MSSI — Modular Structure of Stochastic Process Information for Power System Control

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The usage of process information in a real-time and out of it is a very comlex but also an important segment of the electric power system automatic control. A model of the process information events of electric power stations is worked out, whereby process information is defined by points in the space. Generation of electric power system process information is a discrete statistical phenomenon. In the paper both the space of elementary events and the space of electric power system probabilites process information are presented on the level of components as well as on the level of the whole system. The process information group with n-dimensional random values is described, and then a method of transforming the n-dimensional random values into one dimensional space is presented by the function D. This procedure enables process information set to be modularly defined as random values, and the model is used for the computer calculation of process events restoring times.

1. Introduction

In the modern research of natural phenomena various tehnical objects or plants are observed as defined "SYSTEMS" that can act independently or be a part of an oversystem as in the case of power system (PWS). The system of power substation (PSU) is a set of organized components (field), spatially distributed by selected locations with a purpose to achieve precisely the definite aim. Functioning of such a system, in the course of time, is regarded as definite "PROCESS" whereas its behaviour is described by a selected set of parameters [2]. The "PARAMETER" is thus, in the context of this research, a quantity used as a reference for describing observed system operation, whereas the system, during the process, can be in certain "CONDITIONS". In the plants of technical system, four basic "types" of parameters are used:

- **measuring parameters**, in the dynamical process characterized by the shift higher — lower,
- **alarm parameters**, characterized by the yes-no shift,
- **status parameters**, characterized by the on — off shift,
- **control parameters**, characterized by the active — passive condition

Along with space **"location"** of the parameter, selected **"function"** of the parameter in the process and definite **"term"** of the parameter, the model of **"static"** structure of the set parameters S is formed in the "PASSIVE" condition of the system. At any chosen process interval Δt , the parameters can change their condition, so corresponding "INFORMATION" is "generated" presenting new knowledge, eliminating uncertainty and functioning as "decision making ground" [6].

The presented model of set parameters S exhibits, on the level of the plant, a **"source"** that displays information at eny interval Δt of the process, whereas the observed system changes its condition in the process in connection with the condition change of one or more parameters. The set of possible system conditions is in fact a result of condition change of any basic parameter combination.

Parameter condition changes in the power substations are mainly regarded as STOCHASTIC

FCM ↗ ↘

$(FCM_m)_{tl}$	$(FCM_m)_{ge}$	$(FCM_m)_{tr}$	...	$(FCM_m)_{bs}$	FM_m
$(FCM_a)_{tl}$	$(FCM_a)_{ge}$	$(FCM_a)_{tr}$	...	$(FCM_a)_{bs}$	FM_a
$(FCM_s)_{tl}$	$(FCM_s)_{ge}$	$(FCM_s)_{tr}$	...	$(FCM_s)_{bs}$	FM_s
:	:	:	...	:	:
$(FCM_c)_{tl}$	$(FCM_c)_{ge}$	$(FCM_c)_{tr}$	...	$(FCM_c)_{bs}$	FM_c
CM_{tl}	CM_{ge}	CM_{tr}	...	CM_{bs}	M

↖ ↙ FM

↖ ↑ ↗

CM

m — measurements	tl — transmission line	M — substation modul
a — alarm signals	tr — transformer	FM — function modul
s — switching signals	ge — generator	CM — component modul
c — command	bs — bus	FCM — function component modul

Table 1. Plant parameters moduli

QUANTITIES and only the probability of definite condition can be defined for the system having a progress in the future. System condition in the future cannot be uniquely determined. However, the definite probability distribution can be determined in an array of all possible conditions. The amount of processed information for such systems is regarded as stochastic phenomenon with descrete conditions and descrete time parameters.

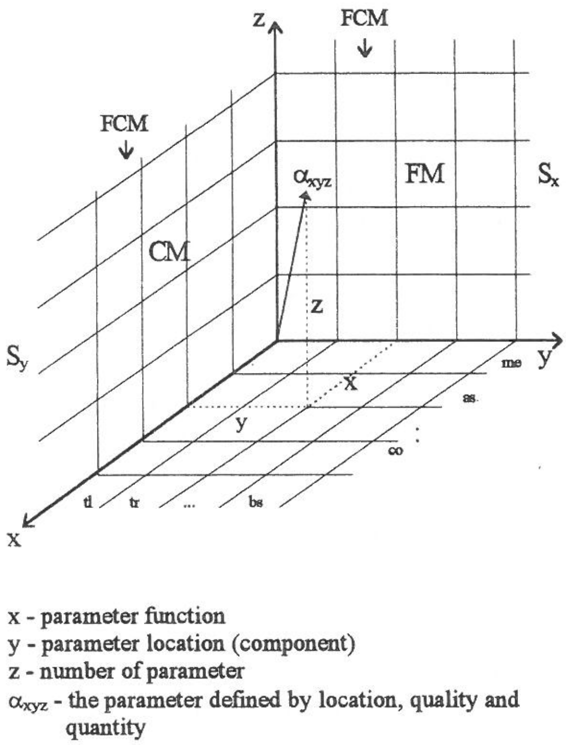
Systems of micro and mini-processed computors for power system controlling have been utilised in the power substations for fifteen years. In this way, very precise process event recording with time resolution of 1 to 10 ms was made feasible. Millions and millions bits of processed information in single power systems have been recorded for years. Enormous effort and capability are indispensable for relisation of intelligible and coherent software and it would in turn enable an efficient analysis and application of all bits of information. A great many bits of processed information have unfortunately remained unprocessed and unemployed in the system of control of power system used so far. Furthemore, the questions of **how**, **where** and **why** to use and to file a great amount of process information often remained unsolved. This paper sets out to examine these complex aspects.

