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The Efficiency of Algorithms and Number of Control Hierarchy Levels of Building Electronic Control System

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***Abstract*—In the paper the building electronic control systems (BECS) are introduced, existing trends of their development are identified, and related important efficiency research problems are defined, their factors are distinguished which strongly influence the operation of entire BECS methods of efficiency evaluation of selecting operation algorithm and hierarchical control levels.**

General diagram of factors impacting general *i*-th component of algorithm is presented, parameters of these factors are indicated, and it is also demonstrated, that the values of these parameters are independent of each other. Methods are offered how to select optimal numbers of BECS hierarchical levels.

***Index Terms*—Algorithms, building electronic control systems, efficiency, hierarchy level efficiency.**

I. INTRODUCTION

It is not possible to find a unified and precise definition of building electronic control system (BECS). In each particular case different features of such system are presented, which are typical when analyzing a selected system in respect of specific aspect. In most cases BECS is intended to manage the building engineering systems in a way to ensure appropriate conditions for building users.

With decreasing cost of electronic control measures (ECM) and increasing degree of their integration, they inevitably penetrate all technical areas. BECS is not an exception: they are being used to control building engineering systems more and more widely, granting them more and more functions to perform. Also, the decentralization of intellectual system features and migration towards its peripheral parts can be observed, i.e. control functions are increasingly less concentrated in centers, and increasingly more of them are transferred to peripheral devices. However, an opposite trend exists for information flows: they increase in complexity and become more centralized. In order to make more proper management decisions, it is required to process more information, therefore the need for information centralization and problems related to this question remain and even become more accurate. When a larger number of smart devices are available in the system, a problem of their optimal coordination and application to perform required function becomes more relevant, but by solving it properly, solution enables achieving of better results of management [1]. As it is mentioned, information flows becomes more and more complex, therefore more efforts to manage it properly more scientific research methods are needed – this paper tries to contribute to solve this issue; this is the main originality of this paper.

It is obvious, that problems of BECS efficiency increase remain relevant [2]. In this paper the efficiency evaluation methods of BECS operation algorithms and selection of number of system hierarchical levels – attributes, which strongly influence the efficiency of entire BECS – are presented.

II. EFFICIENCY OF ALGORITHMS OF BUILDING ELECTRONIC CONTROL SYSTEM

Efficiency of electronic control measures is determined by the efficiencies of their electronic devices (ED) and processes, which take place inside them. ED efficiency increases in a long-term, although with the increase of their internal processes the efficiency research does not lose its scientific relevance. Due to abundance and variety of the processes it is difficult to evaluate their efficiency in each device. The efficiency of these processes is determined by conformance of purpose functions to the needs and possibilities to accomplish these functions. Technical peculiarities of these possibilities can be characterized by task performance non-interruptance, inviolability of performed process (in intended and (separately) extreme, unforeseen environment) and system persistence [3].

The first property characterizes possibilities of emerging of functioning disturbances, which disappear naturally during other cycle or cycles, the second – possibilities of non-repairable process disturbance (failure of devices used in it, software failures, loss of information used in the process, etc.), and the third – possibilities for the process to transform itself after occurrence of mentioned disturbances or/and failures and to proceed further with the task accomplishment. All these properties are heavily dependent

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on the BECS operation algorithm – precisely or stochastically determined order of processes (actions) inside it, beginning with the definition of initial conditions, to the operation result presentation. Thus, when speaking about efficiency of algorithm, not diagrams of order or its structure are assumed, but the efficiency of sets of the processes spanned by it, their allocation and control (by assessing states of devices used in them).

The probability to accomplish BECS processes in a qualitative manner and probability to accomplish the task performed during its processes over pre-defined period of time are the main indicators of technical efficiency of BECS operation algorithm.

When task accomplishment duration is limited, it is necessary to assess one additional feature of BECS operation algorithms: resultativity, or a possibility to achieve acceptable result of functioning over defined period of time. [3]. However, with aim to avoid duplication of first three properties by the fourth property of processes, these cases are not considered during evaluation of resultativity of BECS processes.

The value of resultativity indicator (probability to achieve an acceptable result of operation during defined period of time) will decrease, if a search for data and its analysis would take up too much time, if operation algorithm of models used in it would be too complex, if a shortage of resources (information, memory, etc.) would emerge, and if other unfavorable conditions would appear.

Let's form the operation algorithm efficiency evaluation method for information-based BECS. We make an assumption that the system efficiency is characterized by task accomplishment probability.

