Application of the object-oriented approach to intelligent DCS data flow optimization

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Abstract. This paper is on the thermal power plant intelligent DCS data flows optimization for increase of control performance and technical and economic efficiency. The proposed object-oriented approach for control system data flow interpretation allows building a hierarchical directed structure to trace value transformations through measuring and informational channels. The problem of parameter influence evaluation on the technical and economic efficiency estimation using the described approach is set.

1. Introduction
Most of the modern distributed control systems (DCS) are designed to a template and inherent the old functions using new software and hardware features, so the functionality stays on the same level and mostly performance the tasks related to parameter checkout and individual operating mechanism local control [1].

Application of the software and hardware complexes as template solution, which mostly control process parameters and in a sufficiently lesser degree optimize object performance overall, when upgrading and designing thermal power plant DCS leads to ineffective technical system use and doesn’t represent the broad picture of the object performance.

Implementation of the full-scale DCS based on extension of the software and hardware complex functionality to achieve optimal technological and operational process control at the unit and station levels allows addressing the challenge, described above. The intelligent DCS represents a multi-level hierarchical technological process control structure - a functionally aggregated DCS, consisting of three control levels [2, 3]:

- Aggregate – value measuring and processing, signal validation, technological parameter monitoring etc.);
- Unit – technological parameter control performance optimization, unit performance estimation and analysis, equipment operating mode control etc.);
- Station – operating and regulatory station performance estimation and analysis, choosing an optimal entry to power joint market (PJM) strategy etc.
Design of such a hierarchical distributed information processing system requires meeting the following criteria: reliability, efficiency, data flow volume between adjacent levels, performance, station tasks solving capability and practicability, cyber security. Implementation of the described levels in DCS allows control aggregation by function: station level solves the station control strategic problems, when the lower ones regulate and optimize the technological and operating processes. Applying such an approach also means the data flow conjunction, what obfuscates monitoring and control.

The objective of the research is the intelligent DCS data flow optimization for thermal power plant (TPP) technological process control performance and reliability increase.

2. Material and methods
The DCS can be used efficiently when all three mentioned levels are considered integrated, i.e. the system should have the common information field to store aggregated data (sensor values, processed data, estimation results etc.) instead of multiple separate ones for each level. The data flow directions can be ascending (from lower level to higher) and descending (from higher level to lower) (figure 1). The former ones are, for instance, sensor values, data processing results transmit from aggregate level, and the latter ones, for example, are setting adjustments according to the operating mode analysis in order to reach higher performance.

![Figure 1. The intelligent DCS structure and data flow directions](image)

2.1. The intelligent DCS structure
The functionally aggregated DCS manipulates the common information field data, consisting of the aggregate, unit and station levels. It is suggested to consider each level a slice, which contains the certain data, corresponding to the level business logic, that are hidden from the adjacent levels to address directly – only the particular values are visible to them. In such manner, each DCS level represents a black box with the input and output vectors, what allows encapsulating its logic, thus the ascending and descending data flows create function chains of the information units processing. The advantage of the approach is separating the business logic of DCS between levels.

2.1.1. The data flow diagram
It is convenient to present the DCS aggregation by function and data flows as data flow diagram (DFD), which shows the intelligent DCS structure and relations between its components [4]. The general DCS data flow diagram is illustrated in figure 2.
In the structure the lower level procedures, which are regulatory ones, are separated from the higher level strategic tasks, which are optimizing object operating performance according to the determined criterions established by the plant strategic market plan. Therefore, to meet these conditions the generating equipment control optimization problem at the unit level and target parameter control at the aggregate level should be solved. In their turn the equipment performance indexes should be fed back to the higher level. The data flow optimization means efficient allocation of both logical and physical channels on each informational field level of the intelligent DCS in order to improve technological processes of energy production.

2.2. The object-oriented approach
For the purpose of data flow optimization it is reasonable to develop the informational field model using the object-oriented programming (OOP). OOP allows representing the system under investigation as collection of entities with various properties and defining relations between them. It is possible to describe the intelligent DCS informational field structure irrespective of actual data transmission, but representing the relationships between them [4].

Figure 2. The general intelligent DCS data flow diagram
For the system under investigation the model has been developed, its class UML diagram is represented in figure 3. The informational field overall is defined in ControlSystem class, that contains a set of the system levels - a LevelList class object, which is double-linked list of Level objects. The double-linked list approach is applied to make the model more flexible and structured - each Level object can refer to its preceding (Previous) and following (Next) ones if they are defined, otherwise the pointers are set null, thus each object of the list can see only its adjacent levels [5]. The LevelList object also defines the head (the lowest level) and tail (the higher level) of the list.

Each level contains a collection of data units - a list of Data class objects. For the control system supposes constant value conversions during long chains of calculations, then it is reasonable to add sources to each data unit, i.e. to link a unit data with the related ones that are used to calculate it. If a value is given by default, obtained from sensor or entered by user, then it has no source, so its Source property is null. Such a structure of Data class resembles Composite pattern, which is purpose for tree data structures, except for it doesn’t contain leaf elements (terminal points) - instead of them there are objects of the same class (Data) as well, which can also refer to other data units or be null.

Such an abstraction and representation allows inspecting both ascending and descending data flows of the control system, for data units are connected with Association relationship, therefore it is possible to investigate data conversions at each level. Developing a data flow model starts with creating a ControlSystem class object, then all the levels of the intelligent control system under investigation are added to the LevelList by AddLevel() method, which takes as an argument a Level instance. A Level object contains information about level name (Labeling), ID and refers to the adjacent levels. Each level then is populated with data units by AddData() method, where a Data
instance contains data unit description (Labeling), order number (a unique number of data unit set by user) and sources list, which can be determined by AddSource() with reference to a Data instance.

2.2.1. Building a tree structure
The relationships between data units can be described by a square matrix of size equal to the system data units - an incidence matrix. To create a system incidence matrix there is GetIncidenceMatrix() method in ControlSystem class, which returns a two-dimensional array of bytes of corresponding values True or False for cases where there is a direct relationship between two certain data units or not respectively. The matrix is filled during girth of all data units at each level - the columns and rows indexes consist of level order number in the level list and data order number with underscore delimiter (example, 1_15, 2_36 etc.). To interpret and visualize the data flows in the control system under investigation it is possible to draw a graph (figure 4) [5]. For each data unit represents a single conversion of one or more related ones, then the graph should be directed representing ascending and descending data flows within and between its levels. The developed structure could be considered a computational graph, for its nodes represent variables, but to address the problem of data flow optimization it is necessary to evaluate each variable importance in meeting the desired control efficiency. Addressing the problem of parameter selection by its importance in distributed control system is the subject of our further research.

Figure 4. Control system data flow graph

Conclusions
The proposed thermal power plant intelligent DCS data flow model has flexible structure for detailed description of data transformation, representing data flows of any complexity and tracking them at each system level. Such an approach allows addressing the problem of parameter selection by its importance in distributed control system. The linked data structure allows tracking value transformations through the system overall in both ascending and descending directions. Results of variable influence evaluations can be represented as graph edge weights, so the end result will be a product of the weights on the way of a certain data flow.

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