2. Parameters Moduli of the System and Process Information

2.1. Modular parameter presentation

The parameter is a static quantity used as a reference for describing operation quality of a plant. A power substation is used as an example for making the modular parameter set visible. First, we have to define COMPONENT MODULI (CM) as technical location plants regarded in their entirety (transformer, generator, transmission lines, busbars, ...) and FUNCTIONAL MODULI (FM) must be then determined for each component as parameter sets of plant operation (measurement, alarms, switching signals, command, ...). Therefore, CM displays a modulus that contains a parameter set of various types of one component and FM presents a modulus that contains a parameter set of one type on various plant components.

Corresponding combined FUNCTIONAL — COMPONENT MODULI (FCM) are realised by connecting selected FM with CM. Through FCM synthesis by **columns** the corresponding CM_i can be defined and through synthesis FCM_i by **lines** the corresponding FM can be presented. At the end the synthesis of marginal columns and lines results in summary modulus M representing a set of all parameters of a plant. (Table 1.)



x — parameter function
y — parameter location (component)
z — number of parameter
α_{xyz} — the parameter defined by location, quality and quantity

Fig. 1. Vector parameter presentation of power substation

In Fig. 1 a vector structure of process parameter is depicted by using an elementary moduli presentation in the table 1. The necessary characteristic parameter set, used in model elaboration for process information flow calculation, will be defined by this structure. Parameters set S on the level of the plant for **all components** and **all types** of parameters can be defined as:

$$S = \{\alpha_{xyz}\} \quad x = 1, 2, 3, \dots, m \quad y = 1, 2, 3, \dots, n \quad z = 0, 1, 2, \dots, r \tag{1}$$

Parameters set S_x of a FM for **one type** of parameter but on **all components** of the plant can be indicated in the equation

$$S_x = \{\alpha_{xyz}\} \quad x = const. \quad y = 1, 2, 3, \dots, n \quad z = 0, 1, 2, \dots, r \tag{2}$$

This set is also defined by yz-plane in Fig. 1.

Parameters set S_y (modulus CM) for **one component** and for **all types** of plant parameters is indicated by the expresion (3), and described in Fig. 1 by xz-plane.

$$S_y = \{\alpha_{xyz}\} \quad x = 1, 2, 3, \dots, m \quad y = const. \quad z = 0, 1, 2, \dots, r \tag{3}$$

At the end set S_{xy} (FCM) depicts the set of parameters for **one component** and for **one parameter** quality (columns xz and planes yz) and is defined by the equation

$$S_{xy} = \{\alpha_{xyz}\} \quad x = const. \quad y = const. \quad z = 0, 1, 2, \dots, r \tag{4}$$

Operation evaluation of a PSU is an attempt at an exact judgment what parameters from the given set change their condition in the definite time process Δt.

2.2. Process Information Structure

Definite units of **information** are generated as events of the observed experiment by every condition change of one or more system parameters of the time Δt. The information concept, referred to as process events, can have an array of connotations, depending on the experiment quality and on the level with primary system on which a unit of information is observed. Thus a unit of information can be examined for instance, as an event ε in the plant on a level with only **one parameter** by the equation

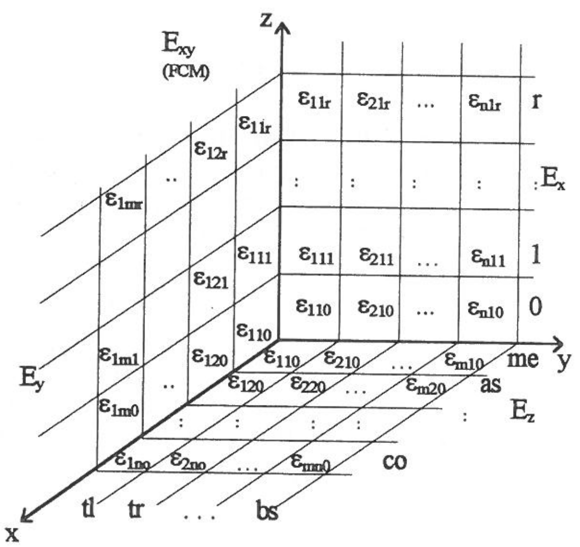
$$\varepsilon_{xyz} = \frac{a_{xyz}(t + \Delta t) - a_{xyz}(t)}{\Delta t} \quad x, y, z = const. \tag{5}$$

Furthermore, information event can be observed on a level with the set S_{xy} of a FCM, on a level with the set S_x of a FM or else on a level with the set S i.e., with the whole plant. Besides, we have to point out, that process information can be analyzed in both ways, regarding qualitative-quantitative relation:

a) as **quantitative information event**, and accordingly only the parameter number is required for the observed modulus that changed its condition in the time Δt.

b) as **qualitative information event** for which the knowledge of the parameter term is required, which changed its condition in the process time Δt.

