ON-LINE FAULT PREDICTION ALGORITHM FOR THE PULSE SYSTEM.

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Abstract: In the paper the problems of the pulse system dynamics identification and its evolution prediction are analyzed. The offered approach to these problem solutions consists in one-to-one mapping of a system stable state by a point (a vector) within the special space designed, but a transitional process – by a vector trend. Then dynamics evolution forecasting is realized as the vector trend treatment relatively to the motion existence domains in this space. To illustrate the approach, the results of numerical modeling of the synchronous back voltage converter dynamics are used.

Keywords: Pulse Systems, On-line Dynamics Identification and Prediction, Fractals.

1. INTRODUCTION

The problems, connected with system safe operation under main operating conditions (motions) one can pass to one of the most actual practical problems of pulse energy conversion system (PECS) identification and prediction. A stability loss of the fundamental operating system motion is an emergency (or a pre-emergency). Under the “motion” hereafter will be implied the stable system state with the certain frequency characteristics, defining its type (m=1 motion type is fundamental one, m – type of motion corresponds to the frequency $f_m=1/mT$, where T is a period of the pulse modulation, m=1, 2, …).

In consequence of the high frequency control influence, high-speed electromagnetic transitional processes, essential non-linear dynamics it is necessary to foresee the on-line mode realization while the algorithms of pulse system dynamics identification and prediction are worked out. Therefore, demand to the time limitation on decision making ($T_{decision\text{-}making}$) is essential and in the paper it is implied, that this does not exceed the time of transitional process in the system ($T_{transitional\ stage}$), then:

$T_{transitional\ stage} \approx T_{decision\text{-}making}$ (identification problem)
$T_{transitional\ stage} > T_{decision\text{-}making}$ (prediction problem).

The preliminary data of one or another kinds use is a widespread situation with the purpose of the data processing time minimization (Alpigini, 2000; Calvo and Malik, 2004; Matsumoto, 2003; Povinelli and Feng, 2003). However, for nonlinear systems two moments are characteristic:

1. Multi-meaning treatment of system dynamics a-priory data (for example, the direct and reverse Cauchy problems (Kolokolov and Monovskaya, 2003), the false neighbors (Potapov and Kurths, 1998), and so on);
2. Probable component presence in the dynamics evolution (for example, the stiff bifurcation possibility (Baushev and Zhusubaliyev, 1992)).

As a consequence, fuzzy logic (for example, see Awadallah and Morcos, 2004) and neuro-nets (for example, see Calvo and Malik, 2004) are used. On the other hand, the possibility of the time series processing effectiveness rise is researched with the purpose of data acquisition time minimization (Kahveci and Singh, 2004; Li, *et al.* 2004). Besides, it is necessary to single out direction, connected with data visualization (Keim and Ward, 2002), and including the perspective technique of multidimensional space mapping into 2-D parallel coordinates (Berthold and Hall, 2003).

The main idea of the approach offered consists in such system dynamics presentation, which allows one-to-one treating its present state. Then the complex of interconnected on-line problems is solved:

1. The transitional process beginning identification (the stability loss of an initial state);
2. The next system state prediction (including the motion type changing);
3. Both the transitional process ending and next system state identification.

At an approach realization, structurization of the preliminary data about system dynamics is carried out in accordance with fractal regularities in 2-D special space projections.

2.OBJECT CONSIDERED.

A synchronous buck voltage converter with the second kind pulse-width modulation and proportional regularity law allows illustrating the on-line prediction problem of pulse system dynamics and proposed approach to this solution. An equivalent circuit of the converter is shown in Fig. 1a. A mathematical model of the converter is presented in the form of the differential equation system with a discontinuous right-hand side, which solutions for the constant structure sections are carried out similarly the solution of the ordinary differential equation system. The general form of the mathematical model is described by:

$$\frac{dX}{dt} = AX + B(K_F(\boldsymbol{x}))$$

where A is a matrix of the invariable coefficients; B is a matrix of the variable coefficients which describe the constant structure sections; X is a system state vector, including the inductance current *(i)* and condenser voltage *(u)*; K_F is a pulse function. The mathematical model presentation in terms of shift mapping was used for the system dynamics investigation. In this case the fixed points of mapping X_{C_i} (i=1,…m) are determined through the following condition:

$$X_{C_1} = G^{(1)}(X_{C_m}) = G^{(m)}(X_{C_1}), \quad (1)$$

where $G^{(m)}$ is m-iteration of mapping (the number of fixed points equals m). The following numerical values of the mathematical model constant parameters were used for the computer simulation: R_1=R_2=0.1Ù, L=10^{-4}H, C=10^{-5}F, E_0 = 24V(a power source voltage), β=1, U_y=12V, U_o=3V, T=10^{-5}s. The vector of the variable parameters (P) includes an error signal amplification coefficient of the regulator (α=1…15) and load resistance (R_3=1…20 Ù).

