

DEVELOPMENT OF THEORY AND METHODS OF COMPLEX OPTIMISATION OF CONTROL AND OPERATIONAL RELIABILITY OF INTERCONNECTED POWER SYSTEMS

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The paper presents a short description of research results of the Baltic Association of System Research in Energy (BASRE) considering international collaboration and their application in development of the theory and methods of complex optimisation of the control of operation and reliability of Interconnected Power Systems (IPS) with respective net of coordinating dispatch centers. The centers operate at the interstate and regional level in free-market conditions. The game theory applied considers the possibilities of providing optimal reliability of operation in the case of large disturbances. The theory and methods are applied to the control of IPS of Baltic States in the interstate control center DC Baltija which is unique in the whole world.

Introduction

Short overview of the development, present state, prospects and strivings of Baltic States is given considering broader international cooperation in:

- the development of the theory and methods of complex optimisation of the control and operational reliability of IPS, with respective net of coordinating dispatch centers, at the international and regional level in free market conditions;
- the experience and problems of corresponding interstate cooperation;
- strivings to realize the results of this cooperation, preferably with Russia, Germany and other states in the framework of Programs of the European Union.

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The paper deals with development of the theory and methods of complex optimisation of the control and operational reliability of IPS **first** in conditions of Soviet Union, **second** in conditions of independence of Baltic States, and thereafter, **third**, at the international level.

As an assumption of successful implementation of such studies, the principle of sufficient unanimity of participants – governments and power systems (PS) of regions (or states), which have had a common inter-region dispatch control center like DC *Baltija* for IPS *Baltija* – should be applied.

Regrettably, for the time present this unanimity is lost at the level of PS of Baltic States, and therefore a question arose – to be or not to be DC *Baltija* in the free-market conditions. **Forth**, in connection with the circumstances the special role and importance of DC *Baltija* is discussed, and, **fifth**, the necessity and possibility to form a respective international research project on development of those studies, and, in particular, on motivation of forming interstate and interregional coordinating dispatch centers, applying methods of complex optimisation, are outlined. In particular, the occurrence of total blackouts could be prevented by coordination of the market mechanism, providing complex acceptability of the complicated hierarchical structure of IPS. Also, optimal correction of operation of IPS applying methods of complex optimisation in the case of large disturbances, and optimisation of the reliability of complicated hierarchical systems of IPS would prevent those blackouts.

These topics were presented in more detail by L. Krumm at All-Russian scientific seminars “*Methodical problems of the reliability research of large energy systems*”, which took place in Pskov on July 2–6, 2006 on restructured power systems, and in Harkiv, on July 1–5, 2006, on subjects of the energy markets, as well as at the 5th International Conference on Operational Research: “*Simulation, and Optimisation Business and Industry, SOBI 2006*”, held in Tallinn on May 17–20, 2006.

The soviet period

The roots of this work are connected with Russia and, particularly, with L. Krumm who worked about 25 years at the *Siberian Energy Institute of the Siberian Branch of the Soviet Academy of Sciences (SB AS of USSR)*, which under the new name the *Institute of the Energy Systems of the Academician L. A. Melentiev (IESM)* is still playing the main role in Russia in this field [1]. L. Krumm led the department of large energy systems of the Academy of Sciences of USSR and cooperation with socialist countries. In three Baltic States – Estonia, Latvia, Lithuania – the corresponding research was carried out in academical energy research institutes and corresponding polytechnic institutes.

The development of the methods of complex optimisation of the control of operation and of development has been a new line, where, as restrictions

in the form of inequalities, state equations of the system and the requirements to the quality and reliability in the form of inequalities were considered to be direct and complete. Thereby at the beginning only one optimisation criterion was considered – the minima of total costs. Problems of complex optimisation in general form were considered to be hierarchical and multistage in time, space and contingency approaches.

For solution of these problems and sub-problems the generalised method of reduced gradient (GMRG) and the corresponding rational mathematical tools were developed. These developments were based on the corresponding theory of complex optimisation and control using methods of etalon modelling. An important role in the GMRG is played by different generalised Newton-type modifications.

