Russian Far East Interconnected Power System Emergency Stability Control

A. A. Grobovoy

***Abstract*--Conventional angle stability controls do not always meet the power consumers' requirements. There are spread interconnected power systems where application of generator tripping for stability improvement is accompanied by load tripping to counterbalance the effect of tripping the generators. This resume discusses a concept having potentialities for advanced stability control for such power systems. The concept is based on unconventional combining of centralized and decentralized control. That would be possible if to make use of repeated-several-times dynamic braking and repeated-several-times fast valving to maintain synchronism within several seconds following an emergency. Those seconds could be used to predict the process evolution applying a software for power system dynamics simulation to determine indispensable control actions for keeping stability in post-emergency state.**

***Index Terms*--centralized control, decentralized control, power generation, power systems.**

I. Introduction

The next-generation concept of emergency stability control is considered here for the Russian Far East interconnected power system. The south-eastern outskirts of the Russian Power Grid is a typical spread power system (Fig. 1). It includes four power systems operating in synchronism: the Dalenergo, Khabarovskenergo, Amurenergo, and Yakutskenergo. Its reliability is supported by the regional control centers situated in the following cities: Vladivostok, Khabarovsk, Blagoveshchensk and Yakutsk respectively. The emergency control complexes (hereinafter, "control complexes") are located at the Zeya Hydro Plant (1350 MW, 6 units), Primorskaya Power Plant (400 MW, 4 units, and 1000 MW, 5 units), and another one will be situated at the being built Bureya Hydro Plant (2010 MW, 6 units). The Zeya Plant has six 54-MW braking resistors. The Bureya Hydro Plant will have six 84-MW or 134-MW braking resistors.

These power plants have units connected at both 220-kV and 500-kV busses, with autotransformers connecting the 220-kV and 500-kV busses. The Zeya and Bureya Plants, approximately 500 km apart, will be connected by two 220-kV and one 500-kV transmission lines. Khabarovsk and Vladivostok are approximately 650 km apart.

A. A. Grobovoy is with the Power System Emergency Control Laboratory, Ltd., 26/38 Blukherr Str., Novosibirsk 630064, Russia (e-mail: andrey.grobovoy@aees.power.nstu.ru)

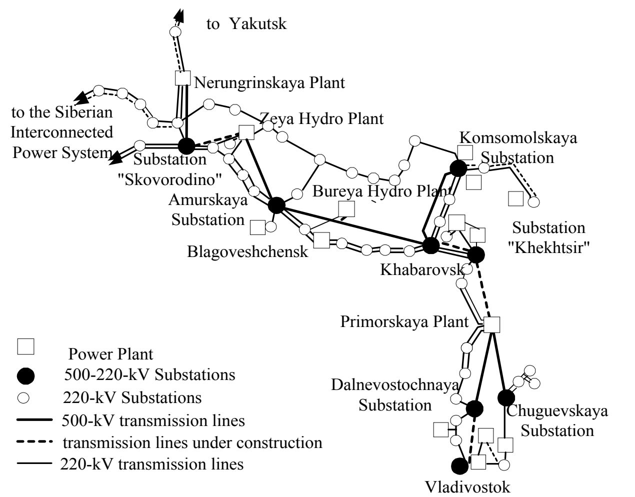

Fig. 1. Configuration of the Russian Far East Interconnected Power System

The area of Vladivostok, being the southern part of the Far Eastern interconnected power system, is characterized by active power shortages. The Primorskaya Plant, being the main power supply for the south of the power system, is 400 km to the north from Vladivostok. The Khabarovskenergo power system partially meets the Dalenergo power system need of electricity.

The power grid dynamic properties are conditioned by large spread of the network and low transfer capability of the interconnection between the Amurenergo and Yakutskenergo power systems. In the future, the Far-Eastern and the Siberian Power Grids will operate in synchronism. That means that in case of improper emergency control actions taken in the Amurenergo and Khabarovskenergo power systems there will be loss of synchronism. Operating conditions of the Zeya Plant – Khabarovsk transmission system are such that losing any of its 500-kV sections is accompanied by overloading 220-kV transmission lines.

