Concepts to Plant Optimization”, Prentice Hall Internacional, 1996.

[5] J.M. Martín Sánchez. and J. Rodellar, “Control Adaptativo Predictivo Experto: Metodología, Diseño y Aplicación”, UNED, 2005.