FULL-SCALE COMPLEX ANALYZERS FOR PROCESSES OF FUNCTIONING POWER PLANTS' ELECTRICAL EQUIPMENT

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ABSTRACT

For Russia for the first time a fully digitized complete engineering model of a power plant electric circuit that is able to work in the real time in a frame of a computer simulator has been developed. The model and the simulator can be used by the power plant operational personnel to predict what operation mode of the power plant electric circuit shell happen at the real equipment as a result of a required change over.

INTRODUCTION

According to the existed circumstances the main facilities of Russian Federation power plants were put into operation in a short time of the second half of XX century. The same situation was arisen as well in the West European countries, the USA, Canada and some other countries.
From this it follows that the equipment with finished service life should be substituted by the new one in the comparatively short time and in large qualities. It is necessary to attract for it the huge funds. At the same time the investigations showed that the service life could be continued, if the equipment is maintained under soft conditions.
The new software system, which is able to help in providing of the soft conditions of electrical equipment operation, is described in this article.

STATEMENT OF A PROBLEM AND GENERAL TOPICS

When a power utility dispatcher makes an order for a power plant to output certain power along the requested transmission lines, neither this dispatcher nor the power plant specialists beforehand know well, which regime of electrical equipment operation would be installed as a result of operating this command. The assessment of obtained result can be made only after operating the order. However the necessary volume or the amount of measuring devices is traditionally not installed at some electric circuits, and therefore even after operating the dispatcher order the personnel has not the full and accurate estimation about the formed regime of electric equipment operation. But if even after operating the dispatcher command it became evident that one of the elements of electrical equipment works with overload, it is still not clear, how it should be necessary to change the regime to avoid this overload and at the same time to fulfill the dispatcher order.
Until recently there was no technical means to forecast on the fly the mode of operation of a power plant electric circuit as a result of a planned switching over. The available systems for calculating the parameters of electrical regimes are oriented for the long preparation of initial data in a certain format, they have not a convenient user friendly interface, and in addition the time of calculating one regime by means of such software is still quite large. All these facts limit their utilization at the real power plants. Another systems (the simulators of switches) that have a user friendly interface are not able for the most part to calculate the operating conditions of electrical equipment.
The Russian company "Power plants simulators" managed together with the electric stations' chair of Moscow Energy Institute (MEI) to solve first the pointed problem in the full scale.
The technical problems, which had to be solved, concern the following areas:

- Algorithms of functioning the separate elements of electric circuit;
- Optimization of the rate of solution;
- Organization of software structure;
- Complex debugging of complicated systems.

As a result the "Complex analyzer of the processes of power plants' electrical equipment functioning" (CAEE) was developed, while the high accurate model of electrical equipment functioning lays in the basis of it. Being created for a particular power plant with taking into account all its distinctive features, this model allows to calculate the main parameters of the power plant electric circuit under any switching over.
It is evident that in order to successfully forecast the operating conditions of electrical equipments of a power plant, CAEE must manage to simulate in full-fledged manner:

- generators of any kind including their excitation systems,
- transformers,
- switches
- and so on.

It is extremely important that the developed software system allows to execute the calculations of processes occurring in the electrical equipment in the real time.

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CAEE doesn't demand the exhausting preparation of initial data for calculations. It has a user friendly interface that allows easy to learn how to use it.

If we have the high accurate model, it is possible not only to forecast the operating conditions of power plant's electric part, but to analyze as well the occurred emergency situations. A function of creating the oscillograms of "fast" transient processes was included in CAEE for facilitating the analysis of emergency situations by means of the CAEE. It is supposed to use as a "oscillograph", for example, Microsoft Excel, while CAEE is able to create the data that are necessary for it.

Moreover, if the additional means for training the personnel are included in CAEE, it is possible to obtain a high quality simulator for training of electricians, which is totally adopted with the special features of given power plant. The CAEE development engineers envisaged a possibility of its equipment with the subsystem supporting the personnel training. In such configuration the CAEE can be equipped with the following features:

- additional protection and blocking, which are absent at the real power plant, but which prejudice the trained person about approaching to the emergency situation in a few steps before it;
- subsystem of calculating the residual reliability of electric circuit during any switches over and an integrated estimation of the whole transient process from one regime to another in accordance with the conditions of reliability;
- the traditional servicing functions of training simulators such as:
  - loading an initial state;
  - saving the current state;
  - real/accelerated time modes;
  - run/freeze modes;
  - a feature that a previously performed exercise can be later repeated in automatic mode,
  - and so on;
- the CAEE can be run on a few computers interconnected to a LAN

The Russian company "Power plant simulators" has already more than 10 years occupied the leading positions in Russia in the area of development of simulators-analyzers of thermo mechanical processes of thermal power units. In this period the company delivered to the customers in Russia and abroad more than 20 simulators of different type. The joining of its advanced simulation technologies with the advanced scientific research of the leading specialists of MEI electric stations' chair resulted in the development of the software product, which has no analogues not only in Russia, but in our opinion also abroad. The software product can allow the electric power plants and utilities to reduce substantially the expenditures for running repair and updating of electrical equipment.