Our selection and method of process information analysis depends on the experiment which is described. As this paper deals with the model of restoring time information (RTI) estimate in the control centre of the PWS, we shall analyze quantitative information event on a level with a FCM (Fig. 1). Moreover, FCM determines exactly what type of parameter is actually to be communicated with reference to secondary information flows and which component of the primary system is to be observed in the plant. This is the way to solve the questions of how to form addressed process messages and procedures in the communication between the plant and control centres (15). As process information of the PWS is a random quantity [12], the observed experiment also has to be analyzed as a stochastic model.



x-axis → functional moduli
y-axis → component moduli
z-axis → units of information
ε_{xyz} → information event

x-axis → functional moduli

y-axis → component moduli

z-axis → units of information

ε_{xyz} → information event

Fig. 2. Presentation of information sets on a level with the plant (PWS)

If the **plant components**, associated with corresponding parameter sets by which in turn the plant's behaviour is described, are marked on the **axis-**y in a three-dimensional system, and if the **type of parameters**, with reference to function in the information system, are marked on the **axis-**x, and if **units of information** appearing in the process as a result of the condition of one or more parameters in the process time Δt, are marked on the **axis-**z, then the information structure represented in Fig. 2 is determined.

The model of restoring time information estimate in control centres will be described as a stochastic experiment [11,12]. Information evaluation is required here on a level with the columns yz-planes (FCM). The information concept exy (or information event) on a level with FCM will be defined by using the expression (4) as follows:

$$\varepsilon_{xyz} = \frac{S_{xyz}(t+\Delta t) - S_{xy}(t)}{\Delta t} = \frac{z_{xy}}{\Delta t} \qquad (6)$$
$$x, y = const., \quad z \in \{0, 1, \ldots, r\}$$

The value $S_{xy}(t+\Delta t)$ represents parameter condition of the observed set $S_{xy}(t)$ in the time $(t+\Delta t)$, the value $S_{xy}(t)$ represents parameter condition of this set in the time (t) and z_{xy} represents the number of set parameters S_{xy} which changed the condition during the time Δt (for instance if alarm signals are marked by $x = 1$, generator by $y = 3$, and if $z = 4$, then event ε_{134} signifies the 4 alarm signals activation on the generator in the time Δt).

It is useful for us to stress that **columns of the** yz**-plane** represent information (event) **set** E_{xy} of one type on a technical component (location) of the plant, and the entire yz-plane represents the set of one type information on all of the components of the plant. The very information sets E_x on a level with the yz-plane represent relevant process information sets on which data communication between the plant and control centre of the plant (PWS) based on. Therefore, not only are stochastic interpretations derived, but also the model on the basis of the modular structure of the event ε_{xyz} by the expression (6).

3. Processed Information Stochastic Analysis

3.1. The set Ex and the associated random vector $(E_{x1}, \ldots, E_{xn})$

Processed information set of one type on all the components of the plant encompassed by yz-plane can be represented as follows:

$$E_x = \left\{ \begin{matrix} \varepsilon_{x1r} & \varepsilon_{x2r} & \cdots & \varepsilon_{xnr} \\ \vdots & \vdots & \vdots & \\ \varepsilon_{x12} & \varepsilon_{x22} & \cdots & \varepsilon_{xn2} \\ \varepsilon_{x11} & \varepsilon_{x21} & \cdots & \varepsilon_{xn1} \\ \varepsilon_{x10} & \varepsilon_{x20} & \cdots & \varepsilon_{xn0} \end{matrix} \right\} \quad (7)$$
$$\begin{matrix} \uparrow & \uparrow & & \uparrow \\ E_{x1} & E_{x2} & \cdots & E_{xn} \end{matrix}$$

Columns of the presented set E_x comprise component elementary information sets E_{xy} whereas information events ε_{xyz} within one component are disjunct in relation to observed time interval Δt .

$$\varepsilon_{xy} = \varepsilon_{xy0} \cup \varepsilon_{xy1} \cup \varepsilon_{xy2} \cup \ldots \cup \varepsilon_{xyr}$$
$$x, y = const. \quad z \in \{0, 1, \ldots, r\} \quad (8)$$

We read the symbol "$\cup$" here as "or" and it has exclusive meaning [3,5]. This means that if we observe components separately at time interval Δt only one value on a level with the set E_{xy} (columns in the expression (7) may appear). The total number of elementary events is r. Units of information regarded as process events appear as random quantity [10,12]. Therefore, the set E_{xy}, as a matter of fact, represents elementary event space. If we attach corresponding probability pxyz to each unit of information from the set E_{xy}, then E_{xy} represents a random variable of the information event of one plant component (y) for exactly determined type of the parameter (x). Since we are, further, familiar with process technology, we have to examine n-components simultaneously. Therefore, n units of processed information appear also simultaneously as one n-dimensional information unit on a level with yz-plane of the set E_x respectively. For this n-dimensional information ex, the expression shows

$$\begin{aligned} &(\varepsilon_x)_u = \varepsilon_{x1z_1} \cap \varepsilon_{x2z_2} \cap \ldots \cap \varepsilon_{xnz_n} \\ &x = const. \qquad\qquad (9) \\ &y \in \{1, 2, \ldots, n\} \quad z_y \in \{0, 1, \ldots, r\} \\ &u \in \{1, 2, \ldots, \sigma\} \quad \sigma = r^n \end{aligned}$$

A complex unit of n-dimensional information on a level with the plant represents that a unit of information appears on the component 1, and one unit of information on the component 2, and ... and a unit of information on the component n. The set of all the units of complex n-dimensional information can be obtained as Cartesian product of the set E_x from the expression (7). This set has to be designated by Ω and it represents the space of n-dimensional elementary events for processed information on a level with the plant. σ from the expression (9) is the total number of n-dimensional elementary events. For the set Ω the expression [3] is valid

$$\Omega = \left\{ \begin{matrix} (\varepsilon_{x1z_1}, \ldots, \varepsilon_{xnz_n}) : \varepsilon_{x1z_1}, \ldots \varepsilon_{xnz_n} \in E_x, \\ z_y \in \{0, 1, \ldots, r\} \end{matrix} \right\} \quad (10)$$

That is, the set Ω is a set of all n-fold events having the characteristic feature that each element exyz belongs to the set E_x whereas z may receive the value from o to r. By probability theory [3,5] both associated event algebra $\mathcal{A} = \{\phi, A, \Omega\}$ and corresponding probability range $(\Omega, \mathcal{A}, P)$ may be defined for the elementary event set Ω.

