

Reliability problems in UPS of Russia regimes management in market and insufficient network transmission capacity conditions

A. F. BONDARENKO, V. P. GERIKH*, L. A. KOSCHEEV,
Yu. N. KUCHEROV, Yu. A. TIKHONOV
(RAO "EES ROSSII", RUSSIA)

Abstract

The transfer from centralized energy sector management in the frameworks of the vertical integrated utility to liberal energy market requires several concerns to be dealt with. The most important one for the United Power System (UPS) of Russia conditions is the definition of the network constraints for active power exchanges between areas within the UPS according to approved security criteria.

Some of adopted security criteria could be observed by the use of emergency control automatics (ECA) preventing stability violations at dangerous disturbances. These ECA schemes were duly tested in the UPS of Russia, do not require considerable investments and its implementation could ease the network constraints in a considerable way.

The ECA in market environment will be considered as new ancillary service, which allows to increase the power exchanges via bottlenecks. Providers of this service could be the Federal Grid company, which implements ECA on its objects, power plants, with their units (for the needs of ECA as production shedding and fast starting reserve, etc), demand-side regulating consumers, which reduce their load upon ECA commands.

The ECA users are buyers, who are interested in increasing the power exchanges via the bottleneck because of the possibility to conclude contracts with cheaper producers in exporting area.

Keywords: Network Constraints - Security Criteria - Emergency Control - Market.

1. Introduction

The transfer from centralized energy sector management in the frameworks of the vertical inte-

grated utility to liberal energy market with the creation of such companies as generating companies, Federal Transmission company, distribution and resale companies, requires several concerns to be dealt with. The most important one for the United Power System (UPS) of Russia conditions is the definition of the network constraints for active power exchanges between areas within the UPS of Russia. This is caused by the fact that the transmission capacity of interarea links is often equal to only 5-10% of the area total load.

As the approved security criteria cause network constraints it becomes necessary to reduce them by defining possible ways to increase the loading of certain electrical links. In the UPS of Russia certain measures were developed and respective schemes were implemented to provide the possible increasing of the power transfer and thus decreasing network constraints at electricity trading transactions in the market. These measures can be used if the involved market participants provide a certain type of ancillary services, ensuring the respect of the mentioned security criteria.

2. Security criteria defining network constraints

There are two groups of security criteria in the UPS of Russia that define the maximum permissible active power flows through the controlled sections and thus the network limitations of power exchanges between areas.

The first one determines the rated stability margin standards on active power and voltage in the normal (initial) regime.

The second criteria group defines the requirements for the power system stability considering normative perturbations (disturbances), i.e. transient stability,

* Central Dispatching Office of the UPS of Russia, 7, Kitaigorodsky proezd, Moscow, 103074; gvp@cdu.elektra.ru

active power and voltage stability margins, permissible current overloads for equipment in the stabilized post-fault regimes.

More detailed view on these groups implies the following items (according to "Guidelines on power system stability"):

1. Active power margin factor at any boundary (section) for the given network topology should be no less than 0.2.

This item is defined as

$$(P_{Lim} - P_{OS} - P_M)/P_M \geq 0,2 \text{ or}$$

$$P_M \leq (P_{Lim} - P_{OS})/1,2; \text{ where:}$$

P_{Lim} - the active power flow limit of the aperiodic static stability in the section;

P_M - maximum permissible power flow in the section;

$$P_{OS} = k \times \sqrt{\frac{P_{\Sigma 1} \times P_{\Sigma 2}}{P_{\Sigma 1} + P_{\Sigma 2}}} - \text{amplitude of irregular oscillations in the same section;}$$

$P_{\Sigma 1}, P_{\Sigma 2}$ - respectively, total load (MW) of each considered subsystem on each side of the section;

$k, \sqrt{MW} = 0.75/1.5$ - automatic/manual regulation (limitation) of the power flow in the section.