There take place problems with the Dalenergo power system emergency stability control, too. Losing any of the parallel 220-500-kV transmission lines adjoining to the Primorskaya Plant busses results in overloading the rest of the lines. To prevent loss of synchronism in this case, generator tripping at the Primorskaya Plant and load tripping in the south of the system are applied. In most cases, the load tripping is applied with excessiveness due to uncertainty of actual operating conditions.

II. Innovative controls

An unconventional control technology for improving the Amurenergo and Khabarovskenergo power system stability is being used at the Zeya Plant. The technology has been developed and introduced to ensure successful high-speed reclosing of the Zeya Plant - Amurskaya Substation - Khabarovskaya Substation 500-kV transmission line sections because the effect of three-pole reclosing and single-pole switching on this transmission system is very essential.

Besides, the new technology has been developed for preventing excessive tripping of generators. Normally, such situations are accompanied by excessive tripping of the load in the receiving part of the transmission system, and that should be avoided.

At last, an innovative technology is being proposed for fast valving to be used for angle stability improvement at the Primorskaya Plant.

These technologies are considered in the following paragraphs.

A. Repeated-Several-Times Dynamic Braking

In order to eliminate excessive generator/load tripping, a modernization of the control unit of dynamic braking has been made. For the purpose, the control principle has been changed from “feedforward” to “feedback”, and dynamic braking has been made as “repeated-several-times” dynamic braking. There is no generally accepted term for denotation of this control method in Russia. So, in this summary, we also use term “multiple” in order to label it.

The multiple dynamic braking augments capability of successful three-phase (0.5-0.9 sec) high-speed reclosing and one-pole switching (1.5 sec) because it prevents the dangerous increase of generator angle. If operating condition of the power system is severe, one or two insertions of the braking resistors may take place. In less severe conditions, two or three insertions of the resistors may occur. The multiple dynamic braking is also applicable in case of emergencies taking place on the 220-kV lines. In these cases, there usually three insertions of the braking resistors occur. In order that the control actions were effective under all possible operating conditions with various types of high-speed reclosing of the 500-kV transmission line sections, the control law of the multiple dynamic braking has been accepted [1] as shown below:

$$U = sign(\omega + k \cdot m \cdot \delta) \tag{1}$$

where U is the control function; ω and δ are the rotor speed and the integral of the function $\omega(t)$ respectively; m is a scale coefficient; k is a coefficient defined as:

$$k = \begin{cases} 1, \text{ if } & sign(\omega) > 0 \cap sign(\delta) > 0 \cap J \le \alpha \\ 0, \text{ if } & sign(\omega) > 0 \cap sign(\delta) > 0 \cap J > \alpha \end{cases} \tag{2}$$

where α is a setting value determined at the stage of the control device tuning, J is a parameter calculated by a special electronic scheme. The algorithm can be described as follows:

$$J = \begin{cases} \dfrac{d\omega}{dt}, \text{ if } & (\dfrac{d\omega}{dt} > 0) \cap (\dfrac{d^2\omega}{dt^2} \ge 0) \cap (\dfrac{d\omega}{dt} > J) \\ J_m \cdot e^{-\frac{t}{\tau}}, \text{ if } & (\dfrac{d^2\omega}{dt^2} < 0) \cup (\dfrac{d\omega}{dt} < 0) \end{cases} \tag{3}$$

where $J_m = \dfrac{d\omega}{dt}$ is calculated at the moment of time when

$$(\frac{d^2\omega}{dt^2} = 0) \cap (\frac{d\omega}{dt} > 0) \cap (\frac{d\omega}{dt} > J) \tag{4}$$

The control law (1) - (4) allows to take into account the specific features of the dynamic brake switches and the transmission system performance under disturbance.

B. Step-By-Step Generator Tripping

In addition, as was shown in [1], the Zeya Plant’s dynamic braking is used to determine the number of generators that should be tripped during the first insertion of braking resistors to keep angle stability. This idea is very simple. It consists in monitoring the sign of acceleration of the rotor of one of the generators (load/generation imbalances) during the first insertion of braking resistors to find out if there is need for tripping generators.