Assume that the probability to accomplish the task performed by each i-th component of the algorithm during time t_i is $P_{ui}(t_i)$. It is obvious, that

$$P_{ui}(t_i) = f_i[\{D_{ij}\},\{F_{ij}\},\{A_{ij}\},\{M_{ij}\},...,t_i], \qquad (1)$$

where $\{D_{ij}\}$, $\{F_{ij}\}$, $\{A_{ij}\}$ and $\{M_{ij}\}$ – sets of parameter values for reliability of ED, used in i-th algorithm component, factors influencing this component, algorithmic measures and models used in it. General diagram of factors influencing i-th component of the algorithm is presented in Fig. 1.

In this figure: $\{I_{ij}\}$, $\{B_{ij}\}$, $\{H_{ij}\}$, $\{R_{ij}\}$, $\{Y_{ij}\}$ and $\{O_{ij}\}$ are sets of indicator parameter values for information system, software, regulating document basis, measures for ensuring the resultativity, and for external control measures and system operator-ES.

It can be seen from Fig. 1, that in case these indicator values are independent of each other, then

$$P_{ui}(t_i) = P_{EIi}(t_i)\cdot P_{Ii}(t_i)\cdot P_{Ai}(t_i)\cdot P_{Bi}(t_i)\times$$
$$\times P_{Mi}(t_i)\cdot P_{Hi}(t_i)\cdot P_{Ri}(t_i)\cdot P_{Yi}(t_i)\cdot P_{Oi}(t_i), \qquad (2)$$

where $P_{EIi}(t_i)$, $P_{Ii}(t_i)$, $P_{Ai}(t_i)$, $P_{Bi}(t_i)$, $P_{Mi}(t_i)$, $P_{Hi}(t_i)$, $P_{Ri}(t_i)$, $P_{Yi}(t_i)$, $P_{Oi}(t_i)$, – probabilities that ED, information system, internal algorithms, software, methods, regulatory basis, resultativity-ensuring measures, external control measures, and operator will complete their tasks during time t_i

$$P_{Ii}(t_i) = P_{PIi}(t_i)\cdot P_{VIi}(t_i)\cdot P_{ISi}(t_i)\cdot P_{IKi}(t_i)\cdot P_{ITi}(t_i), \qquad (3)$$

where $P_{PIi}(t_i)$, $P_{VIi}(t_i)$, $P_{ISi}(t_i)$, $P_{IKi}(t_i)$ ir $P_{ITi}(t_i)$ – probabilities, that initial and control information of required quality will be introduced, it will be properly stored, changed and supplied over time t_i.

When assessing possible reasons of not completing the task for each of algorithm attributes $\{a_{ci}\}$ given in formulas (2) and (3), their persistence and resultativity, it is possible to write, that

$$P_{aci}(t_i) = \{P_{\overline{S}ci}(t_i) + [1 - P_{\overline{S}ci}(t_i)]\cdot P_{Sci}(t_i)\}\times$$
$$\times\{P_{\overline{P}ci}(t_i) + [1 - P_{\overline{P}ci}(t_i)]\cdot P_{Pci}(t_i)\}\times$$
$$\times\{P_{\overline{R}ci}(t_i) + [1 - P_{\overline{R}ci}(t_i)]\cdot P_{Rci}(t_i)\}, \qquad (4)$$

where $P_{\overline{S}ci}(t_i)$, $P_{\overline{P}ci}(t_i)$, $P_{\overline{R}ci}(t_i)$ – probabilities, that c-th attribute of i-th algorithm component will not be disturbed, will not be breached, and that will ensure the required resultativity; $P_{Sci}(t_i)$, $P_{Pci}(t_i)$, $P_{Rci}(t_i)$ – probabilities, that this attribute after its disturbance, breach or due to lack of resultativity-ensuring measures will be capable to transform over time t_i and complete performing its task in a quality manner.

Let's consider ways of calculating indicator values of several $\{a_{ci}\}$ attributes used in formula (4). Probability that i-th ED used to perform i-th task will not fail during time t_i, is

$$P_{\overline{S}EIi}(t_i) = e^{-\lambda_{Si}\cdot t_i}, \qquad (5)$$

where λ_{Si} – intensity of emergence of factors with probability close to unity, which condition disturbances of i-th ED, when the type of their flow is simplest.

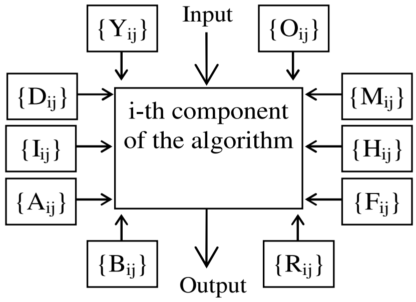


Fig. 1. Diagram of factors influencing i-th component of the algorithm.