In addition to modular information structure described in this way on a level with the plant, for the selected type of parameter, we can introduce an n-dimensional real function $(E_{x1}, \ldots, E_{xn})$ which attaches an n-tuple of process component information in the set $\mathbf{R}^n$ to every complex event $\varepsilon_x \in \Omega$, and by which probability load is transferred from Ω to $\mathbf{R}^n$:

$$\begin{aligned} \varepsilon_x \in \Omega &\to [E_{x1}(\varepsilon_x), \ldots, E_{xn}] \\ &= (\varepsilon_{x1z_1}, \ldots, \varepsilon_{xnz_n}) \in \mathbf{R}^n \qquad (11) \end{aligned}$$

The model will be so developed that for every arranged n-fold event $\varepsilon_{x1z_1}, \ldots, \varepsilon_{xnz_n}) \in \mathbf{R}^n$, the following is valid:

$$\begin{aligned} &\{\varepsilon_x \in \Omega E_{x1}(\varepsilon_x) = \varepsilon_{x1z_1}, \ldots, E_{nx}(\varepsilon_x) = \varepsilon_{xnz_n})\} \\ &= A(\varepsilon_{x1z_1}, \ldots, \varepsilon_{xnz_n}) \in \mathcal{A} \qquad (12) \end{aligned}$$

Consequently, $(E_{x1}, \ldots, E_{xn})$ is an n-dimensional random vector above probability range $(\Omega, \mathcal{A}, P)$. Arranged n-fold events $(\varepsilon_{x1z_1}, \ldots, \varepsilon_{xnz_n})$ of the random vector $(E_{x1},\ldots,E_{xn})$ represent actually simultaneous processed realisations of the definite units of information on all plant components for one parameter type ($x = const.$).

In conclusion, the expression for the set $\mathcal{R}(E_{x1},\ldots,E_{xn})$ of all the values of the random vector $(E_{x1},\ldots,E_{xn})$ will be:

$$\mathcal{R}(E_{x1},\ldots,E_{xn}) = \left\{ \begin{array}{l} (\varepsilon_{x1z_1},\ldots,\varepsilon_{xnz_n}) \in \mathbf{R}^n : \\ z_y \in \{0,1,\ldots,r\}, y \in \{1,\ldots,n\} \end{array} \right\} \quad (13)$$

Accordingly, cardinal set number $\mathcal{R}(E_{x1},\ldots,E_{xn})$ is defined as

$$k[\mathcal{R}(E_{x1},\ldots,E_{xn})] = \sigma = r^n \quad (14)$$

being congruent with the expression (9). The relation for corresponding probabilities of particular events from the set $\mathcal{R}(E_{x1},\ldots,E_{xn})$ holds in general that

$$P(\varepsilon_x)=P(E_{x1} = \varepsilon_{x1z_1},\ldots,E_{xn}=\varepsilon_{xnz_n})\geq 0 \quad (15)$$

3.2. Probability Distributions of Component Units of Information

Information event ε_x (the expression 9) is a complex multidimensional event composed of single component units of information, so probability $P(\varepsilon_x)$ may be obtained as prescribed combination of single probabilities of component units of information.

Consequently, information probabilities should first be defined on a level with the plant component (columns of the yz-plane). A probability survey dealing with the information on a level with components (p_{yz}) is presented in the table 2. The columns of the stated table represent probability distributions for single components. In order to define probabilities p_{xyz}, we should first examine frequencies of process information event at given intervals Δt taken from 5-second intervals by experiment than define empirical information frequency distributions (12) for each component of the given yz-plane.

When the number of performed experiments is large enough, values of relative frequencies $(f\,r)_{yz}$ tend towards adequate values p_{yz},

$$(f_r)_{yz} \underset{n\to\infty}{\longrightarrow} p_{yz} \quad (16)$$

zy	1	2	3	...	n
0	$p10$	$p20$	$p30$	...	$pn0$
1	$p11$	$p21$	$p31$	...	$pn1$
2	$p12$	$p22$	$p32$	...	$pn2$
:	:	:	:	...	:
r	$p1r$	$p2r$	$p3r$	...	pnr

Table 2. Probabilities of Component Information

and probabilities p_{yz} may be thus defined. Another method is to approximate empirical frequency distributions of processed component information to corresponding theoretical classification [12].

The expression for probabilities of a complex n-dimensional event can be derived now on the basis of known component probabilities p_{yz} in the following form

$$P(\varepsilon_x)_u = \prod_{y=1}^{n} p_{yz_y} \geq 0 \qquad 0 \leq z_y \leq r \quad (17)$$

presuming the independence of component information and taking into consideration the expression (15).