Remark: The limit flow practically always depends on a variety of factors, some of them are of weak influence and others influence it considerably. Therefore it is represented in general case as a function of influencing parameters $P_{Lim} = \phi(\pi_1, \pi_2, \dots)$.

2. Voltage margin factor at each node i in the initial regime should be no less than 0.15, or:

$$(U_i - U_{CR})/U_i \geq 0,15 \text{ or } P_M \leq P(1,15 U_{CR}); \text{ where:}$$

U_i - voltage at node i at the same regime;

U_{CR} - critical voltage at the same node.

Remark: This condition in particular means that the required voltage margin in case of exhausted reserve of voltage control should be maintained by reducing the amount of power transfer through the relevant section.

3. Power flow at any boundary should not exceed the transient stability limit for all normative disturbances:

$$P_M \leq P_{Lim}^{tr}$$

4. Active power margin factor for any steady state post-fault regime appeared as a result of a normative disturbance should be no less than 0.08, i.e.:

$$(P_{Lim}^{P/\varepsilon} - P_M - P_{OS})/P_M \geq 0,08; \text{ or}$$

$$P_M \leq (P_{Lim}^{P/\varepsilon} - P_{OS})/1,08; \text{ where: } P_{Lim}^{P/\varepsilon} - \text{aperiodic steady state stability limit at the considered section in the post fault regime in case of tripping of a network element.}$$

When considering an emergency imbalance the same criterion is presented as:

$$P_{M,il} \leq ((P_{Lim} - P_{OS} - K_{im} * P_{imb})/1,08; \text{ where:}$$

P_{Lim} - from item 1;

$K_{im} * P_{imb}$ - power increment at the boundary caused by the normative emergency power imbalance P_{imb} (here - deficit);

$$K_{im} = \lambda_{re} * P_{re} / (\lambda_{re} * P_{re} + \lambda_{ex} * P_{ex}), \text{ where:}$$

$\lambda_{re}, \lambda_{ex}, P_{re}, P_{ex}$ - accordingly, regulating energies and total loads of the receiving and exporting subsystems.

5. In every node i and in every steady state post-fault regime after any normative perturbation the voltage margin factor should be no less than 0.1, i.e.

$$(U_i^{P/\varepsilon} - U_{cr})/U_i^{P/\varepsilon} \geq 0,1; \text{ or}$$

$$P_M \leq P^{aff}(U_i^{P/\varepsilon} = 1,1 U_{cr}); \text{ where:}$$

$U_i^{P/\varepsilon}$ - voltage at the node i in steady state post-fault regime (one may consider the node with the maximum voltage deviation).

At the ante-fault regime the transfer P^{aff} dependence from the minimal voltage at the steady state post-fault regime is based upon the numerical simulation of the normative disturbances by varying the power flow values at ante-fault regime.

6. Current load of any network element after any normative disturbance in the steady state post-fault regime should not exceed the values permissible for 20 minutes, i.e.:

$$P_M \leq P^{aff}[I_i^{P/\varepsilon}(t = 20 \text{ min})].$$

This dependence is formed at the same principles as in criterion 5. It is assumed that during this time (20 minutes) operators on duty should correct the post-fault regime with reduced stability margins and/or equipment overloads (criteria 4-6) so as to provide the criteria conditions 1-2 are observed in the given situation.

Therefore the maximum permissible active power flow at the considered boundary is defined by the minimal value of criteria 1-6.

It should be mentioned that permissible power exchanges in the UPS of Russia are defined mainly by the synchronous stability and very seldom are limited by minimal voltages or current overloads. That is the origin for the complexity of calculation algorithmisation.

Network constraints could have been reduced radically through the reinforcement of the bottlenecks which include building new transmission lines, introducing controllable reactive power compensators, etc., but taking into account large geographical spread of the UPS of Russia this option will be time-consuming and will require considerable amounts of investment. Besides the construction of the lengthy lines together with huge investments is limited by the growing difficulties for obtaining the right-of-way for the line routes.