Assume, that available disturbance detection measures will provide the possibility to notice them; theoretical duration of task performance without disturbances for i-th ED is t_{ti} , and average duration:

$$t_{vi} = \lambda_{vi} t_{ti}^2 + t_{ti}, \quad (6)$$

$$t_{vi} \geq t_{ti}, \quad (7)$$

$$\lambda_{vi} = \frac{\lambda_{i1} \cdot \Delta t_{i1} + ... + \lambda_{ij} \cdot \Delta t_{ij} + ... + \lambda_{in} \cdot \Delta t_{in}}{t_{ti}}, \quad (8)$$

where λ_{ij} – intensity of disturbances of i-th ED part performing j-th stage of the task; t_{ij} – duration of performing j-th task stage (without disturbances); n – number of task stages

$$\sum_{j=1}^{n} \Delta t_{ij} = t_{ti}. \quad (9)$$

Probability that k disturbances will emerge while performing the task of i-th ED

$$p(k) = \frac{\left(\sum_{j=1}^{n} \lambda_{ij} \cdot \Delta t_{ij} \right)^k}{k!} \cdot e^{-\sum_{j=1}^{n} \lambda_{ij} \cdot \Delta t_{ij}}. \quad (10)$$

Let's mark the probability, that after failure of i-th ED its time reserve (t_i) will be sufficient to repeat the failed stages, as $p\{(t_i - t_{ti}) \geq k \cdot t_{mi}\}$; here t_{mi} – average duration for completing single stage of i-th ED. Then the probability, that i-th ED component will complete its task without failures during time t_i is calculated as

$$P_{EIiS}(t_i) = \sum_{k=0}^{\infty} [\frac{\left(\sum_{j=1}^{n} \lambda_{ij} \cdot \Delta t_{ij} \right)^k}{k!} \cdot e^{-\sum_{j=1}^{n} \lambda_{ij} \cdot \Delta t_{ij}} \times \times p\{(t_i - t_{ti}) \geq k \cdot t_{mi}\}]. \quad (11)$$

In this case

$$P_{EIiSS}(t_i) = P_{\overline{S}EIi}(t_i) + [1 - P_{\overline{S}EIi}(t_i)] \cdot P_{SEIi}(t_i). \quad (12)$$

Similarly, it is also possible to calculate the probability, that i-th ED will accomplish its task regardless of disturbances, i.e.

$$P_{EIiPp}(t_i) = P_{\overline{P}EIi}(t_i) + [1 - P_{\overline{P}EIi}(t_i)] \cdot P_{PEIi}(t_i). \quad (13)$$

Probabilities, that i-th ED will provide required resultativity ($P_{\overline{R}Eii}(t_i)$ and $P_{REii}(t_i)$) are calculated by analyzing its resource needs when performing each j-th stage of the task implementation and real possibilities to provide these resources during this period of time.

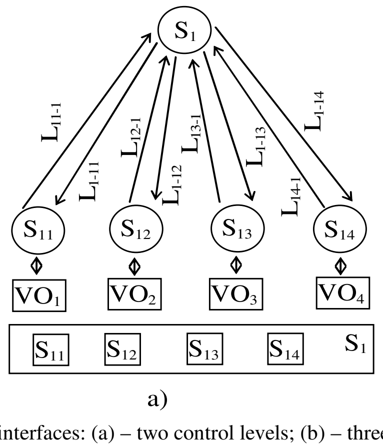
Probabilities, that information system, software, methods and other attributes will ensure the possibilities to accomplish the task of i-th block of algorithm (P_{ui} (t_i)) are investigated in a similar manner.

III. Selection of Number of BECS Control Levels

Number of control levels [3] is often referred to as the number of hierarchical levels (control hierarchy, hierarchy, etc.). It is determined by relations among control and controlled indicators and number of decision levels.

When trying to focus all decisions at one level, this result in excessively large model of management, from which even the most capable measures are not advanced enough to make rational decisions. Furthermore, when looking for more global optimum, the services of lower control levels still have to be used.

When increasing the number of hierarchical levels, often the number of control measures (CM) is also increased, measures for interaction of levels appear, possibilities to lose or distort the information and control commands, when transmitting them from one level to another, emerge, redundancy and contradiction of data, commands or/and models and analysis procedures inevitably come into play. Not in all cases the higher-level system S_1 (Fig. 2(a) efficiently manages the lower-level system S_{11}. Let's consider the structure presented in Fig. 2.