The relation for $P(\Omega)$ holds that

$$P(\Omega) = \sum_{u=1}^{\sigma} \left(\prod_{y=1}^{n} p_{yz_y} \right)_u = 1 \qquad 0 \leq z_y \leq r \quad (18)$$

the probabilities sum of all n-fold events of the random vector $(E_{x1},\ldots,E_{xn})$ with the total number of σ must be equal to the unit.

In this way a description is given of both the random vector $(E_{x1},\ldots,E_{xn})$ with corresponding probabilities on the n-component and the r-process information.

4. Function Δ of the Random Vector $(E_{x1},\ldots,E_{xn})$

4.1. Induced One-Dimensional Information On a Level With the Plant

The described n-dimensional information on a level with the plant, for the exact determined parameter type ($x = const.$) represents, consequently, z_1 parameter change on the first component, z_2 parameter on the second component, ..., and z_n parameter on the n-component and indicates that $z_y \in \{0, 1, \dots, r\}$.

Realized in this modular way, the n-fold units of information, in fact, make possible that, in the first place, the plant information model can experimentally and theoretically be defined on a level with constituent components. Subsequently, the information structures, used for various information flows estimates, will be worked out in modular way according to performed and observed experiment. Information restoring time estimate in the remote control centre (RCC), as one of the experiments for researching processed information flows in the PWS, can be described by using the following four stages:

a) at the first stage both modular mathematical system parameter structure and process information (chapter 2) are defined.

b) at the second stage n-dimensional random vector of processed information with associated probability range is derived from the required modularness of the model and stochasticness of the process. At this stage random variables of plant components (chapter 3) must be experimentally defined.

c) to accomplish process information telecommunication between the PSU and remote control centre (RCC), the information synthesis of the same type and from the various locations on a level with the plant is required, and that theoretically signifies mathematical-statistical transformation of the n-dimensional information into the one-dimensional information and the induction of the new, one-dimensional probability range.

d) Finally, at the fourth stage not only the simulation of communication records of processed computer systems for both processing and transformation of addressed messages of one-dimensional information will be worked out but also the programme for calculation of information refreshing rate in the RCC of the electrical power system.

In this chapter we have analyzed only the third stage of the observed experiment stated under the item c. In conclusion, neither the n-dimensional rector $(E_{x1}, \dots, E_{xn})$ nor corresponding n-fold elementary events in space Ω are the ultimate objective of the research.

The random vector $(E_{x1}, \dots, E_{xn})$ enables the forming of the component information cross-section on a level with the plant, realising thus the possibility of universal modelling of process information flow in PWS. However, the ultimate objective of the research will be gained only by definite modification of the n-fold events $(\varepsilon_{x1z_1}, \dots, \varepsilon_{xnz_n})$, that will be carried out by means of the Δ function of the n-dimensional random vector. The Δ function of the n-dimensional random vector $(E_{x1}, \dots, E_{xn})$ has the characteristic to transfer the probability load from n-dimensional into the one-dimensional space

$$\Delta : \mathbf{R}^n \to \mathbf{R} \tag{19}$$

The additional form of the function is done to required quantitative synthesis of the units of information in plant components, i.e.

$$\begin{aligned} \Delta(E_{x1}, \dots, E_{xn}) &= [E_{x1}(\varepsilon_x) + E_{x2}(\varepsilon_x) + \dots \\ &\quad + E_{xn}(\varepsilon_x)] \in \mathbf{R} \\ E_{xy}(\varepsilon_x) &\in 0, 1, 2, \dots, r \\ x = const. \quad & y \in 1, 2, \dots, n \end{aligned} \tag{20}$$

The definite probability distribution on $\mathbf{R}$ is obtained by transmitting probability load from the n-dimensional probability range into the one-dimensional range. The Δ function represents the random variable of the induced one-dimensional probability range. Accordingly, the values of random variables Δ are different sum realisation of the n-fold numbers of the random variable $(E_{x1}, \dots, E_{xn})$ and therefore it is evident that the definite n-fold events of the random vector variable $(E_{x1}, \dots, E_{xn})$ have the same value, i.e. the same numerical load on $\mathbf{R}$. It is hence clear that higher values of the random vector variable $(E_{x1}, \dots, E_{xn})$ are transferred to a value of the random Δ variable and also that the cardinal numbers of the set $\mathcal{R}\,(E_{x1}, \dots, E_{xn})$ and the set $\mathcal{R}(\Delta)$ will not be congruent. The set $\mathcal{R}(\Delta)$ will be marked by Λ and expression for given n and r is

$$\begin{aligned} &\Lambda = \left\{ \begin{array}{c} \lambda_\nu \in \mathbf{R} : (\varepsilon_{x1z_1} + \dots + \varepsilon_{xnz_n}) = \lambda_\nu, \\ z_y = 0, 1, \dots, r, \; y = 1, 2, \dots, n \end{array} \right\} \\ &1 \le \nu \le \mu \\ &0 \le \lambda_\nu \le (\mu - 1) \\ &\mu = n(r-1) + 1 \end{aligned} \tag{21}$$

the number μ represents the **cardinal number** of the set Λ which is defined in the same way as σ by the number of the plant components n, and by the units of information on the component r. The stated transformation of the n-dimensional information into the one-dimensional will be exemplified on the two plant components ($n = 2$) and three units of infornation of a component ($r = 3$). In this relation the set E_x from the expression (7) has the following form

$$E_x = \begin{Bmatrix} \varepsilon_{x10} & \varepsilon_{x20} \\ \varepsilon_{x11} & \varepsilon_{x21} \\ \varepsilon_{x12} & \varepsilon_{x22} \end{Bmatrix} \quad x = const. \tag{22}$$

