Intelligent Decision-Making Systems for Monitoring Power-Plant Dispatchers' Knowledge

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***Abstract*—In article describes an intellectual-information system that will be used to make managerial decisions on the operation of technical personnel of power plants and similar process facilities. In particular, the results of its work will help to make a decision on the appropriateness of upgrading the skills of technical personnel. The methods of intellectualization used to determine the level of knowledge based on odd logic allow not only to assess the level of knowledge, but also to automate the process of its consolidation and enhancement. The use of this method allows the training of technical personnel on the job. The method of intellectualization of an estimation of a level of knowledge of the basic theory of calculation of optimum feeding parameters of regulating devices of automatic control systems is described. Solving this problem in the example of automation evaluation on the parametric synthesis of one-loop, cascade and combined control systems. Control of the level of knowledge for parametric synthesis determined by the correct choice of a point on a graph of the amplitude-phase characteristics and D-partition graphs. The adequacy of established fuzzy output system tested in a program FuzzyTECH.**

Keywords—expert system; intellectualization; technical staff; knowledge level; fuzzy logic; automatic control systems; parametric synthesis.

I. Introduction

Modern automation systems ensure continuous production process with the best techno-economic parameters to optimize performance, product quality, and energy saving. The human involvement in the process becomes ever less significant, and there arises a need in high-skilled specialists to create and support automated process control systems (APCS).

APCS efficiency is a function of the knowledge of dispatchers responsible for the maintenance of such systems. In order to improve the quality of APCS operations, dispatchers' knowledge in key areas must be continuously monitored and improved.

Human resources management (HRM) systems control the knowledge and skills of the company's specialists. This task is automated by the HRM-class automated control systems (ACS), the functions of which overlap with the that of computer-aided manufacturing (CAM) systems. Despite HRM ACS being economically efficient and relevant, the problems and specifics of such systems are not well-studied in Russia, especially in the context of evaluating and improving dispatchers' knowledge.

One of the basic dispatcher competences consists in the knowledge and skill of ACS structural synthesis (SS) and parametric synthesis (PS). SS is usually a one-time operation done at the design stage, while PS has to be repeated at all steps of ACS operations. This is why it is critical that dispatchers are knowledgeable about how to carry out the ACS parametric analysis. Therefore, knowledge monitoring, generation, and consolidation (KMGC) is a critical HRM task that, when completed, has a positive effect on the APCS functionality. Given that dispatchers are continuously employed in the production process, HRM tasks can be automated by using advanced intelligent self-study tools. This can be done by the deployment of automated training systems (ATS) based on information and communication technologies (ICT) using fuzzy-logic methods.

According to [1-4], the use of fuzzy logic helps develop intelligent learning, which, when combined with ATS, improves the efficiency of KMGC compared to conventional approaches. Compared to other intelligent-learning methods, fuzzy logic and expert systems (ES) can be used to organize this process faster and more reliably.

Review of literature in the field of intelligent APCS learning has revealed lack of such solutions. There exists a contradiction: on the one hand, KMGC is absolutely necessary; on the other hand, there are no tools or methods for intelligent learning. This is why implementing intelligent KMGC with respect to the APCS PS is a relevant problem.

II. Man-machine process control system

The paper dwells upon the use of HRM systems and their place in the ACS employed by power-engineering and petrochemical companies. We specify the APCS ACS mostly frequently used by JSC Far-Eastern Generating Company ("the FEGC"). We analyze the intelligent KMGC tools for the APCS personnel based on the FEGC dispatchers' job descriptions.

Papers [5–7] discuss HRM problems and make an emphasis on knowledge evaluation while virtually neglecting knowledge generation and consolidation.

In their turn, KMGC problems are the subject matter of numerous research efforts [7–12]. Most papers on this topic note the necessity of enhancing and expanding the use of ICT in KMGC.

Papers [13–17] demonstrate the demand for, and efficiency of using, ATS for CCGC, which ATS can be made part of the HRM system. Notably, it is frequently third-party training centers that are tasked with KMGC, although the ATS could be integrated with HRM systems to train personnel on the job.

Papers [18–20] propose an APCS implemented as a man-machine system with feedback and two inputs (one with a clear deterministic value of the vector x_{in} and one with a fuzzy value of the vector $x^{\sim}_{in}$). Process control and efficiency improvement decisions are based on the vector $x^{\sim}_{in}$ and are made by employees specializing in a certain subject area. Improvement of the fuzzy-channel control channel in terms of input depends directly on the employees' knowledge.

To improve the control quality and efficiency in this system, M.A Gorkavy proposed modifying the feedback loop to include the knowledge model (KM) generation modules, which could be used to control employees' basic knowledge while neglecting the generation and consolidation of such basic knowledge [5]. Generation and consolidation can be accounted for by adding a KMGC block in the feedback loop.