Mathematical models and program packets were disseminated over the whole Soviet Union to various dispatch centers (DC) of interconnected power systems by the Institute “*Elektrosetprojekt*“, in particular in North-West DC in Riga, West Siberian DC in Kemerovo, DC in Moscow, and Ural DC in Sverdlovsk, also in some large power systems – *Irkutskenergo*, *Mosenergo* and others. This information is given in more detail in [2].

Independent Baltic States

In the conditions of independence of Baltic States it became strategically important to develop the methods and theories of complex optimal control, considering free-market conditions in these and neighbouring countries. Here the optimisation problems appeared, with interests of different partners to consider.

Therefore, for further continuation of these works and for preservation of our potential as much as possible in Baltic, the Baltic Association of Power System Research (BAPSR) was founded in 1991. It was reorganised into the Baltic Association of System Research in Energy (BASRE) in 1999.

The main actual problem here was optimal control with consideration of free-market interrelations between different power systems, bearing in mind a certain unanimity between the partners, Baltic States in particular. An important role was played by cooperation of Baltic States in the energy field leading to the preservation of the dispatch center DC *Baltija* in Riga at the international level. This is even more actual now because the DC of Baltic States is a special center even on the world scale, with extremely uneven distribution of corresponding reserves of different kinds and capacity of energy, for automatic control and emergency reserve in particular. Therefore the control at the international level is important. At that, multiobjective optimisation problems of dividing the net income could be reduced to single-objective problems by certain conventions between partners (minimizing total costs, for instance), or, on the other side, they could concern direct improvement of equilibrium states of partners (which are established by

some market mechanism in the interests of the partners), when being outside the so-called Pareto domain of the control.

Pareto domain is the domain where it is impossible to improve the state of all partners at the same time. Every time this improvement (for someone) will be made at the cost of someone else, but, outside this domain it is always possible to improve the state of all, and all three Baltic States in particular, using min-max or max-min criteria of optimal correction of operational states. Here it is assumed that the initial state is established by some approximate market mechanism in the interests of all three partners, using certain criteria. Thereby, GMRG was correspondingly generalised for solution of such Pareto-optimal correction problems.

However, in the case of a coalition of partners with different power interconnections, for instance, with essentially different interests and contradictions, the approaches should be solved in the scope of the game theory, although in general they are non-antagonistic games. Antagonistic games should be considered in extreme cases only. In the best case, the optimal correction is made just considering narrower different interests.

Main aspects of the survey are presented in [2], and especially in [3–5].

The main six principles of the solution are:

- **first** – the application of five basic provisions of GMRG;
- **second** – by discrete optimisation, optimisation of the number of units operating in parallel and network structures, for instance, application of GMRG with continuous idealisation of discrete changing variables;
- **third** – generalisation and development of the mathematical tool of GMRG according to the first main principle for various conditions of multiobjective game approaches;
- **fourth** – multiobjective optimisation and Pareto-optimal correction of Equations of Steady State (ESS) – application of continuous idealisation of discrete changing variables and of the method of adaptive equivalent states. However, strict adjustment of approximate solutions in the frames of the above-mentioned continuous idealisation in the process of deformation of the equations is made with approximation of objective functions by the integral form of the least square method and its developments – with orthogonal wave functions. Thereby, for acceleration of the computing process, in the frames of GMRG a certain combination with new developments, e.g. the method of control planes, is used;
- **fifth** – rational Pareto-optimal correction of the control of ESS of partners in the frames of their separate coalitions, considering the conflicts between coalitions (parallel operation of DC *Baltija* and IPS of neighbouring states, for instance) on the basis of the game theory in general;
- **sixth** – application of the optimality principle while reducing multi-level hierarchical dynamic programming problems to solution of

separate complex optimisation sub-problems considering all the above-mentioned principles.

Based on these principles, the main methodological approach to the analysis and optimisation of the reliability of the operation and development of IPS on the international level with complex approach is given in [2] (look also [3–5]). These main principles and solution methods are considered in more detail in the paper that follows this one (P. 389–399).