whereas the set Ω referred to as the space of the elementary n-dimessional information by the expression (10), is presented by the following set (23):

$$\Omega = \begin{Bmatrix} \varepsilon_{x10} \cap \varepsilon_{x20} & \varepsilon_{x12} \cap \varepsilon_{x20} & \varepsilon_{x12} \cap \varepsilon_{x21} \\ \varepsilon_{x11} \cap \varepsilon_{x20} & \varepsilon_{x11} \cap \varepsilon_{x21} & \varepsilon_{x11} \cap \varepsilon_{x22} \\ \varepsilon_{x10} \cap \varepsilon_{x21} & \varepsilon_{x10} \cap \varepsilon_{x22} & \varepsilon_{x12} \cap \varepsilon_{x22} \end{Bmatrix} \tag{23}$$

A_1, A_2, A_3, A_4, A_5

The cardinal number of the set Ω in the presented example is $\sigma = r^n = 9$, which can be seen from the expression (23) whereas event A, (algebra A contains the set of all possible events regarding the observed experiment [3, 11].

Probability load transformation from the n-dimensional space into one-dimensional space is depicted in Fig. 3 whereas two-dimensional units of information are presented by their numerical characteristic, i.e. values of the third dimension z.

Events $(\varepsilon_x)_u$ by the expression (9) are marked by ω_n for easy presentation reference. Quantity $\Lambda = \{\lambda_\nu\}$ for $1 \leq \nu \leq \mu$ represents the set of **elementary** one-dimensional events in the induced probability range $(\Lambda, \mathcal{B}, P)$. Since probabilities in the observed experiment are known only for algebra A of events in n-dimensional space, only the events for wich the expression (24) is valid have to be treated in one-dimensional space (on the set $\mathbf{R}$).

$$\{\varepsilon_x \in \Omega : \Lambda[E_{xy}(\varepsilon_x)] = \lambda_\nu\} = A_\nu \in \mathcal{A} \tag{24}$$

It is normal course now to attach probability to every event λ_ν

$$P(\lambda_\nu) = P(A_\nu) \tag{25}$$

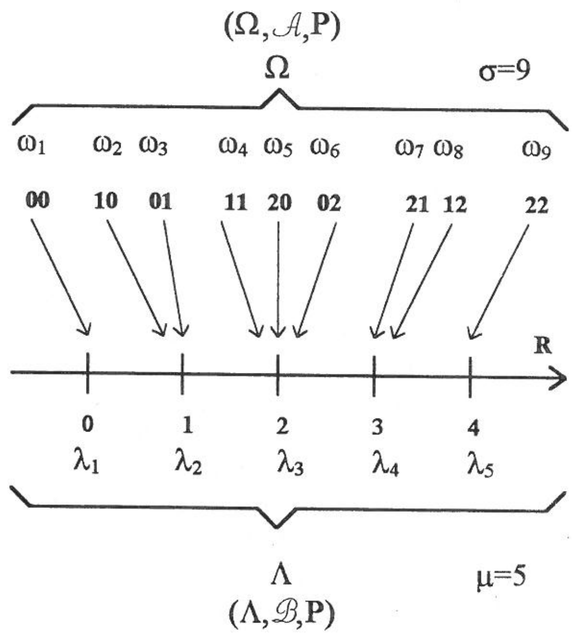


Fig. 3. Transformation from n-dimensional into one-dimensional space of elementary events

that is, event probability A_ν in probability range $(\Omega, \mathcal{A}, P)$ is transferred by the function Δ into the event $\lambda_\nu \in \mathcal{B}$ in probability range $(\Lambda, \mathcal{B}, P)$. It is only the event **"the number of units of information at time interval τ on a level with PSU equals λ_ν"** that is interesting in the observed experiment. Consequently, algebra $\mathcal{B}$ can be defined as:

$$\mathcal{B} = \{0, \lambda_\nu, \lambda'_\nu, \Lambda\}, \quad 1 \leq \nu \leq \mu \tag{26}$$

A new probability range $(\Lambda, \mathcal{B}, P)$, the actual objective of the experiment in the researching of restoring time information in RCC is induced by described stochastic model with the function Δ.

4.2. One-Dimensional Information λ_ν Probability

N-dimensional information probabilities (ex)u are determined by the expressions (17) and (18) in probability range $(\Omega, \mathcal{A}, P)$, and on the basis of these probabilities, information probability lv in probability range $(\Lambda, \mathcal{B}, P)$ will be defined. According to the exposition and by analyzing

Fig. 3 for probabilities $P(\lambda_v)$ of induced bits of information λ_v, it can be expressed:

$$P(\lambda_v) = \sum_{u=\sigma'}^{\sigma''} \left(\prod_{y=1}^{n} p_y z_y \right)_u , \; z_y \in 0, 1, \ldots, r$$

$$\sum_{y=1}^{n} z_y = \lambda_v \tag{27}$$

The condition that the sum of elementary event range probability Λ equals number one must necessarily be fulfilled, i.e.

$$P(\Lambda) = \sum_{v=1}^{\mu} P(\lambda_v) = 1 \tag{28}$$

In the expression (27) the method of determing summation limit σ' and σ'' has remained undefined, i.e. the n-fold number, for which the condition $\sum_{y=1}^{n} z_y \lambda_v$ is fulfilled with precisely selected n and r, has to be defined. The total number of elementary events $(\varepsilon_x)n$ is calculated according to the expression $\sigma = r^n$ and Fig. 3 shows visually that the number σ may be obtained by summing up cardinal numbers for events A_1 to A_μ, i.e.