KMGC (see Figure 1) includes a set of training materials and guidelines that comprises training materials (TM) and practical tools (TP) necessary to generate and consolidate knowledge, as well as a test system (TS) to monitor it. The expert system (ES) analyzes the employee's knowledge at each KMGC step and decides on the basis of the KM whether the employee needs to re-iterate their training or is ready to work in production.

The ES specifics means that analysis of the employee's key knowledge must be intelligent, as PS is a key skill for ACPS dispatchers; intelligent PS knowledge control becomes imperative.

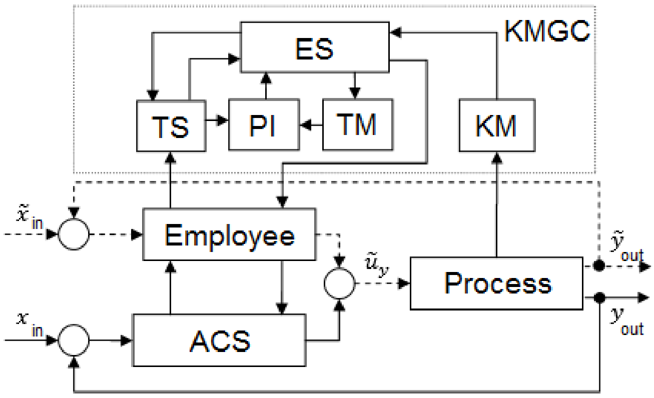

Fig. 1. Man-machine process control system

There exists a lot of PS software; however, technologies in use do not make for an intelligent PS learning process [21–27]. The papers cited above dwell upon a rather short list of typical ACS used in process automation, which limits their scope of use.

Given the efficiency of expert training systems (ETS) coupled with their relative simplicity, it is advisable to use the ETS principles in automating the HRM KMGC tasks and APCS PS learning.

III. Intelligent knowledge-quality decision making system

Knowledge monitoring is a crucial component of the intelligent learning process. We have divided the learning of parametric synthesis in single-loop, cascaded, and combined ACS into basic steps, and found methods of intellectual learning monitoring.

It has been found out that PS mostly consists of plotting with subsequent search for points matching the specified conditions. In this regard, the accuracy of finding a plot point makes one of the basic PS knowledge criteria. To make this PS step intelligent, we introduce the linguistic variable (LV) Distance-to-Point with terms Match, Close -/+, Far -/+, and Beyond +-/. To construct the membership functions (MF) of LV terms, we use a U-shaped function generated by the product of two sigmoidal functions.

MF boundaries for Distance to Point terms depend on the plot type and the initial problem situation.

Knowledge is controlled by the LV Knowledge with its terms Poor, Satisfactory, Good, and Excellent.

As a result, an intelligent PS learning process requires fuzzy knowledge-base (KB) rules, where the hypothesis of rule is based on the Distance-to-Point, whereas the conclusion of rule is Knowledge-based knowledge criterion. The LV in use enable experts to make KB entries using human-readable concepts.

Below are the basic principles of parametric synthesis in single-loop, cascaded, and combined ACS, as well as intelligent learning methods suitable for them.

A. Single-loop control systems

In single-loop ACS, PS problems follow proportional-integral (PI), proportional-derivative (PD), and proportional-integral-derivative (PID) control laws based on the expanded Nyquist plot (ENP) for the specified degree of oscillations.

In this case, the PS task consists of the following steps:

Find the initial frequency ω_i and the final frequency ω_f to plot the D-decomposition line that satisfies the specified degree of oscillations in the tuning-parameters plane for the selected controller.

Find the operating frequency ω_{op} on the D-decomposition line as well as such tuning parameters of the controller that match the best value of the transient-response quality criterion.

For the first-step PS in this single-loop ACS, the trainee selects ω_i and ω_f on the ENP (see Figure 2); their input is used to generate Distance-to-Point-based rules.

Angle y_{spec} in Figure 2 is pre-determined based on the requirements to the ACS stability margin. During PS, each controller has its own frequency range found by reference to the ENP to meet the conditions above. For PI controllers, the range is ω_1 to ω_2; for PD controllers, the range is ω_2 to ω_3; for PID controllers, the range is ω_1 to ω_3. Thus, points with such frequencies are the required points. To find how accurately each point is found, use the LV Distance-to-Point.

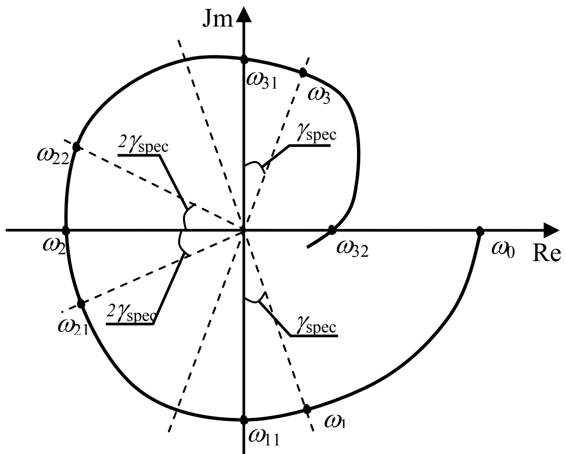

Fig. 2. Expanded frequency responce of the control object

The basic variable here is the percentage of the length of the plot segment from the required point to the export-specified MF boundaries for Distance-to-Point terms.