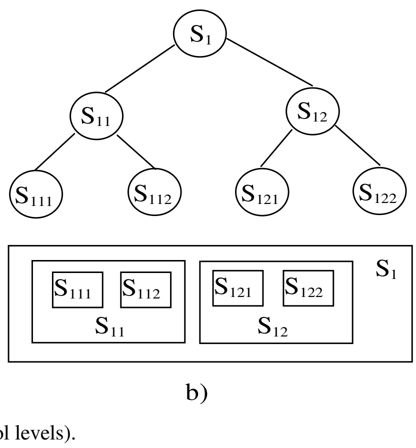


Fig. 2. Variants of system interfaces: (a) – two control levels; (b) – three control levels).

Often, the quality of such set of systems can be described by number of normally operating lower-level systems [3]. Each system of lowest level (e.g., S_{11}) will operate normally, when it will function normally itself, also when its interface with higher level system (in both directions – L_{1-11} ir L_{11-1}) and the higher level system (S_1) will function normally. The higher-level system will operate properly, when it will accomplish its (systematization) functions and will properly manage the S_{11} system. The probability, that S_{11} will complete its task during time t is $E_{11}(t)$, and same probabilities for its interface – $E_{1\text{-}11}(t)$ and $E_{11\text{-}1}(t)$, for system S_1 – $E_1(t)$. Thus the probability, that the left branch (Fig. 2, a) will complete its tasks

$$E_{11\Sigma}(t) = E_{11}(t) \cdot E_{1-11}(t) \cdot E_{11-1}(t) \cdot E_1(t) \cdot E_{11S}^{(1)}(t), \quad (14)$$

where $E_{11S}^{(1)}(t)$ – the probability, that S_1 will accomplish its task of controlling S_{11} during time t:

$$E_{11}(t) = P_{11}(t) \cdot P_{11}^{'}(t), \quad (15)$$

$$E_{1-11}(t) = P_{1-11}(t) \cdot P_{1-11}^{'}(t), \quad (16)$$

$$E_{11-1}(t) = P_{11-1}(t) \cdot P_{11-1}^{'}(t), \quad (17)$$

$$E_1(t) = P_1(t) \cdot P_1^{'}(t), \quad (18)$$

where in each equation the first multiplier is the probability, that devices will accomplish their tasks during time t, and the second multiplier is the probability, that this task will be accomplished by processes taking place inside those devices.

Control objects VO_1 – VO_4 (Fig. 2(a)) may form a set (set of any single-purpose devices), or a complex (entirety of interrelated devices dedicated to perform a sequence of different functions). In case of BECS, VO form a set most often, hence the efficiency calculation for the case of complex formation is not relevant. In case of a set (when objects are identical and perform the same functions, and the efficiency of lowest-level systems is identical to the efficiency of VO) one would expect the additivity of their operating values, i.e.

$$E_{\Sigma}(t) = \sum_{i=1}^{n} \frac{1}{n} E_i(t), \quad (19)$$

where n – number of VO; $E_i(t)$ – efficiency of i-th VO.

For the case illustrated in Fig. 2(a), we could note that

$$E_{11S}^{(1)}(t) = E_{12S}^{(1)}(t) = E_{13S}^{(1)}(t) = E_{14S}^{(1)}(t) = E_{iS}^{(1)}(t), \quad (20)$$

where $E_{iS}^{(1)}(t)$ – efficiency of system S_1 during control of either i-th lower-level system. Then the overall efficiency of entire hierarchical system (Fig. 2(a)) is

$$E_{\Sigma}(t) = E_1(t) \sum_{i=1}^{n} \cdot \frac{1}{n} E_{1i}(t) \cdot E_{1-1i}(t) \cdot E_{1i-1}(t) \cdot E_{iS}^{(1)}(t). \quad (21)$$

When the number of hierarchical levels is H, the probability, that one (first) lowest-level system will properly accomplish its task (under influence of all higher-level systems) can be calculated in analogous way to (14), i.e.