At the same time the adopted security criteria could be observed by the use of emergency control automatics (ECA) preventing stability violations at dangerous disturbances. These devices were duly tested in the UPS of Russia and do not require considerable investments, the use of these devices could ease the network constraints in a considerable way [1].

3. Means for increasing the permissible transfer in electrical links

The purpose of ECA implementation is that at the initial situation (N) the transmission capacity is used

fully (with the normative margins on criteria 1-2) and if in case of normative disturbance (i.e. in situation N-1) criteria 3-6 are violated control actions are used in order the mentioned criteria to be respected.

Because of the huge variety of dangerous disturbances this automatic system uses two fundamentally different control methods:

- Event based: the occurrence of a predetermined disturbance is detected, and depending on the system configuration and operating conditions, specially selected control actions are realised. The advantage of this method is that the control can start immediately at the occurrence of a disturbance, without waiting for the change in parameters, which makes this type of control very effective.

- Response based: the outgo of given parameters values and/or their combinations from the given stability domains, that characterise the degree of instability risk, is detected and then control actions are activated. The advantage of this method over the first one is that the disturbance, causing the violation of stability, is not detected, which would be a difficult and expensive task, as it would require a complex network of emergency signals transmission, but, on the other hand, the control is less efficient, because it is delayed, when the transient state parameters have already reached dangerous values.

Many kinds of control actions (CA) are used for emergency control: ones which rise the transport capacity of the network – switching off reactors, switching on shunt compensators, forcing of series compensators and alternators excitation, however, these CA are not very effective; others which reduce the active power transfers in section.

- Production shedding ΔG in the exporting part of the power system by switching-off the generator breakers and/or fast valving on thermal units. Steam turbines are discharged through a control system using two inputs: a fast acting electrohydraulic converter and a slow acting turbine control mechanism. The unloading of turbines can be short-term, or impulse, through partial shutting of the control valves for several seconds, only for the duration of the transient state, with a subsequent restoration to the initial production level. It can also be long-term, with the reduction of the boiler output, when the network is weakened, for the duration of the post-fault operating conditions, constraining the power flow based on static stability. The power of the turbines can be reduced to several levels.

- load shedding ΔC and starting fast power reserves ΔR in the importing subsystem, usually used together. In this case ΔC ensures the rapidity and ΔR allows to restore the power supply of the disconnected consumers. It is to notice for the purposes of emergency control special customers are disconnected, the ones that would not suffer disruptions of their technological process during a short term disconnection (sufficient for the start up of the reserve), such as electric furnaces, aluminium smelters.

It should be underlined that load shedding is a forced CA. There is no alternative to load shedding for the emergency control purposes, if the importing subsystem is considerably smaller than of the exporting one as the reserve activation is insufficiently fast and production shedding in the exporting subsystem in this case would have been inefficient from the point of view of power flow reduction through the section, that is:

$$K_{PS} = \Delta P / \Delta G = \lambda_{re} * P_{re} / (\lambda_{re} * P_{re} + \lambda_{ex} * P_{ex});$$

from where if $P_{re} / P_{ex} \rightarrow 0$, then $K_{PS} \rightarrow 0$,

where K_{PS} , ΔP , ΔG , λ_{re} , λ_{ex} , P_{re} , P_{ex} - accordingly, efficiency factor of ΔG , active power flow change in the boundary, amount of production shedding in the exporting subsystem, regulating energy of the receiving and exporting subsystems, total load of the receiving and exporting subsystems.

The control actions are distinguished by their duration – short-term CA for securing transient stability (criterion 3) and long-term action – for establishing the rated stability margins (criteria 4-6). Often CAs are used in different combinations. For example, as it is mentioned above, for ensuring the rapidity ΔC is used in the receiving subsystem, ΔR would have been ineffective for maintaining stability because of insufficient rapidity (60-300 sec), but it allows to restore the power supply of the disconnected consumers comparatively fast. In order to provide the selectivity the automatic system is made as a multi-step device carrying out minimal necessary control actions for the given situation or the system uses balanced control actions (e.g. ΔG and ΔC) for the reduction of the caused power imbalances in one areas that could lead to stability violations in other areas.