After submission of the paper [2] for publication, further research of the Estonian group working in this direction in the frames of BASRE in 2004 and 2005 gave the following results:

- 1) within the scope of the third main principle, in cooperation with mathematician A. Tauts and Prof. O. Vaarman, the mathematical basic principles of Pareto-optimal correction of the equilibrium states between partners were studied and published [6, 7];
- 2) within the scope of the second and fourth main principles, the methods of discrete optimisation and Pareto-optimisation with any accuracy, ([8], in particular) were developed together with A. Tauts;
- 3) in the frames of the third main principle, a methodical approach to the multi-objective optimisation of the ES for search of compromise solutions between partners inside the Pareto domain was proposed, together with O. Vaarman, for the case in which there does not exist a Pareto-optimal solution [9, 10]. The multi-objective optimal search depends on specific compromise conditions, which are to be adjusted to the real operational situations;
- 4) in the general statement of the target setting for complex optimisation of the IPS operation reliability at the interstate level by available reserves [2] the equivalent state of separate sub-problems of optimisation is of central importance – the multi-stage hierarchical problem of complex optimisation is to be solved by objective functions and by approximation of the allowable domain (taking into account large disturbances and the fuzziness of the rest of the initial information), in the space of independent limiting equations (parameters, which bound the corresponding sub-problems into a general hierarchical structure). Together with O. Vaarman, the research is set up on rational combination of the methods of local approximation, with application of mathematical tools of GMRG and methods of new information technologies [11], artificial neuron nets in particular, enabling to improve essentially the levelling process owing to generalisation of corresponding information about development of the control of IPS at the interstate level;
- 5) the methods of complex optimisation of the reliability of IPS operation at the interstate level considering disposed reserves in the general form makes it possible to develop mathematical models, which are the main development in corresponding rational controls in the complex approach. It is essential to proceed from the existing

development level of approximate methods. By some optimisation aspects, e.g. operative reserves, O. Terno together with M. Valdma [12] have generalised approximate methods;

- 6) etalon modelling that considers mainly specifics of multi-objective and game approaches has been applied to generalize the theory and methods of complex optimisation of IPS control and reliability at the interstate level.

The experience and problems of international cooperation on the example of independent Baltic States

The efficiency of international cooperation in the research and development of these methods depends on the level of unanimity and dimensions of mutually complimentary research, first in Baltic States themselves having competence in system analysis in the historical sense, and on consideration of their development and financing requirements from different sources.

The basis of this solidarity was laid down in the soviet time already in ISRE of SB of Russian AS in the frames of the all-union cooperation and coordination of the research.

In the conditions of independence, this solidarity and cooperation were lost at the beginning of new international relations, that placed the research in an extremely difficult situation. For overcoming these difficulties, the following bodies were founded:

- BAPSR (later BASRE) for provision of solidarity of Baltic States in the field of research activities [2];
- Council of the Ministries of Economic Affairs and Power Systems (CMEAPS) of Baltic States that enabled to preserve the North-West DC IPS of the USSR as the international control center DC *Baltija* in Riga.

At the same time the financing of the system research in the energy field, especially in academic institutions of Baltic States, has decreased considerably, especially in Estonia, what has led to a deep decrease in the staff of research institutes. Owing to strong roots of solidarity between scientists of previous socialist countries, also to a certain cooperation with Nordic countries, especially with Sweden, with the support of CMEAPS, the formation of Baltic-German-Portugal-Sweden research projects took place in the first half of the 90-ties, in the frameworks of the EU Copernicus program (1993–1996), which enabled to lay down the basis for studies referred to in [2], and to preserve the research potentials of academic institutes of Baltic States, of the ITEP of Estonian AS in particular [2]. The research results of this project in the frames of the Copernicus program deserved high evaluation marks in Brussels and Munich.

As known, no more finances were assigned by EU for the research connected with IPS, as it was assumed that further development of these urgent studies has to be financed by Baltic States and their power systems.

All the later finances were assigned to the research of renewable energy sources only.

For further funding of the development of system research in power technology, the national programs of Baltic States and their intersection as Interbalt program were developed for prosecution of the above-mentioned research at the interstate level. Unfortunately, these programs as well as Inter-Baltic program have not been funded.

Only in the frames of contracts between BASRE and DC *Baltija* (owing to the personal support of Ministers of Economic Affairs and power systems of Baltic States), investigation of the most urgent research at the interstate level was provided, considering problems of optimal control in the case of large disturbances first.