$$\sigma = k(A_1) + k(A_2) + \ldots + k(A_\mu) \tag{29}$$

If we for easy reference, substitue $k(A_v)$ for ζ_j and if we gradually sum up cardinal numbers which stand for A_v events, we may obtain cumulative numbers of elementary events from the set Ω which define the event A_v. In fact, stated cumulative values, that will be marked by σ_v, indicate also the number of elementary n-dimensional events from the set Ω (Fig. 3). These events realize **"the information number at the plant level $\leq \lambda_v$"**. For σ_v, we may now write:

$$\sigma_1 = \zeta_1$$

$$\sigma_2 = \zeta_1 + \zeta_2$$

$$\sigma_3 = \zeta_1 + \zeta_2 + \zeta_3 \tag{30}$$

$$\vdots$$

$$\sigma_\mu = \zeta_1 + \zeta_2 + \ldots + \zeta_\mu = \sigma = r^n$$

The number in bracket, in every line of expression (30) represents cardinal numbers of cumulative values for particular events λ_v , Fig. 3. In general, values up to σ_v may be calculated as

$$\sigma_v = \sum_{j=1}^{v} \zeta_j \tag{31}$$

By careful observing Fig. 3, by using the expressions (30) and (31) and by definition that $\sigma_0 = 0$, summation limits may be determed from the expression (27).

$$\sigma' = 1 + \sigma_{(v-1)}$$

$$\sigma'' = \sigma_v \tag{32}$$

For the expression (27), which defines probabilities of induced one-dimensional events λ_v in the probability range (Λ, B, P), it may be stated as follows:

$$P(\lambda_v) = \sum_{u=1+\sigma_{(v-1)}}^{\sigma_v} \left(\prod_{y=1}^{n} p_y z_y \right)_u ,$$

$$z_y \in 0, 1, \ldots, r \tag{33}$$

$$\sum_{y=1}^{n} z_y = \lambda_v$$

The stochastic model for modular conversion of the n-dimensional units of information on a level with PSU **components** into the one-dimensional information lv at the level of the whole PSU, is completely elaborated by this expression.

5. Programme Solution and Model Application

Programme systems in dispatching control centres (DCC) for power control system require short process information restoring time. The described mathematical-stohastic model (Chapters 2, 3 and 4) shows that time defining is a complex and demanded procedure because it associates range diffusion, time simultaneousness and type diversification of the processed units of information. Stated requirements along with all interrelated correlation are solved by a processed information flows estimate programme. The programme is realized by means of programme package database "ORACLE" which is based on a multi-dimensional structure where database elements are arranged by observed object attribute, entity and category. Due to precisly so formed programme structure, "Oracle" was an efficient tool for elaboration of restoring time information programme in DCC for power system on the basis of a model provided in this work.

With the RTI programme we also elaborated a simulation of routines for communication information record between PSU and DCC.

Communication record simulation is elaborated by defining the algorithms which in turn determine procedures for forming and exchange of addressed messages in PSU — DCC relation. Simulations represent a qualitative-quantitative message structure in which the bits number of the addressed block, the number of addressed blocks and restorig time rate are based on priority level and by the expression

$$t_r = \frac{\sum_{i=1}^{\lambda_\nu} N_i}{\mathbf{R}} \tag{34}$$

N – number of bits for each addressed block,

i – number of addressed blocks,

R – information transmission rate.

In this programme simulations of communication record of existing computer systems in Croatian Electrical Economy (CEE) were elaborated. This part of the programme is variable depending on the producers who installed processed computer systems in PSU and DCC.

Block diagram of a programme for calculation of restoring information time rate in RCC-es is presented in Fig. 4. According to the block diagram, the stated programme enables: **modular creating** of database for process information, calculation of information event **probability** at 5 s interval of the Δt process and calculation of information **time restoring** (t_r) by type and priority. Restoring time (t_r) as an estimate result may be calculated for m distributions of λ_ν units of information by yz-planes and for three to five priority groups of information. In Fig. 5 output estimate result is presented. The first column

