**Brand new** **centralized emergency automation in UPS of East and the experience of its exploitation**

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**SUMMARY**

In article the description of new algorithms of the centralized system of emergency automation (CSEA) is provided.

In the new CSEA the algorithms of solving the following problems are implemented and improved:

* development of computation model of CSEA;
* calculation of control action (CA) by the condition of the prevention of the violation of dynamic stability.

In part of calculation of CA in terms of providing the admissibility of post emergency conditions with providing of the active power normative margins, voltage normative margins and without any current overload of network elements.

In part of development of computation model of centralized emergency control system the entirely new approach is implemented. This approach can be briefly described as follows. In the CSEA database there are two models of the protected area. One is complete model, according to which the dispatcher operates power system, another one is computational model, in which the calculations of control actions are performed. The validation of measurements of the scheme and regime parameters is carried out in the complete model. Because in this case a high accuracy (and more reliable) balancing of electrical mode is provided with the involvement of information about generation and load schedule. To ensure the required speed of calculations of CA the automatic procedure of equivalenting of complete model to the computational model is performed. This procedure uses well known methods with some special corrections.

In part of calculation of CA in terms of providing the admissibility of post emergency conditions some works were carried out on the improvement of the algorithm in part of:

* formation of the differential state vector according to the emergency data;
* design of criterion function of definition of weak sections.

Operating experience of CSEA equipped with new algorithms in UPS of East is also described.

**KEYWORDS**

Centralized System of Emergency Automation - Power System, Stability - Emergency Automation, Control Action

Now the new algorithms of the centralized system of emergency automation (CSEA) based on the modern software and hardware means are developed. This allows formulating and solving of problems of an automatic emergency control on the basis of known classical descriptions of process in power systems.

In article the algorithm of an assessment of aperiodic static stability and calculation of control actions for support of a normative reserve of the active power in estimated weak sections [1] taking into account frequency change in post emergency operation conditions (PEC) of power system is provided. Unlike [2], algorithms of calculation of operating conditions (including marginal), formation of a vector of weighting (change) of an operating condition, determination of weak sections and a choice of steps of control actions are significantly revised.

**MATHEMATICAL MODEL FOR THE COMPUTATION OF OPERATION CONDITIONS OF POWER SYSTEM**

As estimated model for determination of the PEC admissible parameters the unilinear mathematical model of a power system similar to those which is used for calculations of in widespread software is accepted. Unlike that software in presented algorithms the synchronous machines are represented as constant EMF behind reactivity. It expands possibilities of simulation of PEC, allowing if it is necessary to imitate a statizm of excitation regulators by the implementing of the appropriate internal resistances of the synchronous machines. Thus there is a possibility of simulation of maintenance of voltage in a point of regulation invariable on value (by means of implementation of small resistance of the synchronous machine) until the restriction on the maximum or minimum value of reactive power appears.

Particularity of the mathematical description of the operating conditions is the use of two systems of equations solved jointly:

 С⋅δ = D (1)

and

 A ⋅ U = B. (2)

The equation (1) – the matrix linearized equation of change of phases of voltage as a function from the unbalance of active power in the nodes, which obtained as a result of drawing up of the equations of balance of active power in nodes and the linearization of non-linear function of an active power flow in branches of the scheme [3]. The equations are worked out for all nodes except the balancing.

Non-linear function of the dependence of an active power flow in a transformer branch from a difference of voltage phases on its ends is linearized as:

 Pij = |Ui|⋅|Uj|⋅|Kij|⋅|Yij|⋅δij, (3)

where **|**Kij|, **|**Yij|, **|**Ui**|**, **|**Uj**| –** modules of the transformation ratio of a branch, conduction of a branch and voltage in the branch’s i and j ends in an initial operating conditions correspondently;

δij = δi – δj – voltage phases in i and jnodes;

С – square matrix with dimensions (N–1)×(N–1) (N – number of the nodes in the scheme) consists of the elements from (3).

The vector of a right part of D on each iteration step is defined as a difference between the preset and calculated value of the active power in scheme nodes.

The vector of EMF of in initial operation conditions is computed basing on the parameters of an initial mode (voltage, generator’s power) and internal resistance of generators.

The equation (2) – the matrix equation of balance of currents in the nodes, written down in a complex form. A – the square matrix of conductivities of a network of the N × N size (N – number of nodes of the scheme), includes as diagonal elements the conduction of generators (10+6 Sim) and the shunts of loads in the initial operation conditions, defined for node i as:

 Y0н i = S′0н i /|Ui|2, (4)

where S′0н *i* – the conjugate complex of power of load in the node,

|Ui| – node’s voltage.