As the solidarity disappeared at the beginning of 2001 due to monopolistic interests of Estonian Power System to close DC *Baltija* and CMEAPS (and for coordination only the Council of Accredited Representatives of Baltic Power Systems (CARBPS) was created), the contracts between BASRE and DC *Baltija* were cancelled.

Estonia's strategically incorrect national policy in the situation of independence which tended towards limitation of state funding of technical and economic scientific research, especially of the system research in power technology, has led to the following results:

- abolishing of so-called basic financing of institutes and financing by state programs;
- limitation of research topics – by targeted financing and financing of grants.

That created a situation in which those studies could be closed not only in the oldest and strongest academic institute on the system research of power technology of Baltic States – Energy Research Institute of Estonian Ac. Sci, but also in Tallinn University of Technology, especially in the Department of Electrical Power Engineering. Therefore, the integration of the research of academic institutes and universities was not realised as financing of the academic institutes was cut down and funds for the universities were not increased.

Further struggle for solidarity of the mutually complementary research initiated in 2004 and 2005 in conditions of improving international collaboration in activation of Baltic cooperation with broader international involvement of big countries has led to the following results:

- 1) a foothold was found in the Department of Electrical Power Engineering (EPE, in the new building of Power Technology) of Tallinn University of Technology (TUT) to house the critical mass of our working group;
- 2) understanding arose concerning the necessity of solidarity in mutually complementary research between our new research group (mainly at the interstate level on optimisation of IPS) and the Department of EPE of TUT;

- 3) solidarity has grown in Estonia within representatives of different technical sciences, also within system research in power technology and economics, aiming at essential improvement of the funding of these researches not in the form of targeted financing only, but also providing funding of basic research and supporting state programs whose funding has been zero;
- 4) it has become possible again to improve the cooperation in energy technology between Ministries of Economic Affairs and power systems of Baltic States with creation of the pool of Baltic power systems, so as the monopolistic strivings, especially those of Estonian Power System, are weakened by the change in their leadership due to:
 - the requirement to open the Estonian electricity market at a required level in coming years,
 - foundation of common Baltic Ignalina NPP in Lithuania,
 - the requirements of the EU for integration and coordination of the control of IPS of EU.

The positive opportunities listed above have offered the possibility of new formation of Baltic scientific project with international participation of big countries, such as Russia, headed by the Institute of Power System Modelling of the Siberian Branch of the Russian Academy of Sciences, but also with Germany and other states, in which case it would be possible to get some international funding from the European Union in Brussels.

The role, significance and state of DC *Baltija* as a center for reliability and trade

DC *Baltija* – the interstate center for optimisation of control and reliability of IPS of Baltic countries – was formed in Riga in 1992, in the time of restored independence of Baltic countries. Its activity included also cooperation with neighbouring IPS, especially with Russian and Belarussian ones. Further, in the end of the nineties, the activities were started to broaden the functions of *Baltija* as a coordinator of free market of electricity – i.e. an independent operator of regional systems.

Now it is clear that *Baltija* as such, liquidated on November 30, 2006, has been, in large measure, a unique – might be even on the world scale – dispatch center at the interstate level in free market conditions.

This statement is based on the following:

First, the special role of DC *Baltija* is characterized by the following facts:

- **first** – in the conditions of both Soviet Union and restored independence of Baltic states **there has been no total emergency caused by large disturbances** although the probability of large disturbances in IPS of Baltic States is essentially higher due to lower

reliability of various elements of the system. At the same time in Western countries (the USA, Canada, England, Sweden, Germany) total emergencies have become more frequent causing huge damages as there are not such coordinating centers in these countries.

A similar situation arose in the Caucasus and Middle East after closing coordinating centers, i.e. former IDC of power systems of these countries.

In East European countries, especially in Russia, those coordinating centers were maintained, although the situation of transition to market conditions was probably different from western one. That enabled to avoid total emergencies, besides, the experience and potential of the example of DC *Baltija* could be useful here as well;

- **second** – provision of optimal control at the interstate level, profitable for partners in the given market conditions, in particular, taking into account the high potential of application of Pareto-optimal corrections of ESS in the general case in the unantagonistic game situations in the future. It could yield an essentially higher economic effect than a situation without such a cooperation;
- **third** – the possibility to develop DC *Baltija* as a commercial center in the future, enabling a certain optimal coordination of the market mechanism between partners, considering the offer of accepted operational conditions.