A development of the first CAEE for Moscow power plant number 26 is completed in April 2004. The main circuit of electrical connections at the power plant reproduced in CAEE consists of the following elements:

- 32 nodal points (points of electrical connection of the groups of elements),
- more than 300 switching elements (switches and disconnectors),
- ten 220-500kV-transmission lines,
- 14 transformers with power from 32 to 400 MVA
- 7 generators with power from 120 to 320 MWт

REGIMES THE CAEE REPRODUCES

The regimes of possible overloads of equipment on current and voltage are most important in the context of preserving the service life of electrical equipment.

Based on the accurate mathematical modeling, CAEE allows to reproduce practically all steady-state and transient regimes of generators, transformers, switching equipment etc. including both the normal and abnormal regimes.

In this chapter we will enumerate some most frequently met and most important regimes of electrical equipment operation, which are reproduced in CAEE.

Transformers

The overload of coupling transformers (generator switchgear - GSG) of generator voltage and OSG (outdoor switchgear) of HV (high voltage), OSG of MV (middle voltage) is possible with the generators operation along the schedule of heat production and the reduction of 6-10 kV-local consumer load. In this case the disconnection of one coupling transformer will result in the overload of another ones. The duration of this overload is determined either by the duration of transformer disconnection or the time, which is necessary for the readjustment of technological conditions of heating system and the unloading of generators required. The level of overload can be significant and exceeds the systematic overloads admissible by Russian State Standards (GOST) as well as the admissible short-term overloads permitted by the "Rules of technical maintenance" (RTM). For the transformers, for which the service life is about over, such overload can result either in the final malfunction or in the failure of devices for VCL (voltage control under the load) or for SWE (switch without the excitation). The disconnection of the transformer can be caused both by the failure of the transformer itself and the failures in the work of switching equipment in its circuit. CAEE allows to the operating personnel to analyze all possible ways going out the formed critical situation with the full control of operating conditions.

The overload of coupling autotransformers HVSG (high-voltage switchgear) – MVSG (middle-voltage switchgear) in the power systems with the relatively short transmission lines are caused, as a rule, by the power system regime. Taking into account, that the relation of inductive reactance's in the transformers of power units and transmission lines constitutes 5-10 in such systems, the capacity redistribution at the generators of power units effects poorly on the transit flow through the coupling autotransformer. The solution of a problem is possible only by the combined actions of operating personnel of the power plant and the power utility. For the electrically remote power plants the mentioned regime can be corrected by means of load redistribution between units switched for HVSG and MVSG. In all these cases CAEE gives the exhaustive information on the possible consequences of operating personnel actions and the operating conditions.

The overload of unit transformers at the units of Russian power plant is unlikely, because their rated power exceeds the power of unit generators. The overload of reserve transformer for auxiliaries in the regimes, when it works simultaneously for a few units, is possible, if there is a failure of some working transformer of auxiliaries. In this case the overload duration is determined by the possible overswitching in the circuit of reserve power supply of power plant auxiliaries or the duration of unit outage. CAEE covers the pointed regimes and allows to forecast the optimal actions of operating personnel.

Generators

The steady-state regimes of generators' operation at real power plants are also conducted in some cases by the overloads exceeding the permissible ones. We enumerate the most often met regimes, which are successfully implemented by CAEE.