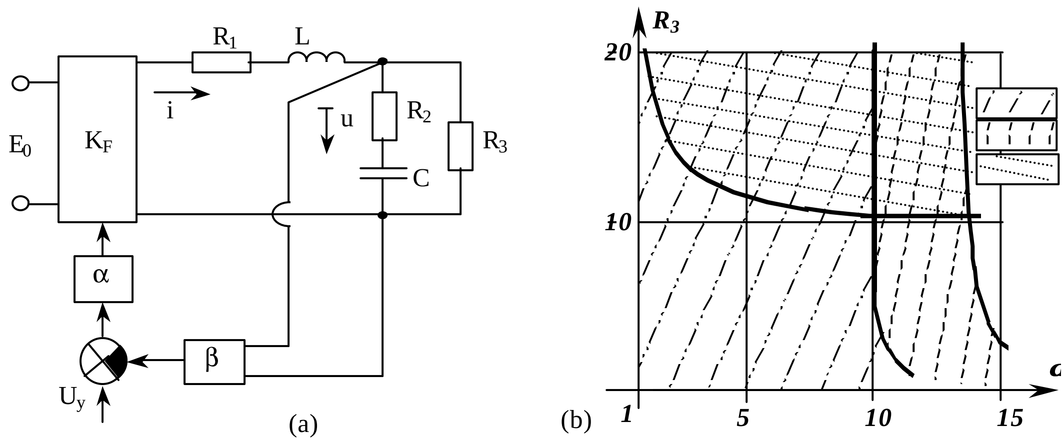
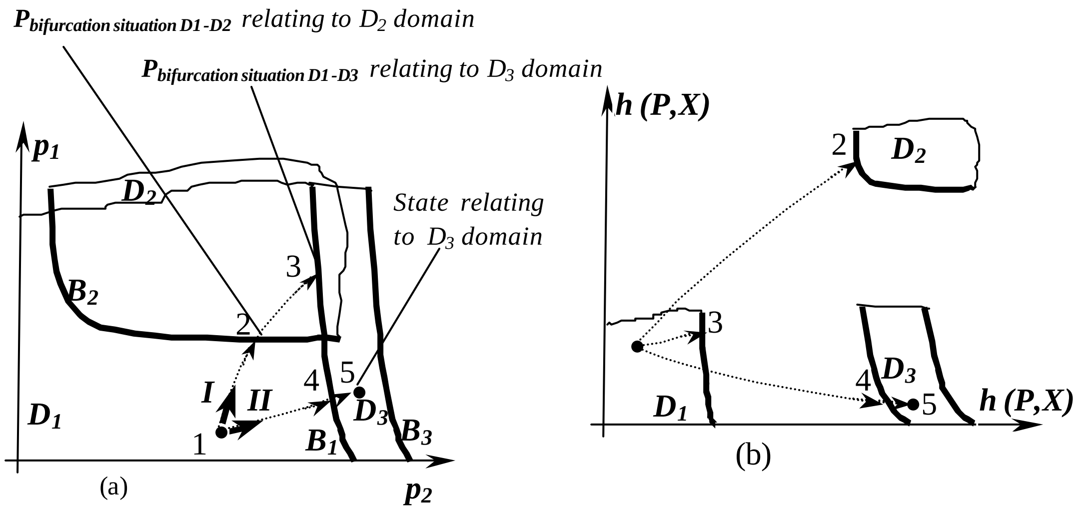


Fig. 1 (a) The equivalent circuit of the synchronous buck voltage converter with the proportional regularity law. (b) The parametric diagram for 1,2,10- motion types.

We admit that the preliminary information about 1,2,10-motion types in the form of the parametric diagram of the motion type existence domains (2-D bifurcation diagram) is received in one or another way (experimental researches, model-based simulations), — Fig. 1b.

