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Mathematical Modeling of Regional Isolated Electrotechnical Complex

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Abstract

Mathematical modeling of isolated power systems in terms of energy efficiency in the region, leads to the concept of "regional isolated electrotechnical complex". An essential feature of this complex are "business affairs" typical for certain geographically and/or administratively standalone complex of isolated systems and significantly affecting the performance of energy efficiency and the design concept of each of them.

Revealed original structure of the mathematical models of major energy conversion elements of this complex has a fundamentally different by recording form from the standard form of Cauchy. It requires specialized methods and algorithms of information retrieval. In respect to developed model, problem-oriented three-stage numerical method has been designed and implemented, the range of its applicability in which it has the advantage in terms of "time accounts is the accuracy of the account".

Keywords: wind power engineering, numerical methods, energy efficiency.

INTRODUCTION

The nature of development of the world economy and its growing demand for consumption of electric and thermal energy, the movement of the extractive industries in remote regions, caused the quantitative growth of independent energy systems and increase of their total installed capacity. In Russia this phenomenon required the creation of a Technological platform "Small distributed energy" (TP SDE). Integral assessment of the program documents TP SDE shows that the main trend of the further development of small distributed energy and its components "...should be typed equipment and design of the variant modules' projects of small distributed energy based on combined separate elements (different types of generation, local network, monitoring tools and automation, means of energy accumulation, etc.). This approach will provide ... minimization of costs for introducing and distributing new equipment, etc." [1].

SETTING OBJECTIVES

A substantial components of small distributed energy are decentralized area of the power supply is built, usually on a diesel power plant (DPP) and with local renewable energy sources (RES). Hereafter, wind energy is RES.

We introduce into consideration the notion of "Separate regional electrotechnical complex (SPEC)" - geographically and/or administratively separate set of isolated power supply systems (IPSS) [1].

SPEC significant feature is the presence of "business affairs"(in the sense of definition of V.K. Lozenko), typical for geographically and/or administratively separate IPSS, significantly affect the energy efficiency and the design concept of each of the isolated power supply systems to a given set.

Clearly there is a need to assess the capabilities and effectiveness of the combined use of the diesel power plants and wind power plants (WPP) in a single isolated power system, and optimization of the entire set of IPSS included in SPEC with regard to "business affairs".

In this context, the first priority goals are:

1. Identification of the original structure of the mathematical model of the aggregate energy conversion elements of SPEC considering typical "business affairs ".
2. Construction of the problem-oriented numerical method applicable to the original mathematical model of SPEC.
3. Realization of the numerical experiment over comparing software implementations of a numerical methods of extracting information from the mathematical model of SPEC.

THEORY

The above-formulated objectives leads to the need of constructing hierarchically ordered set of mathematical models of all the components of SPEC involved in the process of energy conversion, ranked by levels of assumptions with a single mathematical representation of the energy conversion processes in a physically heterogeneous elements constituting

SPEC. The energy approach based on Lagrange formalism and the apparatus of structural energy schemes most fully meets these requirements [1].

Sequential application of the Lagrange formalism leads to the construction of original mathematical models of basic energy conversion elements of SPEC in the following form (different from the standard Cauchy form).

$$\frac{dU_*^T}{dt} = f(Q_\Sigma, Q_b, t), \quad (1)$$

$$U_*^T = U_*^T(Q_\Sigma, Q_b), \quad (2)$$

Where Q_Σ and Q_b the vectors of generalized coordinates and generalized speeds.

The original form of the equations (1) – (2) requires the substitution of the algebraic equations (2) into the equations (1) and the corresponding construction of the Jacobian matrix $A\times(Q_\Sigma, Q_b) = dU_*^T / dQ_\Sigma$.

In turn, there is a need of time consuming inversion operation in this matrix to transition to the models represented by the standard Cauchy form. It should be noted that this procedure takes most of the time account of the numerical method applied to the model reduced to the standard Cauchy form [2]. As a consequence there is a need to design a specialized numerical method applied to the original equations (1) – (2).