For the second PS step, the appropriateness of the selected ω_{op} and its respective controller parameters is also controlled by the LV Distance-to-Point. Ye.G. Dudnikov states that ω_{op} = 1,2*ω_{max} (ω_{max} is the extremum frequency on the D-decomposition line) [28].

Use the expert-filled KB to find the knowledge criterion by the LV Knowledge.

B. Cascaded control systems

In cascaded CS, the PS essentially consists in the iterative computing of the parameters of stabilizing and adjusting controllers. Computation is finished upon reaching the specified error between the current-step and previous-step tuning parameters of controllers.

In connection with the above, when monitoring the learning of parametric synthesis in cascaded ACS, one can use the same methods as applicable to single-loop ACS. Therefore, the LV Distance-to-Point and the LV Knowledge are used in the same fashion. As all the single-loop PS steps are done repeatably in this case, the output is generated by averaging the LV Knowledge value for the selected operating frequency and frequency range.

C. Combined control systems

In combined ACS, the PS is done in two steps: first the tuning parameters of the controller are computed in the same fashion as for single-loop ACS; then the user computes the tuning parameters of the compensator. To optimize the PS and to enable intelligent PS monitoring, we herein propose an analytical method for computing the compensator parameters. Compensator SS and PS includes plotting the ideal-compensator frequency-response vector, selecting a real compensator, and optimizing its tuning parameters.

To find the PS knowledge criterion in case of combined ACS, one first has to determine whether the selected real compensator is appropriate. Selection of a standard link for implementing the real compensator is evaluated by the LV Compensator Type with its terms Best, Good, Normal, Bad.

Then one must select a point that matches the operating frequency in the Nyquist plot of the real compensator, which is necessary for plotting the Nyquist-plot vector and to optimize the tuning parameters of the compensator. This selection is evaluated by the LV Distance-to-Point with the parameters of the point ωcomp.

The final PS knowledge criterion for the combined ACS is found by the LV Knowledge as a conclusion of KB rules that have Compensator Type and Distance-to-Point as hypotheses combined with the controller parameter optimization knowledge criteria.

IV. Results of using the expert system

The created fuzzy-inference model for expert systems has been tested in fuzzyTECH. Below are the test results:

- the proposed fuzzy trainee-knowledge base rules react adequately to all of the trainee's actions necessary for ACS PS;

- the expert system's logical-output block processes all inputs correctly;

- the output knowledge criteria for all the interim and final ACS PS steps are consistent with the expert projections.

The created exert system has been tested by the FEGC personnel as well as by students of some major universities in Far East and Samara Oblast. Tests involved 58 persons. The results were additionally evaluated by experts specializin gin this field (chief FEGC specialists and university professors).

As all tasks were divided into modules, each module was evaluated on a 4-point scale. Final grade could be derived by:

1) finding the arithmetic mean of all task-specific grades;

2) finding the arithmetic mean of module-specific final grades;

3) finding the expert-system fuzzy value.

The results were compared against expert grades to find the following deviations:

- 36% of the arithmetic knowledge-criterion means for interim ACS PS;

- 18% of the arithmetic knowledge-criterion means for final ACS PS;

- 7% of the ETS-derived knowledge criteria.

Therefore, the ETS-derived data was quite close to expert opinions and 2.5 to 5 times more accurate than the arithmetic means. Thus, we can conclude that using ETS for intelligent learning enables reliable APCS PS knowledge grading to make further recommendations on consolidation and improvement.

V. CONCLUSIONS

For the practical application of the developed system, the researchers have analyze the Amur Generation branch of JSC FEGC as well as the job descriptions of dispatchers and dispatcher-operated APCS; the analysis demonstrates the necessity of, and demand for, systems to automate process-related knowledge control, generation, and consolidation in key knowledge areas. Single-loop / cascaded / combined ACS are the most frequently-used ACS types at such facilities.

Lack of solutions for automating the HRM tasks relating to the APCS process KMGC meant that expert training systems for intelligent process learning were imperative.

The created methods and algorithms serve as the basis for a cross-platform ETS for automating the self-study of single-loop, cascaded, and combined APCS. Using ETS for process KMGC is proven efficient compared to conventional self-study methods, meaning it is feasible as an advanced-training instrument in heat and power engineering. ETS implementation at the Amur Generation branch has been found an economically feasible and investment-attractive project.

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