3. APPROACH OFFERED

The main idea of offered approach realization consists in mapping of possible system states by a point in some special space designed – "one-point-image" form. In a similar form, by means of the parametric diagram, motion existence domains are mapped in the parametric space (Fig 1b). For PECS it is characteristic that several motion types (several phase trajectories) can correspond to one parameter vector, therefore the domains of their existence are intersected, for example (Kolokolov and Koschinsky, 2001). In the case of parametric trend directing in such domain (the bold arrow I, in Fig. 2a) prediction treatment multi-meaning of the dynamics evolution (by parametric diagram data) is evident, since even the nearest bifurcation boundary is considered



D_1, D_2, D_3 — domains of m_1,m_2,m_3 type of motions in the parametric space; B_1, B_2, B_3 - bifurcation boundaries of D_1, D_2, D_3-domains.

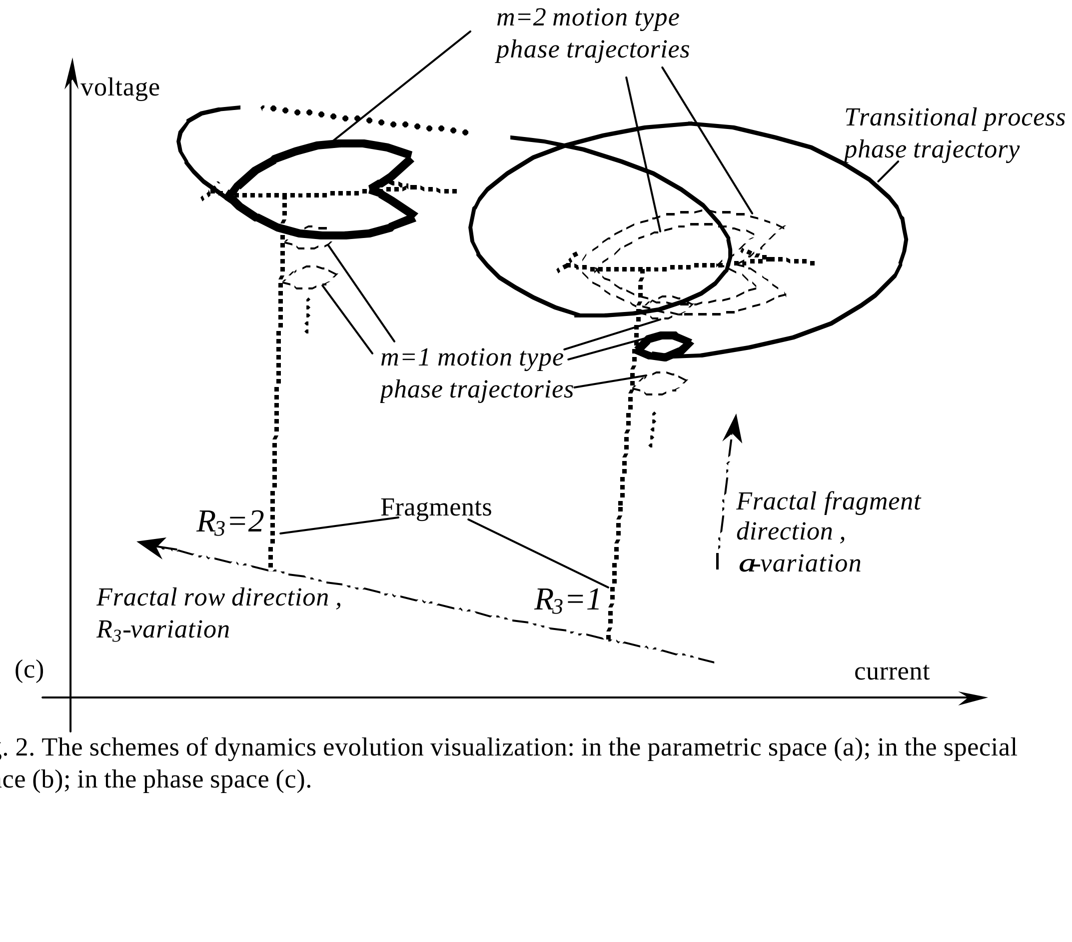


Fig. 2. The schemes of dynamics evolution visualization: in the parametric space (a); in the special space (b); in the phase space (c).

relatively to the specific motion type (the points 2 and 3 correspond the motion types D_2 and D_3). Moreover, there is a problem to predict the system dynamics in on-line mode even in the case of parametric trend directing in the domain with one motion type (the bold arrow II, Fig. 2 a),.