In this direction a three-step numerical method of the following form has been developed:

$$\begin{aligned} Q_{SUM\,(n+3)}(t+3h) = Q_{SUM(n)}(t) + h \times [A\psi - ha_{sbt}A_f]^{-1}_{(n+1)} \times (\beta_{0\,sbt} \times f^T_{*,(n)}(Q_{SUM,(n)}(t), t) \\ + \beta_{1\,sbt} \times f^T_{*,(n+1)}(Q_{SUM,(n+1)}(t+h)) + \beta_{2\,sbt} \times f^T_{*,(n+2)}(Q_{SUM,(n+2)}(t+2h), (t+2h) \\ + \beta_{3\,sbt} \times f^T_{*,(n+3)}(Q_{SUM,(n+3)}(t+3h)(t+3h))), \end{aligned} \quad (3)$$

$$\begin{aligned} Q_{SUM\,(n+3)}(t+3h) Q_{SUM(n)}(t)\, h \times [A\psi - ha_{sbt}A_f]^{-1}_{(n+1)} \times (\beta_{0\,sbt} \times f^T_{*,(n)}(Q_{SUM,(n)}(t), t) \\ + \beta_{1\,sbt} \times f^T_{*,(n+1)}(Q_{SUM,(n+1)}(t+h)) + \beta_{2sbt} \times f^T_{*,(n+2)}(Q_{SUM,(n+2)}(t+2h), (t+2h) \\ + \beta_{3\,sbt} \times f^T_{*,(n+3)}(Q_{SUM,(n+3)}(t+3h) \times (t+3h))) \end{aligned} \quad (4)$$

Where:

$Q_{SUM(n)}$ – sum vector of Q_Σ and Q_b at the moment t;

h – the step of integration;

a_{sbt} and β_{sbt} - free parameters of the method;

$A_\psi = \frac{\partial U(Q_{SUM})}{\partial Q_{SUM}}$; $A_f = \frac{\partial f^T_*(Q_{SUM},t)}{\partial Q_{SUM}}$ – matrices.

The proposed method is the problem-oriented development

of the group of linear multistep methods [3].

RESULTS OF THE EXPERIMENTS

Comparative assessment of the computational properties of the method (3) was being performed on a test set of tasks having an exact solution and containing, both mathematical model in the standard Cauchy form (test tasks № 6 – 16, Tab. 1) and built in the shape (1) – (2) model with variable stiffness coefficients SC and stiff variability coefficients SVC (test task № 1 – 5, Tab. 1). The structure of the equations of this model corresponds to the mathematical model of asynchronous machine in generator mode, on the assumption of unsaturated magnetic circuit. The comparison has been carried out among a well known programs RCGS (implementation methods of Runge-Kutta of the fourth order), DIFSUB (implementation of strictly sustainable methods of Gere), VKM-2 (implementation of two-steps canonical method [1]).

Canonical method (3) implemented in the program BKM-3 with preservation of the principles of the step of integration and estimates of local and global errors applied in the program VKM-2.

Counting time has been estimated when the given relative errors are equal (criterion "accounting time – the accuracy of the account"). Counting time with program VKM-2 has been assumed as a unit.

Analysis of the results of computational experiment showed, that with rising of the stiffness coefficient of the mathematical model: RCGS program loses its effectiveness (test task № 5, Tab. 1 – accounting time 164 times more than the basic program VKM-2); program DIFSUB maintains its effectiveness on the tasks in the standard Cauchy form (test tasks № 6 – 12, Tab. 1 – almost twice as fast as compared to the basic program VKM-2) and yields by an order of accounting time on the tasks in the form of equations (1) – (2) (test tasks № 1 – 5, Tab. 1); VKM-3 program, compared with the basic program VKM-2, counts faster in 1,5 – 3,6 times (test tasks № 1 – 5, Tab. 1), on the tasks in the standard Cauchy form (test tasks № 6 – 12, Tab. 1) – is comparable with the program DIFSUB and surpasses VKM-2 in 1,3 – 1,9 times.