- Separation of a part of power plant to a stand-alone system with the formed shortage of active power of the separated part. The pointed regime is accompanied by the reduction of the separated part frequency, the increase of generators' excitation with the possible overload of rotor and stator on current. The many ways are known for going out the critical regime including: the disconnection of a number of consumers; the attempt of resynchronization with frequency difference exceeding the permissible one for the conditions of accurate synchronization; the transfer of a local consumer feeding that doesn't require the uninterrupted power supply to the reserve system of buses with temporary disconnection of its power supply, etc. CAEE is modeling both the development of situation and the possible ways of going out and returning to a allowed regime.
- The voltage reduction in network is a special phenomenon in the deficit power systems, when a part of the system is separated in a stand-alone system. In this case depending on the adjustment of voltage deviation channel in ACE (automatic controller of excitation), a series of the alternative regimes of generator operation is possible: from the overload on rotor current to going out the synchronism under conditions of static stability. CAEE allows to predict in advance the consequences, to install the desired distribution of reactive power between generators and to select the optimal ACE adjustment by means of pointed channel.
- The loss of generating facilities is dangerous in the deficit power utilities. Therefore, when in such power utilities a generator comes to the asynchronous regime, there are the attempts to keep it in operation in spite of some difficulties to keep its thermal regime. In excess power utilities, the generator that felt to asynchronous regime is, as a rule, switched off. In the same time the rules of technical maintenance don't forbid for some generators to work in the asynchronous regime during a limited time. When the generator works in the asynchronous regime without excitation it consumes a large amount of reactive power, it compensates the generators, which are adjacent with it and are working with excitation. In this case the generators, which have the largest excitation control factor for the voltage deviation, are overloaded for rotor current and stator current by 20-30%. The pointed regime is successfully implemented in CAEE. The power plant personnel obtains a possibility to set up beforehand the limitation of overexcitation of adjacent generators, which is switched on in the asynchronous regime of one of them.
- At the present time the existence of prolonged 500 kV-networks results in the voltage growth both in 500 kV-networks as well as in the 220 and 110 kV-networks connected with them in the case of excess generation of reactive power in the pointed networks. The considerable differences in the consumption of reactive power in daytime and at night promote to it. When the consumption of reactive power in system is insufficient, some generators must be transferred in the regime of reactive power consumption. In this case they are working with the considerable under-excitation. It can result and results in the loss of dynamic stability of generator, if the lengthy short current coincides with this regime. In addition the over-excitation of transformers and autotransformers as well as the increase of voltage for auxiliaries are observed in such regimes. CAEE allows to forecast the pointed emergency regimes and to find the optimal regimes of generators' operation for the reactive power output within the frameworks of dispatching active load curve.
- Some power systems yet currently use the method of switching on the generators in network by means of self-synchronization in the emergency regimes. It accelerates the process of putting the facility into operation if there is a power deficit but creates the dangerous situations both for the generator and the power system. CAEE implements the pointed processes in full as well as the regimes appearing with failure of autosynchronizers and not synchronous connection of generators to network.
- The regime of transferring from the working excitation to the reserve one for electric machines is of great importance for the generators that have not 100%-reserve in the thyristor excitation systems. There were the emergencies with the difficult consequences in some power plants. CAEE implements all these regimes appearing during the transfer to the reserve excitation.

Switching Devices

The current overload of switching devices and current transformers, which is possible with the different switches in the ring circuits, is an abnormal phenomenon because it is not predictable. In the ring circuits with 3/2 and 4/3 of switches for connection, the current distribution takes place on the basis of inductive impedances of buses' sections and resistances of contacts. The repair and after-emergency regimes are possible in such circuits, and during these regimes the separate switches will be overloaded on current. In the case of current overload the superheat of contact system occurs, and that is undesirable. A software block, which allows to calculate continuously the pointed regime and correspondingly to forecast it, was included in CAEE.

The similar phenomenon takes place in the switching devices of generators, which are equipped by sectional current-limiting reactor. The concrete current-limiting reactors for the rated current 4000 A are not produced in Russia since 1990. The service life of pointed reactors is 25 years, and this is determined by the period of service life of concrete. At the present time the majority of pointed devices exhausted their service life. In the same time the overload of pointed reactors is limited similar to the dry-type transformers. The serious emergencies connected with distortion of pointed devices took place at some power plants. The initial analysis of operating regimes of switchgears' sections allows in the case of existence of reserve system of buses to provide the optimal operating conditions for the sectional current-limiting reactor, which eliminate the overloads.

MATHEMATICAL BASES OF CAEE

The special features of block diagrams of the simulated electric circuits, which are typical for power plants and in many cases also for modern power systems, were used during development of CAEE.

For the most part the structure of electric circuit at power plants is represented by the nodes of this electric circuit with series connection. These circuits are begun from the nodes embodying the external power system, and they exceed greatly in power the modeled generators connected into other nodes. A number of cross linkages between such circuits is negligible. As the investigations of networks existing in Russia showed, the similar structures are typical for the circuits adjacent to the power plants. The networks with voltage 110 kV and in some cases also with 220 kV are radial even in the compact power systems. Such structure is used, because the short-circuit current are too large in the complicated loop networks, where there are many jumpers.