The reason consists in that, the parametric diagram doesn’t contain information about a transitional process. The mathematical image of the last is usually mapped in the form of an open curve in the phase space or in the form of time series. In the phase space the motion existence domains always intersect in one or another degree, at that the complex fractal structures are formed (for example, see Bezruchko, *et al.* 2003). Let us consider this problem at greater length by means of the scheme Fig. 2 c, in which the PECS dynamics fractal regularities are used (Kolokolov and Monovskaya, 2005) to combine the parametric and phase spaces. With this purpose the fixed points of mapping are built in phase space through consecutive variation at the beginning of one and subsequently the other parameters.

Accordingly, the geometrical structures are formed: the “fragment” (α-variation) and “series” (R_3-variation). The scheme shows the process essence with an example of one evolution step: system transition from the state R_3=1, α=10.5, m=1 (point 1 in Fig. 2a and bold closed curve in Fig. 2c, at the right fragment) into the state R_3=2, α=11.5, m=2 (point 5 in Fig. 2a and bold closed curve in Fig. 2c, at the left fragment). Before the moment, when the transitional process phase trajectory will be changed by the next motion type phase trajectory, it will intersect the great number of potentially possible solutions, corresponding to different motion types (Fig. 2c, hatched closed curves). And so, only after the transitional process completion it is possible to identify the new system state through some time (depending on the sampling value). The principle of the offered solution is presented in Fig. 2b. With this purpose it is suggested to form a special space.

In such space the motion existence domains are not intersected and the present system state is mapped in “one-point-image” form (OPI-state) in the case of a