Thus, the scope of applicability of the proposed method (3), implemented in the program VKM-3 can be determined as the tasks in the form of equations (1) – (2), where this software implementation has the advantage on the criterion of "accounting time - the accuracy of the account" of up to 30 times in comparison with the classical program DIFSUB and up to 3,6 times in comparison with previously proposed program VKM-2.

Results of the comparative test for a case in given relative error e < 0.01, are shown in Tab. 1.

Table I. the relative time of the test task with a permissible error E< 0,01

The test task No	Scope of problem				Test program			
					RCGS	DIFSUB	VKM-2	VKM-3
1	Asynchronous generator, magnetic structure is unsaturated. M_t= const	Mathematical model in the form of (1)-(2)	SC=3	SVC= 0,1	12	11	1	0,41
2			SC = 30	SVC = 0,1	18	12	1	0,43
3			SC = 300	SVC = 0,1	30	12	1	0,33
4			SC = 1600	SVC = 0,1	68	10	1	0,36
5			SC = 3000	SVC = 0,1	164	9	1	0,28
6	«Enright's tasks» (the standard Cauchy form)		Nonlinear models, λ - actual		-	0,69	1	0,63
7					-	0,54	1	0,57
8					-	0,53	1	0,52
9					-	0,52	1	0,55
10					-	0,53	1	0,64
11					-	0,70	1	0,75
12			Nonlinear models, λ - integrated		-	0,64	1	0,63
13					-	1	1	0,82
14					-	0,61	1	0,85
15					-	0,72	1	0,71
16					-	0,72	1	0,79

DISCUSSION OF RESULTS

Revealed significant feature of SPEC is the presence of "business affairs" or "weak link," defines the features and differences of each separate regional electrotechnical complex as a whole. Individual characteristics of SPEC are formed by significant distance barriers from the center of power loads of IPSS included in SPEC. Climatic differences of the individual zones SPEC often determine the presence of conflicting requirements to the choice of the type of RES within SPEC.

Taking into account these circumstances in a single mathematical model of SPEC and the subsequent assessment of the energy efficiency of all SPEC in a whole, leads to the appearance of the properties of stiffness and of stiff variability of (in the sense of definitions [2,3]) mathematical models (1) – (2).

Thus, the range of applicability of the proposed method (3) implemented in the program VKM-3, is characterized by the

computational properties of the 4 – 5 tasks shown in Tab. 1. Computational experiment shows that the proposed approaches lead to an advantage in this area in terms of "accounting time - accuracy of the account" up to 30 times in comparison to the classical software implementations.

It should be noted that outside the region of applicability of (mathematical model in the Cauchy form) the proposed methods and their software implementation are losing their advantages (tasks 6 – 16, Tab. 1).

SUMMARY AND CONCLUSION

1. The notion of "Separate regional electrotechnical complex (SPEC)" - geographically and/or administratively separate set of isolated power supply systems (IPSS) has been introduced into consideration.
2. Such SPEC significant feature as the presence of "business affairs" (in the sense of definition V.K. Lozenko) typical for geographically and/or administratively separate IPSS, significantly affect the energy efficiency and the design concept of each of the isolated power supply systems to a given set IPSS has been revealed.
3. The original structure of the mathematical models of major energy conversion elements of SPEC based on typical "business affairs" has been revealed. The fundamental difference between the structure of this model and the standard Cauchy form has been showed.
4. A specialized three-step numerical method, applicable to the original mathematical model of SPEC has been designed and implemented in the program VKM-3.
5. The numerical experiment showed the advantage of the program VKM-3 on the criterion "accounting time – the accuracy of the account" regarding application has been carried out.

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