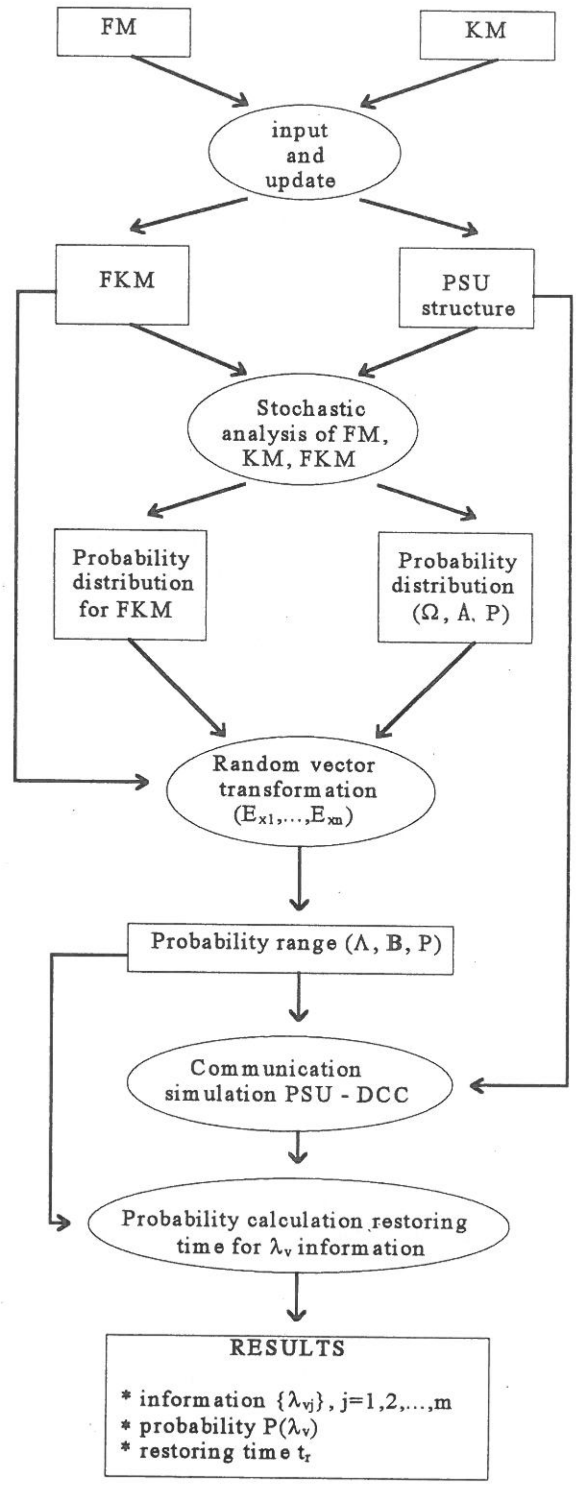


Fig. 4. Block diagram of a programme for restoring information time calculation

Estimate and simulation of PWS information

key <PgDn>→PSU II
key <PgUp>→PSU I
key < F10 >→ simulation

PSU	FM	Priority	λ_v	p=1
012	me1	PR1	0	
012	me2	PR2	1	
012	me3	PR3	1	
012	as	PR1	1	*
012	ss	PR1	0	
012	co	PR1	0	
012	ps	PR3	5	
012	cp	PR2	2	
.	.			
.	.			
.	.			

$t_{r1}(s)=0.51$ $t_{r2}(s)=1.42$ $t_{r3}(s)=6.45$

$P(\lambda_v)=0.0000113$
interval number for λ_v :...71.38

me - measurement co - command
as - alarm signals ps - protection signals
ss - switching signals co - computer signals

Fig. 5. Output programme list

represents a code for PSU, the second column represents a code for information type (function modul), the third column exhibits data on information priority, the fourth column designates the number of addressed blocks of λ_v information and in the last column the code of information correlation is written. At the bottom of the table, the restoring time information results are given by three priorities (t_{r1}, t_{r2}, t_{r3}), set information probability $\{\lambda_{vj}\}$ and corresponding number of Δt interval for the year when presented set information may occur.

The programme realised in this way enables an efficient analysis of process PWS restoring information time for a lot of characteristic operation states and various PSU structures. In Fig. 5 the chosen set event: $\{\lambda_{vj}\}$ represents simultaneous realisation of one block of priority two measurements (me 2), one block of three measurements (me 3), of one block of alarm signals (as), five protected signals of event chronology (ps) and two signals of computer succession hardware (cp).

For described information λ_v, time t_r is calculated for transmission rates 200 bd/s and refer to the units of information of priority one, two and three whereas the event may be expected 71 times a year.

Obtained values 0.51 s, 1.42 s and 6.45 s are within required limits of 2 s, 4 s and 8 s [15] for the units of informaion of stated priority. However, even for a more complex information event with a lot of addressed blocks in FM, which corresponds to the disturbed operation state, time outside permitted limits would be obtained. Therefore, time rates of communication lines in the observed PWS must be increased.

At the end, we should mention that in the process there is an especially great number of various operation conditions (the fourth column, Fig. 5), so the described programme was neither intended nor used to process all possible set events $\{\lambda_{vj}\}$ automatically. Due to numerous event combinations $\{\lambda_{vj}\}$ it would be a long lasting and unnecessary work because the greatest number of events have slight differences which do not affect estimate results. Therefore, a user picks out characteristic operation simulation and in a short while obtains satisfactory analysis results of restoring time information in RCC.

6. Conclusion

The analysis of the structure of processed information flows for complex engineering systems, along with stochastic model interpretation, is an exceptionally complex problem. The described model of stochastic process information enables:

- modular structure of parametar organisation of an engineering system,
- stochastic multi-dimensional interpretation of process information,
- information transformation from the multi-dimensional probability range (Ω, A, P) into the one-dimensional probability range (Λ, B, P),
- communication simulation of addressed blocks between PSU and RCC,
- control and estimate of information restoring time in RCC

By applying the realized programme, estimate for the RCC in Croatian Power System was controlled. The estimate results showed that required time rates of 2 s, 4 s and 8 s for priority information one, two and three [15] will not be fulfilled in the disturbed operation states when needed most.

Further research of exposed model application will be focused on observing each parameter within a FCM (columns *yz*-plane), not only by number but by denomination as well, which brings about information structure change in the expression (6) along the axis *z*, a new experiment defining and an efficient statistical operation analysis.

Abbreviations

1. DCC - Dispatching Control Center
2. FM - Function Modulus
3. FCM - Function Component Modulus
4. CM - Component Modulus
5. PWS - Power System
6. PSU - Power Substation
7. PPL - Power Plant
8. RCC - Remote Control Center
9. RTI - Restoring Time Information

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