The emergency control is accepted to be applied gradually by tripping generators one by one under most operating conditions of the transmission system, if dynamic braking is applied. But in heavy operating conditions and a severe emergency, step-by-step generator tripping is to be executed serially by groups of several generators. At the Zeya Plant, such groups may consist of two generators.

These controls ensure reliable operation of the power system if the transmission line high-speed reclosing is enabled and successfully operated.

Otherwise, to ensure post-emergency power system stability, generator tripping is applied with the control action value determined long before the emergency occurs, on the stage of operating conditions planning.

If, by the moment of an emergency occurrence, the operating condition of the power system is heavy, then up to four generators could be tripped. It is 900 MW of active power when fully loaded. In that case, to ensure operation of the power systems in synchronism, it is necessary to apply balancing load tripping in the Khabarovskenergo power system that will be taken by the Zeya Plant control complex using the special system for transmitting load tripping control signals.

C. Long-term Unloading of Hydro Turbine

When exploited simultaneously, repeated-several-times dynamic braking of generators and unloading of hydro turbines (offered over 40 years ago [3]) form a universal means for maintaining system stability. Its main purpose is to reduce the number of generators tripped.

The modernization of the Zeya Hydro Plant dynamic braking controls will be started in 2001. It is an opportunity to develop and test the next-generation repeated-several-times dynamic braking and turbine unloading controls for both Zeya and Bureya Plants.

Some outcomes of simulation of that control strategy are adduced in the following figures.

D. Repeated-several-times Fast Valving

In Russian power systems there usually rectangular control pulse is used for fast valving control. The pulse activates the turbine valves via a special converter. The shape of the pulse trailing edge may be such as shown in Fig. 2(A). The exponential shape of the pulse trailing edge shown on the right is determined by a time constant τ. The pulses duration is determined long before emergency occur, at the regimes planning stage.

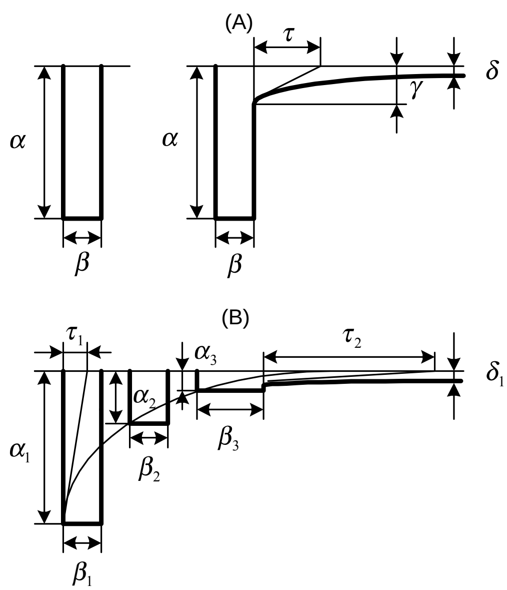

Fig. 2. Pulse forming: (A) - conventional pulse forming; (B) - "complicated" pulse forming. α – pulse amplitude; β - pulse duration; δ – long-term unloading value; τ - time constant; γ – "stage" of pulse trailing edge.

The new fast valving strategy proposed consists in the following. Several electric pulses are formed using feedback principle. The duration of the pulses is determined depending on the generator rotor acceleration. The first (control) pulse must have maximal amplitude, the amplitudes of the subsequent (corrective) pulses exponentially decaying (with a time constant τ_1) as shown in Fig. 2(B). The leading and trailing edges of the pulses are formed when the acceleration sign changes.

The last corrective pulse's trailing edge which may have exponential shape (decaying with a time constant τ_2) determines the post-emergency amount of turbine active power which is reached only in 3-4 seconds since a disturbance occurrence due to sluggishness of turbine.

E. Control Complexes Mission

The control complexes to be established at the Zeya, Bureya, and Primorskaya Plants must choose control and corrective actions. There are two time frames in the complexes operation: "prior" to a contingency and "following" the contingency.