The vector of a right member of B has dimension of current and is defined by vectors of EMF of generators and a difference of the preset and calculated values of loads.

In fig. 1 the function chart of the algorithm of choosing of steps of control actions (CA) on a condition of providing of a static stability in post emergency conditions is given.

From the external program in relation to considered algorithm the following data are obtained:

* parameters and initial operating conditions of computational model of a power system or its fragment containing balancing node (only for such schemes the CA choice in PEC is carried out);
* the available stepped CA and CA used in a dynamic phase of the transient phenomenon (TP),
* the starting element (SE) if its operation does not divide the scheme into several electrically isolated islands. If SE divides the scheme into such islands, than each of such parts is calculated separately.

In block 1 matrixes A and C of the equations are formed and corrected basing on the type of emergency and CA chosen for ensuring of dynamic stability.

**The formation of the vector of weighting (change) of an operating condition (block 2)**

For formation of the vector of weighting (change) of an operating condition (VWC) the nodes are defined, in which the power unbalance appeared. According to results of this analysis four vectors of N dimension are formed:

* vector of surpluses of the active power Rizb and vector of unbalance of reactive power Qizb corresponding to it,
* vector of deficiencies of the active power Rdef and a vector of unbalance of reactive power Qdef corresponding to it.

The vector of weighting (change) of an operating condition is represented as the changes of load in nodes under the linear law:

|  |  |  |
| --- | --- | --- |
| Vp = (Рizb + Рdef)\*(1 – K\_dpar),Vq = (Qizb + Qdef)\*(1 – K\_dpar), |  | (5) |

where Vp, Vq – active and reactive component of V vector;

K\_dpar – length of V vector;

If K\_dpar is equal to zero vector V is fully summarized with the vector of loads in initial conditions Sn\_о=Pn\_о + jQn\_о and computed operation conditions fully matches the initial ones.

The results of block operation are used as initial conditions for the following steps of CA computations.

**Initial conditions computation for choosed СА (block 3)**

In block the correction of vectors of load of Sn and power of the turbines Pt and their rated values of Pt nom is carried out according to chosen CA in addition to the CA chosen for ensuring of dynamic stability (power of the generator differs from turbine power on the small determined by conditions of convergence of a process of calculation of the operating conditions). On the first step additional CA (chosen under the terms of an admissibility of PEC) are equal to zero.

The entrance to this block occurs in three cases:

* after formation of a vector of weighting of an operating conditions (from the block 2, once);



Begin

Input and preliminary analyses of initial data. A and C matrix correction. Correction of C matrix with the CA used for dynamics.

Weighting vector forming

Application of initial conditions on chosen CA

Computation of marginal operation conditions with accounting of frequency variation

Determining of weak section

Is PEC admissible?

Yes

No

No

No

Yes

Yes

Computation of additional CA

Choosing of steps

Choosing of additional steps according to the unbalance

End

Steps have been chosen?

Additional balancing is needed?

**Fig. 1**. Function chart of the algorithm of choosing of steps of control actions on a condition of providing of a static stability in post emergency conditions

* after the next step of calculation (from the block 7) until PEC with demanded parameters (block 6) is provided;
* after an imputing of stepped CA (from the block 9);

As a result of operation of the block vectors Sn and Pt, Pt nom are formed.

**Computation of the marginal operating conditions accounting the frequency variation (block 4)**

For the operating conditions computation it is necessary to determine the values of load Sn\_zadan and generation Рt\_zadan, Рt nom. Accounting of the frequency variation is made by the implementing of a known linear dependence of mentioned parameters from the frequency [4]:

|  |  |  |
| --- | --- | --- |
| Sn\_zadan = Pn\_zadan + jQn\_zadan;Pn\_zadan = Pn ⋅(1 + K\_nag\_f ⋅Df) + Vp;Qn\_zadan = Qn + Vq;Pt\_zadan = Pt ⋅(1 – K\_gen\_f ⋅Df);Df = Nebalans / (K\_gen\_f ⋅ΣPtnom + K\_nag\_f ⋅Σ Pn\_zadan);Nebalans = ΣPt – ΣPn\_zadan – Los, | $$\left.\begin{array}{c}\begin{array}{c}\\\\\\\\\\\\\\\end{array}\\\end{array}\right\}$$ | (6) |

Where parameters with \_zadan index – initial data for the operation conditions computation;

K\_nag\_f, K\_gen\_f – coefficients of the load and generation dependencies from a frequency ;

Df – frequency variation in p.u.;

Nebalans – active power unbalance;

Los – active losses in initial conditions.

The input of K\_dpar value allows to compute according to (6) the initial data for operating conditions computation and according to (1) and (2) the operating conditions themselves.