Under such conditions the modeling of network like quasi complicated loop circuit, especially for the inside circuit of power plant, seems to be not expedient.

The use of methods for calculating the ladder circuits allowed to avoid in modeling power plant circuit the difficulties, which appear with using the methods that are characteristic to the complicated loop circuits.

In our mind the complex technology of processing the sparse matrixes is unnecessary in this case.

The presentation of general circuit in a form of ladder elements with actively inductive couplings allowed also to decline the use of global coordinate system. In this case the ladder circuit is modeled by the power flows from a node to a node by means of solving the system of nonlinear algebraic constraint equations.

The methods for solving the pointed system of equations was developed. They give the steady-state solution, which is calculated at the modern computers in real time scale.

The advantage of used method is a presentation of a branch of a network within the frameworks of general iterative process as a separate element, in which the power flows between the nodes of electric circuit are determined on the basis of vectors of voltages in nodes and without connection with the general system of coordinates.

The use of global coordinate system seems to be necessary only for modeling the cross-linkages. They include the coupling autotransformers of switchgears with different voltage and the sectional reactors.

The determination of magnitudes and phases of voltage vectors in the nodes by means of power balance allows to use locally the diacoptical method for finding the currents in any element of circuit.

The generators are modeled in the orthogonal system of coordinates *d*, *q* by means of the full Gorev-Park's equations. In this case the modeling of network by a balance of powers in nodes allows to avoid the so called coordinate converters.

If the ac generator with rectifier is used in the generator excitation system, this generator is modeled as well by means of the full Gorev-Park's equations, while the rectifier is modeled by means of its characteristics.

The turbines is modeled in CAEE as a complex of automatic frequency control of generator rotation without taking into account the mechanical processes in details.

Thus, the application of above mentioned methods in CAEE allowed to obtain:

- Full modeling adequacy in all operating regimes of power plant's electric circuit for the periodic component of forward sequence currents,
- Full modeling adequacy in all operating regimes of power plant's electric circuit for the flows of active and reactive power,
- Full modeling adequacy in all operating regimes of power plant's electric circuit for the electromagnetic moments in generators,
- Full modeling adequacy in all operating regimes of power plant's electric circuit for the voltages in nodes of an electric circuit,
- Determination with insignificant error, which is admissible by Guiding documents in calculating the short-circuit currents, of aperiodic components in the currents of any element,
- Periodic currents and voltages for the regimes of not symmetric short-circuits by using the equivalent circuit for local section and the equivalent reaction of another part of circuit.

The mathematic methods used in CAEE allowed to avoid the difficulties, which are inherent to the solution of a problem in the global formulation. On the other hand, they allowed to realize the all-regime model of electric equipment operation in the modeling system, in which practically all variables of modeling have the concrete physical meaning. It allowed to lighten greatly the debugging of model, because the diacoptical method allows to fulfill the adjustment of each element model separately.

The model debugging and testing are greatly complicated with the global problem statement, when that is the problem of modeling electric circuit of power plant. It is connected with the fact that the separate element can not be allocated from the general model in the known computa-

tional techniques with the global problem statement, while its parameters are the part of generalized parameters of global model, which can't have a concrete physical meaning.
The means of looking for errors are especially important for the system, which has a few ten thousand of variables. It is extremely important for the solution of a problem of forecasting the power plant, because there is not standard solution for the majority of regimes.
The structure of mathematical provision and software of CAEE allows to develop and to adjust the models of electrical equipment operation for the circuits of practically any complexity.

CONCLUSIONS

At the present time the prolongation of electrical equipment service life represents the serious problem for electric power industry of all the country, and this problem needs the comprehensive solution. The software complex CAEE described in this article can help to solve the problem due to its unique capabilities.

AUTHOR BIOGRAPHIES

VLADIMIR A. RUBASHKIN was born in 1963 in Moscow. He graduated from the Moscow institute of railway transport with "computer science" specialization. After the graduation for 6 years he had been working in the Moscow academic institute of control problems. From 1992 he has been working in the "Power plant simulation" company on the technical director position.

ALEXEY I. POYDO was born in 1938 in Moscow. He graduated from the Moscow Power Engineering Institute in 1960 with "electric stations" specialization. For more 40 years he has been teaching in the Moscow Power Engineering Institute to the students the different branches of the electric station science. He is an author of more then 120 papers in many scientific magazines. He is a co-author of a few textbooks. The main field of his scientific interests is the mathematical modeling of the power plant electrical equipment.