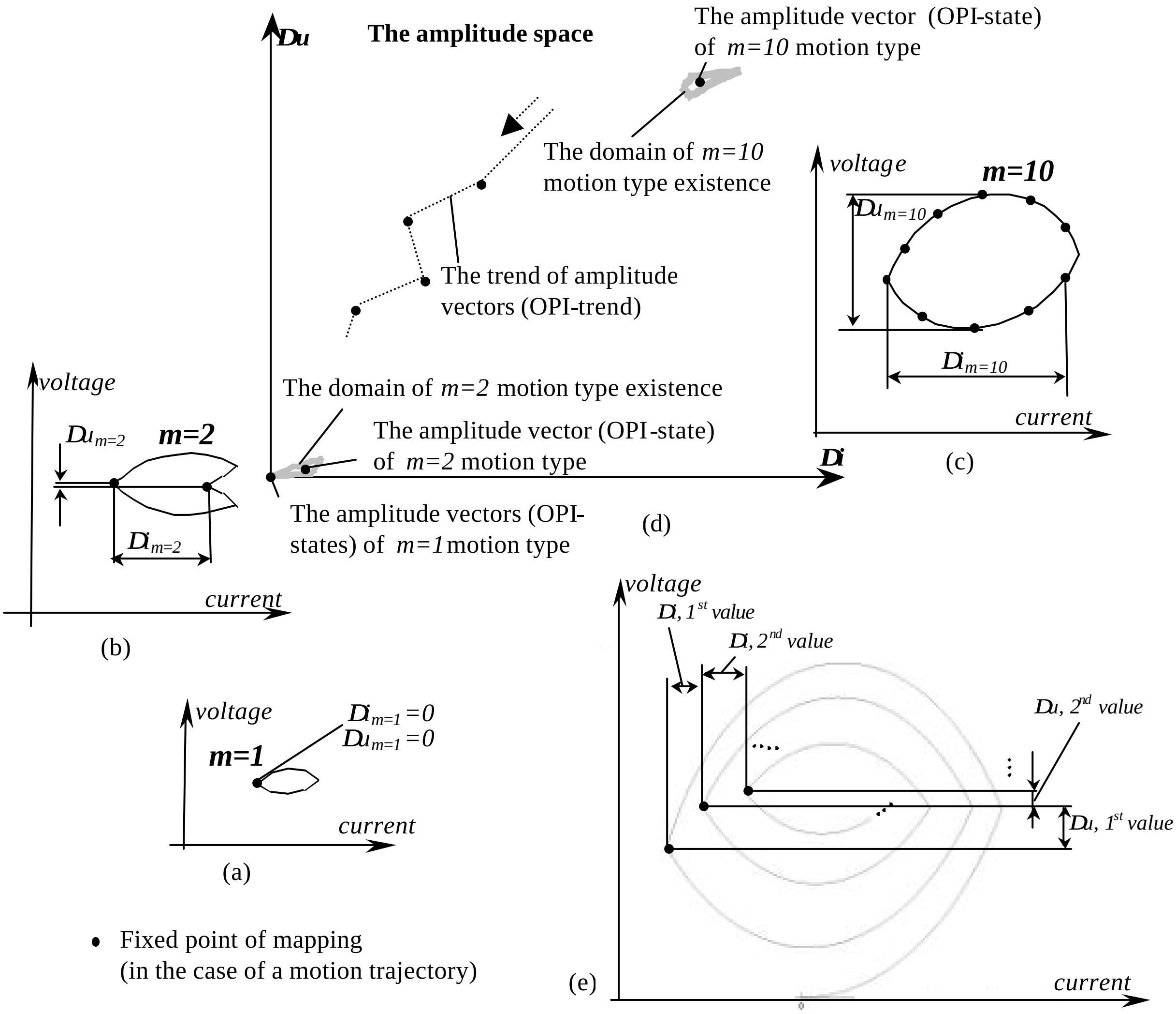


Fig. 3. The formation schemes of amplitude vectors (OPI-states): of $m=1,2,10$ motion types (a,b,c); of a transitional process (e). The scheme of considered objects in the amplitude space (d).

motion stage and as “one-point-image” trend (OPI-trend) in the case of a transitional process. Then, the dynamics prediction problem can be formalized:

1. OPI-trend origin corresponds to transitional process beginning (origins of the dotted arrows in Fig. 2b);
2. Intersection of this motion existence boundary by OPI-trend corresponds to operational motion stability loss (the point 3 in Fig. 2b) ;
3. OPI-trend direction shows the motion type, setting up in the system and allows predicting the dynamics at the transitional process stage (the dotted arrows and points 2,4 in Fig. 2b);
4.Stop of OPI-trend in the motion existence domain corresponds to the transitional process completion and to its result (point 5 within the motion existence domain D_3, Fig. 2b).

The offered principle of present system state presenting uses the notion of fixed points of mapping, the expression (1), and properties of phase trajectories within a particular motion type. So far the shapes of phase trajectories are similar in this case (Kolokolov and Monovskaya, 2005). The amplitudes of the trajectories are either not changed practically (for *m=1* motion type) or changed according to a common trend when with *m* increasing radii of phase trajectories are also increasing.