$$E_{\Sigma 1}(t) = E_1(t) \prod_{j=2}^{H} E_j(t) \cdot E_{(j-1)-j}(t) \cdot E_{j-(j-1)}(t) \cdot E_{jS}^{(j-1)}(t), \quad (22)$$

where $E_j(t)$ – efficiency of j-th level system (in a series from lowest to highest level) during time t; $E_{(j-1)-j}(t)$ – efficiency of interface $L_{(j-1)-j}$ between (j - 1)-th and j-th level systems during time t; $E_{jS}^{(j-1)}(t)$ – probability, that the system of (j-1)-th level will accomplish its task of controlling the system of j-th leve during time t. Then

$$E_{\Sigma}(t) = E_1(t) \cdot \sum_{i=1}^{n_H} \frac{1}{n_4} \prod_{j=2}^{H} E_{ji}(t) \cdot E_{((j-1)-j)i}(t) \times$$
$$\times E_{(j-(j-1)i}(t) \cdot E_{js}^{(j-1)}(t), \quad (23)$$

where $E_{ji}(t)$ – probability, that i-th system of j-th level will complete its task during time t; $E_{((j-1)-j)i}$ and $E_{(j-(j-1))i}(t)$ – probability, that interfaces between i-th system of (j - 1)-th level and its managing system of j-th level and between already mentioned system of j-th level and i-th system of (j - 1)-th level will complete their tasks; $E^{(j-1)}_{ijs}$ (t) – probability, that the j-th level system, which controls the *i-th* system of (j - 1)-th level will accomplish its task during time t, i.e. will properly manage the i-th system; n_4 – number of systems in H-th control (hierarchical) level.

Assume, that:

$$E_1(t) = E_{ji}(t) = E_0 = const., \quad (24)$$

$$E_{((j-1)-j)i}(t) = E_{(j-(j-1))i}(t) = E_r = const. \quad (25)$$

Then from (23) we obtain, that

$$E_{\Sigma}(t) = E_0 \cdot \sum_{i=1}^{n_H} \frac{1}{n_H} \cdot E_0^{H-1} \cdot E_r^{2(H-1)} \cdot \prod_{j=2}^{H} E_{jis}^{(j-1)}(t). \quad (26)$$

When VO forms a set with additive efficiency indicators and the number of these objects remains fixed, and $E_{jis}^{(j-1)}$ depends on H and increases with the increase of H, then (when E_0 = *const.*), with the increase of the number of control levels, the magnitude

$$\Delta E^{'} = E_0^{H-1} \cdot E_r^{2(H-1)} \quad (27)$$

will decrease, and the magnitude

$$\Delta E^{''}(t) = \prod_{j=2}^{H} E_{jis}^{(j-1)}(t) \quad (28)$$

will increase or decrease, in respect of relation between function $E_{jis}^{(j-1)}(t, H)$ and H. Therefore we cannot exclude the possibility, that the multiplication of magnitudes (27) and (28) may have an extremum (maximum). In such case an optimal variant of structure could be found by using this operator

$$\max_{H} E_{\Sigma}(t, H), \; H = 2,3,...N, \quad (29)$$

where N – any sufficiently large number, which must assure that optimal decision will be reached.

Due to the highly theoretical type of paper general methods and mathematically proven way of thinking were presented only. When applying these methods to any practical situation (simulation), a lot more aspects regarding to particular chosen systems must be addressed; and when choosing and assessing these aspects different scientific problems can occur. The simulation is of the scope of this article.

IV. CONCLUSIONS

Presented methods for determining the efficiency of BECS operation algorithm and selection of number of BECS hierarchical levels enable to identify factors, which affect the efficiency of these attributes most, and these inevitably impact the efficiency of entire BECS. Optimal evaluation of efficiency criteria allows avoiding the errors of BECS operation still in its development stage.

When assessing the influence of each algorithm component on the probability of task accomplishment, it is necessary to sum up the influences of different factors (devices, models, information, etc.) on the value of task accomplishment probability in a single mathematical model. That leads to the need to assess not only the efficiency of each individual device or software package, but of entire algorithm, taking into account the persistence, resultativity and other properties of its individual components.

The proposed method does not estimate the quality of the algorithm, and only characterizes its technical efficiency, i.e. task accomplishment possibilities. In order to characterize the quality of the algorithm in a greater depth, its non-failure, correctness, mobility, modification possibilities, verifiability, suitability for development, compatibility, ease of use, unification, persistence, integrity and other features would have to be evaluated.

After evaluating efficiencies of separate BECS levels, and their impact on the efficiencies of lower-level (subordinate) systems, it is possible to calculate the rational number of hierarchical BECS levels. When BECS efficiency is limited and varies over time, the rational number of hierarchical BECS levels also changes.

Minimum number of BECS hierarchical levels is often determined by functional features of $\{VO_i\}$. Although a possibility, that there exists a rational number of BECS hierarchical levels, can be ruled out; methods are presented.

During further research, the measures of ensuring the process adaptability must be introduced into BECS control/management algorithms and their efficiency should be assessed.

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