Second, DC *Baltija* as a unique center integrated and coordinated the control of separate power systems in free market conditions, that in practice required creation of a rational network of coordinating dispatch centers.

Therefore, independent competent experts of the three countries, in particular from the Academies of Sciences of Estonia, Latvia and Lithuania, made a point of preserving and developing such a center, with the support by the EU (see their appeal [13]). They referred to the fact that during the existence of this center there had been no total emergency in the Baltic region, thanks to cooperation between IPS of Baltic States, UPS of Russia and IPS of Belarus, and reminded that at the same time such emergencies have become more frequent and global in Western countries where such centers are missing.

At the same time, the loss of unanimity in Baltic countries, in particular between their PS, due to restricted monopolistic interests of Estonian Energy, has led to liquidation of DC *Baltija* on November, 30, 2006. This situation is extremely absurd, as DC *Baltija* with its experience and scientific potential related to its functions is in many aspects a model for creation of a net of coordinating centers in EU countries in free-market conditions. There does not exist any technical and scientific reason for the need to close DC *Baltija*.

Elaboration of Baltic scientific project

There exist possibility and necessity of elaborating a Baltic scientific project with international partnership of great countries (Russia, Germany and others) on optimisation of the control and operation reliability of IPS, especially on the interstate level, in the case of large disturbances and fall-outs, on the model of IPS of Baltic countries, considering the cooperation with neighbouring IPS and the net of adequate coordinating centers, for which there exists a possibility to get financing from the EU. This possibility exists owing to the following factors:

- readiness of the EU to assign again funds in the frames of international projects for research on large energy systems (LES), proceeding from the occurrence of large disturbances and severe emergencies in the USA and Western Europe in free-market conditions for electricity. The corresponding 7th frame program of the EU has been formed at the beginning of 2007;
- the experience of DC *Baltija* as an interstate center of IPS control providing optimal reliability and corresponding Baltic research on the methods of control optimisation, the basis of which was laid down with mediation of BASRE within the frames of the Copernicus program in the middle of the 90-ties already, considering multi-criterion and game theory approaches. This would grant special support by the Energy Commissary of the EU;
- a special world-scale potential of Russia in this field, of ISRE of SB of the Russian AS, headed by academician N. Voropai, in particular. The eventual involvement of research forces of Germany and Italy, without whose participation the financing of this project will hardly be possible, would increase the potential.

IPS of Baltic States is unique not only by the extremely uneven distribution of energy reserves, but also by its special placement between East and West, involving Russia and Germany as well. These factors increase the possibility of getting financing for this project from Brussels.

This project would play an important role in further development and application of the theory and methods of complex optimisation of control and reliability on most of cases, from the one side, and for laying down the foundation for further development of these optimisation methods and for complex optimisation of a corresponding net of coordinating centers, on the other side, taking into consideration the following:

- costs of development and operation of the net of corresponding centers;
- behavior of optimal market mechanism, providing implementation of acceptable operation conditions of separate sub-systems in the free market.

Main aspects of this project [14] were accepted at the last session of the All-Russian scientific seminar “*Methodical problems of the reliability study of large energy systems*” in Harkiv, July 1–5, 2006.

Besides, this project appears as an important complementary factor for motivating and accelerating growth of the unity in the power field and in cooperation between the Ministries of Economical Affairs and power systems of Baltic States, and, in particular, forseeing re-establishment and development of DC *Baltija* at a new level by financial support of the EU. Temporarily, for a two-years period, DC *Latvian Energy* in Riga will take over some functions of DC *Baltija*.

Conclusions

The experience and results of the research on analysis and optimisation of the control of operation and development of the IPS of Baltic States at the level of interstate dispatch center DC *Baltija* are pioneering in many aspects and could be used as an important potential in further activation of international research and development projects, especially with the expected connection of IPS of the West and the East at a common frequency in the future. Therefore our aspirations concerning BASRE and our old good relations are to be used for new reactivation of cooperation with the ISRE of SB of the Russian AS in the first place, and with corresponding research centers in Germany as well.

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