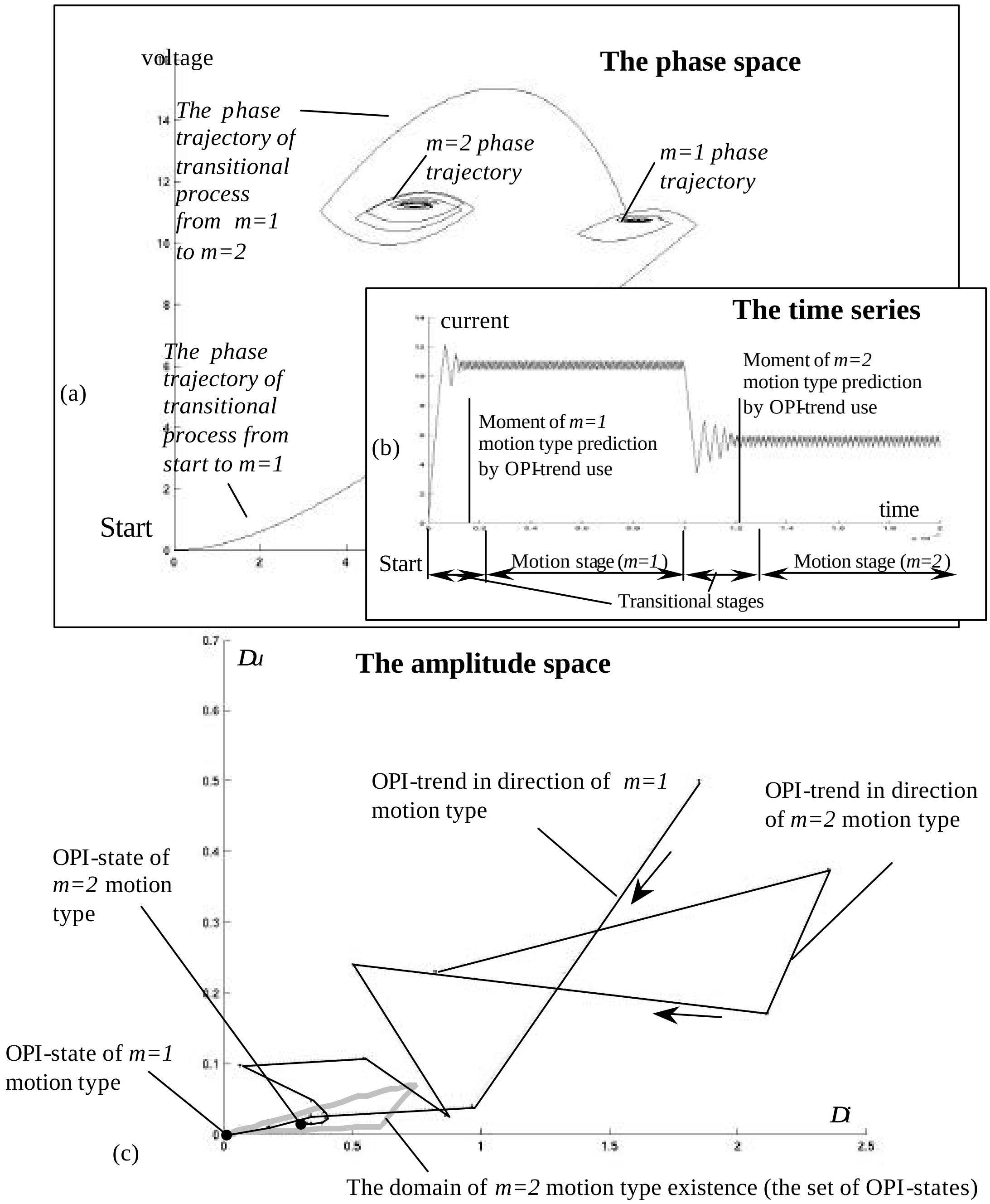


Fig. 4. The simulation results of dynamics evolution ($start \rightarrow R_3=1$, $\alpha=10.5$, $m=1 \rightarrow R_3=2$, $\alpha=11.5$, $m=2$) in the form of : the phase trajectory in the phase space (a); the time series (b); the amplitude trajectories (OPI-trends and OPI-states) in the amplitude space (c).

Hence, it is possible to form the "amplitude space" in which m-type of system motion is described only by the amplitudes of the fixed points (then the Δu-axis corresponds to the voltage amplitude, the Δi –axis corresponds to the current amplitude).). The schemes of object forming in the amplitude space are shown in Fig. 3 a,b,c,d,e. For instance, $m=1$ motion type (Fig. 3a) has only one fixed point X_{C1}, therefore:

$$i_{max} = i_{min} = i_{C1}\ ;\ \Delta i = i_{max} - i_{min} = 0.$$

By analogy, $\Delta u=0$ also. All the rest of motion types have coordinates different from zero. For instance, $m=10$ motion type (Fig. 3c) has 10 fixed points $\{X_{C1}, X_{C2}, X_{C3}, \ldots X_{C10}\}$, therefore:

$$\begin{aligned} i_{max} &= max\{ i_{C1}, i_{C2}, i_{C3}, \ldots i_{C10}\}; \\ i_{min} &= min\{ i_{C1}, i_{C2}, i_{C3}, \ldots i_{C10}\}; \\ \Delta i &= i_{max} - i_{min} \neq 0. \end{aligned}$$

By analogy, the second coordinate $\Delta u \neq 0$ is calculated. As a result, through consecutive parameter variation it is possible to form the motion existence domains in the amplitude space (Fig. 3d).

While mapping the transitional process phase trajectory to the amplitude space, each spiral turn has own coordinates (the scheme of these ones formation is presented in Fig. 3e), and so, vector set is formed – OPI-trend. In Fig. 4 the result of evolutional step (considered earlier in Fig. 2c) modeling are shown. The system dynamics is mapped in the forms of: the phase trajectory (Fig. 4a); the time series (Fig. 4b); OPI-trends and OPI-states (Fig. 4c). The time moments within transitional process stages, beginning from which the next system states are predicted through offered approach using, are marked in the time series.

4. CONCLUSION

In the paper the approach is offered, in which an attention is attracted to the problem of one-to-one prediction of the pulse energy conversion system dynamics evolution in on-line mode. The research direction is possible system state (both transitional processes, and motion types) presentation in "one-point-image" form (OPI-trend in the case of transitional process and OPI-state in the case of motion type stage). This allows:

1. To map one-to-one the system dynamics evolution by a vector trend in the special space;
2. To formalize the general scheme of given type problems.

The numerical modeling results of system dynamics prediction in on-line mode are presented, which doesn't depend on variable duration of evolution stages and the probable character of evolution development. The synchronous buck voltage converter with the second kind of pulse-width modulation and proportional regularity law was used as a modeling object.

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