Practical realization of these principles could be very different from the simplest, e.g. in local automatic systems, where the main parts of this system (starting, logic and executive units) could be combined into a single device to centralized regional systems, most sophisticated ones, where these units are evidently separated. The example of this advanced system is given in fig. 1. In ante-fault regime on the base of telemetry (TM, TS) the state estimation for the given scheme is carried out, preset disturbances are simulated and necessary control actions are calculated and stored for every disturbance cyclically (blue dashed lines show the ante-fault information). When a disturbance is detected the corresponding starting unit activates the associated control actions immediately (red solid lines show the post-fault information – commands).

4. Organization of the service for constraints reduction

It is proposed to increase the power exchange via a bottleneck by implementing new ancillary service - ECA.

Providers of this service could be:

- Power plants, which provide their units for the needs of ECA (generation shedding, fast starting reserve, etc). The payment for them includes:

- compensation cost for underproduction of electricity, because of generation reduction. It is defined

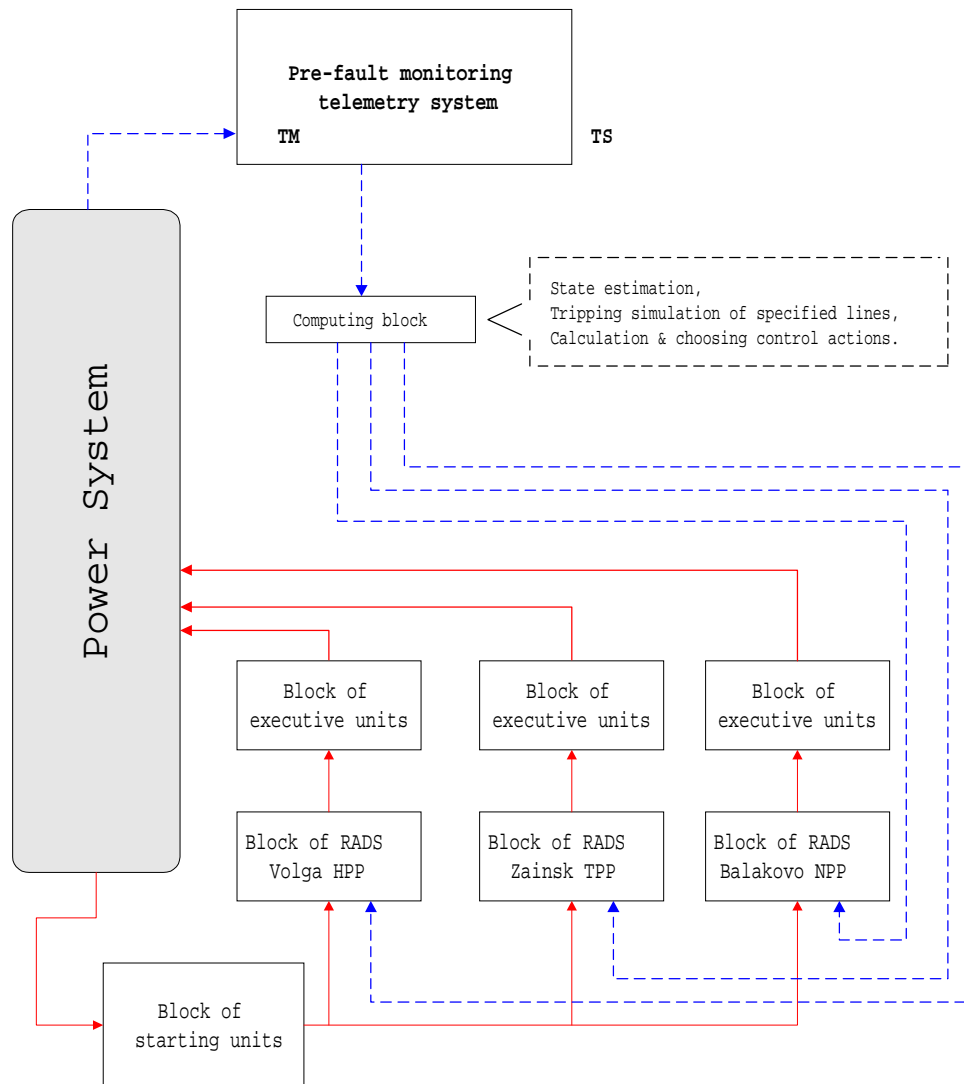


Figure 1. Structural diagram of Central Emergency Control System of Middle Volga Integrated Power System (IPS)
(RADS- remote unit for automatic control action dosage storing)

by the probability of line tripping as well as power flow in the bottleneck and total restoration time;

- additional operational and maintenance (O&M) costs due to the increase of the number of dynamic regimes;
- installation and operational costs for ECA equipment.

- Demand-side regulating consumers, which reduce their load upon ECA commands. The payment for them includes:

- compensation of damage caused by underproduction;
- compensation of additional O&M costs;
- installation and operational costs for ECA equipment.

- The Federal Grid company, which implements ECA on its objects. Installation and operational costs for ECA equipment are covered at the expense of system service payments.