The computation of marginal operating conditions consists in the determining of marginal value of K\_dpar, with which the joint solution of (1), (2), (5) and (6) exists.

Marginal operating conditions are determined with accuracy of 0,1 % from the length of V vector.

**Computation of weak section (block 5)**

Starting point for determination of the weak section (WS) is formation of the vector of change of angles (VCA) of voltage on branches of the calculated scheme when weighting from an initial conditions to the marginal.

The greatest in size component of VCA defines the “most weak” branch. This branch and all branches, related and having the same direction of power flow, define the “most weak” angular power characteristic and therefore they are removed from the further consideration. Remained branches are analyzed again for the “most weak” one and so on until the set of dangerous branches will not divide the scheme into two parts. The specified set of branches defines the WS.

**Control of PEC acceptability on the basis of static stability criterion (block 6)**

Information on marginal conditions and WS allows determining the admissible (with 8% reserve) power flow via WS. If it is higher or equal to the power flow in PEC, the conclusion of admissibility of PEC is made. Otherwise the necessary value of unload of WS (*Р*uload) is determined.

**Computation of additional continuous CA (block 7)**

Under the term of continuous CA we understand the CA chosen with the assumption that generation and load in all the nodes can be varied continuously.

Information about WS allows to determine the effectiveness of CA on the unload of WS.

On each step of CA computing only one WS is fixed and for such case the sum of effectiveness of CA is equal to 1.

The type of control action (load shedding (LS) or generation tripping (GT)) is determined by the part of the power system in which the control action effectiveness on unload of WS is higher. If the corresponding part of power system is redundant then GT is chosen, otherwise – LS. The sum of CA is computed according to:

CA = Рunload /eff\_ch. (7)

Allocation of CA in case of LS is made in the nodes with the lowest voltage levels.

Allocation of CA in case of GT the preference is given to the generators with the maximum change of EMF phase obtained during weighting (change) of an operating conditions.

**Selection of steps with preset capacity of CA (block 9)**

The algorithm of steps selection is implemented similarly either for load steps and generation steps.

Initial data about accessible CAs is organized as the following structure: each accessible CA is a combination of several control steps, and each step is some variety of load (or generation) nodes, for each of which power cutoff is preset.

Let us consider the selection of steps by load.

For each control step the cost of cutoff is determined. It is preset in per unit values, proportionally to the summarized power cutoff by default. Besides, there is a factor, which depends on the number of step: fjr first step the cost multiplies by 1, for second – by 1,1 for third – by 1,2 and so on. This factor is preset. For generation control steps there could be additional coefficients, depending on a power plant type (HPP, TPP or NPP) or other conditions.

The objective is to choose control steps for each CA with minimal summarized cost and power cutoff (within the deficit power system) not less than required capacity.

The deficit and surplus parts are determined by critical sections, which have been targeted during the uninterruptable CA calculation process.

When choosing the steps it is being taken into account that nodes, included in the same control step, could lay on the either side of a critical section. In addition to that some steps could appear to be ineffective. Therefore algorithm has been implemented as an enumeration of all possible combinations of all set CA control steps.

In order to reduce the number of steps combinations considered they are initially discarded: inefficient control steps are retrieved from the list. If some CA contains only inefficient steps this CA is discarded in whole.

In case there are no efficient CA for the particular conditions, the calculation process stops and the message about impossibility of choosing control steps appeared.

Remaining efficient CA are ranged by their summarized power cutoff.

For example, if there is a scheme with 4 control actions and each contains three control steps, then the number of possible combinations is *S* = 256. Generally, the number of control steps for each CA could vary.

In order to enumerate all the possible combinations of steps the cycle from 1 to *S* is organized.

If there is sufficient number of CAs (for about 10 or more) in a power system, then there will be a great number of possible combinations. Therefore during the enumeration process the whole table of combinations is not storaged. Simultaneously, there is only the latest considered combination and current minimal value – combination, which allows to lap over required CA capacity along with having minimal (comparing to all earlier considered options), summarized cost. As at the subsequent cycle step there is combination with less summarized cost and still lapping over required CA capacity, it is got to storage instead of previous option.

The selection of control steps by generation criteria is carried out similarly, with the following differences:

* generators considered effective, if they are located in a surplus part of a power system;
* each control step contains one generator, as a rule;
* initially power cutoff for each control step is not a set value – the whole generation is cut in a particular node.

**Postemergency conditions balance control and the selection of additional steps by the allowed imbalance (blocks 10, 11)**

Allowed imbalances in a power system (resulting from disturbance and the actions of counter-emergency automation) are set as initial data: maximal (positive) and minimal (negative).