The ECA users are buyers, who are interested in increasing the power exchanges via the bottleneck because of the possibility to conclude contracts with cheaper producers in exporting area.

This system service contracts are usually long-term, for 1 year or more.

Here is the simplest numerical example. Let assume the following input data. Maximum load: exporting subsystem - 15 GW, importing subsystem - 40 GW, interconnected by 3 lines (500 kV) with total length of 800 km. According to 1-st criteria group the permissible

transfer is 2200 MW, but according to 2-d criteria group it is limited by 1800 MW.

If there is ECA equipment, which would disconnect a 500 MW unit in the exporting subsystem in case of a line tripping when the transfer exceeds 1800 MW then the permissible transfer could be increased up to 2160 MW.

If one assumes that the difference in marginal costs is e.g.

$\Delta T = 300 - 0,1 P_{12}$, RUR/MW·h, then cost cutting for the purchase of the same amount of electricity equals to:

$$A = 720 \int_{1800}^{2160} (300 - 0,1 P_{12}) dP_{12} =$$

$720(300 P_{12} - 0,05 P_{12}^2) \Big|_{1800}^{2160} = 26,438$ MRUR,

where:

720 h – assumed 2160 MW transfer duration (1 month);

P_{12} - power transferred between subsystems.
 System service cost for the power plant: if one assumes that generator disconnection fee is e.g. 0.5 MRUR and line tripping probability for one 500 kV line

is 0.0025 trippings/km-year then for 1 month (according to the example) we would get $0.0025 * 800 * 1/12 = 0.17$ faults of at least one of three lines (and generator accordingly) per year, thus result in 0.085 MRUR as generator disconnection fees a year.

The ECA costs include capital costs, e.g. $K = 1$ MRUR (as we consider very simple systems we assume that they were built for 1 year period), O&M costs – appr. 20% of the capital costs – 0.2 MRUR.

Total expenses for the ECA – 1.285 MRUR for the first year, and 0.285 MRUR - for every other year.

Comparing cost cutting (in our example – 26,438 MRUR) with total ECA expenses one can evaluate the ECA efficiency.

References:

1. A.F. Bondarenko, A.F. Djakov, M.G. Portnoy, V.A. Semenov, I.Z. Gluskin, V.D. Kovalev, V.I. Berdnikov, V.A. Stroev. Exploitation des reseaux electriques integers a proximite des limites operationnelles a l'aide de systemes de controle des urgencies. CIGRE 1998. Rapport 39-109.