The value of rated imbalance *Nebalanc* is calculated by (6).

If rated imbalance is above maximal, balancing load shedding (LS) CA is needed; if rated imbalance is below minimal then generation trip (GT) CA is needed. When rated imbalance is above set value it is an issue of providing additional CA.

Along with it, the CAs selected by all the conditions of PEC allowance, are basic, and the CAs selected by allowable imbalance are literally additional.

Before block 11 started the deficit and surplus areas have been generally determined. If LS is needed by the conditions of balancing, it is executed at a number of nodes, excluding surplus area. Similarly, when areas are balances with GT, a number of nodes excluding deficit area are selected. Apart from that the algorithm of block 11 is matching with algorithm of block 9.

If balancing CA does not provide the allowance of PEC then the calculation process stops with the message about impossibility to balance the system.

If further examination provides the fulfillment of considered above conditions, then the execution of small-signal PEC stability CA calculation algorithm accomplishes successfully.

The execution of the algorithm accomplishes also in the case of impossibility to fulfill of one or another condition to provide an allowable PEC with accessible CAs. In that case the data about selected CA steps is outputted with the message about unfulfilled condition. In order not to complicate the exposition of main algorithm principles, this logic is not presented in pic. 1

**BRAND NEW CSEA IMPLEMENTATION IN THE EASTERN UPS**

The Eastern UPS selection as an object of first implementation of brand new CSEA is determined, generally, by two causes – there was no centralized emergency automation in the Eastern UPS and scheme-regime peculiarities of this power pool specify strongly marked dynamic phase of the transients in many rated disturbances. Besides, in a number of post-emergency conditions along with the limitations because of small-signal stability there can be limitations because of current overload. Therefore all the three components of main technological algorithm could be implemented in the mutual interaction during the selection of control actions.

Comparatively simple scheme of the main Eastern UPS grid allows to organize an efficient stability violation preventing system in the cases of rated disturbances by using local counter-emergency automation unit. It obviously determines less comparative efficiency of CSEA by the criteria of the Eastern UPS control actions reduction.

However estimation of CSEA efficiency must be determined taking into account its usage in all the over regional UPS and UPS of Russia in whole. Besides, it should be considered that although CSEA can be referred to the instability prevention automation (IPA), in particular cases CSEA action can prevent successive development of fault in the cases of unrated disturbances, i. e. CSEA can be referred to the means of power systems life expectancy increase. And in that case in opposition to the local units, CSEA prevents successive development of fault, providing preservation of synchronism in power system (or in the parts of divided power system).

In the whole extent the economic effect from allowable conditions area extending is reserved.

Besides, it should be marked that new CSEA software complex in different modifications could be used to solve the following practical tasks:

* Conditions (stability margin) monitoring in the main grid sections and acquisition of recommendations for conditions directing;
* Conditions analyze during the maintenance scheme preparation;
* Operative calculations of transient and post-emergency conditions of power systems for the determination and selection of automation sets;
* Express-estimation of the conditions of complex power system stability on a projecting stage.

At the moment of publishing of this journal, CSEA in the Eastern UPS is on an operational test. The main goal of this test is not the revealing of possible effect from hypothetical CSEA action, but the determination of the fact of correct CA selection in the cases of rated disturbances in all of the scheme-regime operational conditions. Control must be provided by means of transient processes calculations in real scheme-regime conditions at the rated disturbances and selected CAs with the estimation of accuracy of allowable CA steps, i.e. the selection must be optimal.

Positive results of the operational test are a cause to reposition of CSEA in the mode of normal operation and projecting of new CSEA in other UPS.

The multipurpose character of main technological algorithm does not exclude any additions and usage peculiarities. The number of usable control actions could be increased; there could be necessity to take into account of protection systems organization at faults and AR and so on. The perspectives of usage of basic algorithms for the issues of conditions monitoring, advising for operative personnel, maintenance schemes analysis by the criteria of reliability and so on.

All that implies the possibility to make changes and additions to any part of basic algorithm and its software.

Therefore, development and implementation of CSEA on the basis of new algorithm provides the increase of counter-emergency system efficiency in UPS of Russia and opens new possibility of usage of CSEA algorithm for UPS of Russia observability and controllability increase.

**CONCLUSION**

In Russia has been developed the central counter-emergency automation system with the technological algorithm, using only traditional acknowledged calculation methods and providing selection of control action not only by the criteria of required stability margin in post-emergency conditions and prevention of current overload, but also by the criteria of preserving system stability during the dynamic phase of the transient process.

By these means the CSEA, based on this algorithm, is versatile. It also provides the ability to use the algorithm for the issues of observability, reliability and controllability increase of UPS of Russia and regional power systems.

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