Prior to a contingency the control complexes, along with the task of collecting and processing information from telemechanics, about generation status, operating condition parameters and network topology, etc., should perform two main tasks:

1. Power flow simulation to obtain and memorize the initial parameter values (this will allow to run dynamics simulations immediately following a disturbance).
2. Storing the "solution table" of long-term unloading of turbines control actions to be applied immediately following a contingency.

Following a contingency the control complexes must fulfill the following tasks:

1. Power system dynamics simulation with taking into account the actions of controls and the results of transmission line high-speed reclosing (was it successful or not).
2. Determination of exact value of power imbalance produced at the first stage of transient condition before governor actions take place. Calculations of power flows taking place for quasi-steady-state stability condition and determination of the safety margin of the quasi-steady-state operating condition.
3. If it is found that a correction of transmission systems unloading to maintain stability in the quasi-steady state must be done, then the correction of the control actions is carried out.
4. Simulation of the second stage dynamics taking into account frequency dynamic performance.
5. Calculation of the post-transient steady state power flow and that of the extreme for static stability condition.
6. Producing additional corrective with station-level automatic load-frequency controls.

Thus, disturbance liquidation will be the result of two processes interaction. The first process is the application of repeated-several-times dynamic braking and step-by-step generator tripping (it will be repeated-several-times fast valving for steam power plants) using local measurements of transient parameters, and long-term unloading of turbine using the table of "rough" solutions. The second process is the computer simulation of controls during transient condition and determination of extreme for stability condition with subsequent correction of turbine unloading volume.

III. Computer Simulation Results

The effectiveness of these controls has been assessed using the Siberian Electric Power Research Institute's transient stability program software. The studies were based on the system planned for the year 2003 when the first three generators of the Bureya Plant will be put into operation.

Fig. 3. compare the use of various controls at the Zeya Plant. In these cases an emergency loss of the Zeya Plant–Amurskaya Substation transmission line has been simulated. There were controls at the Zeya Plant only. The number of braking resistors closures was limited to 4. The example of

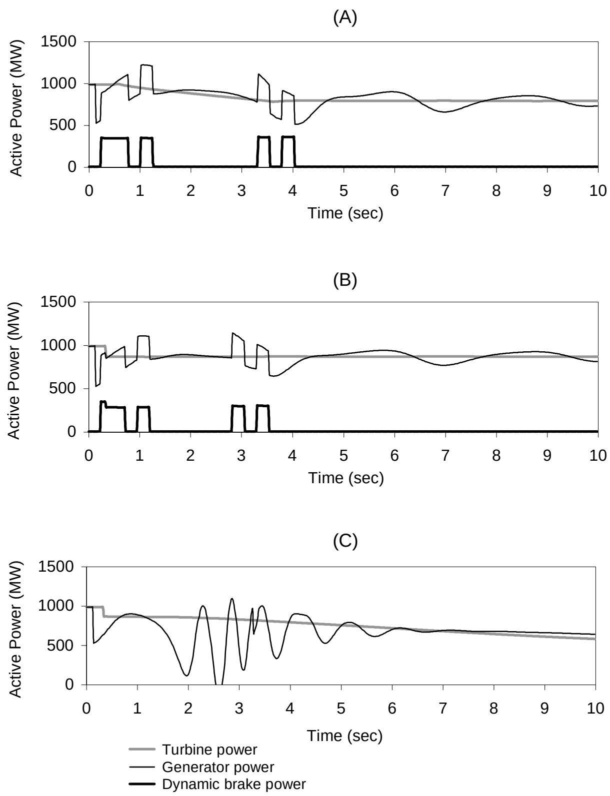

Fig. 3. Assessment of various controls: (A) repeated-several-times dynamic braking coupled with long-term hydro-turbine unloading; (B) repeated-several-times dynamic braking coupled with step-by-step generator tripping; (C) conventional generator tripping without other controls.

instability is observed in (C)-plot. Here, the sudden step of the curve at approximately 3.25 sec is explained by the effect of devices used for instability liquidation. This group of computing experiments was conducted under the following conditions: the Zeya Plant initial power output is 990 MW; the transfer power capability limit of the transmission system under loss of the line is 980 MW; the post-emergency stability margin was accepted equal to 15%.

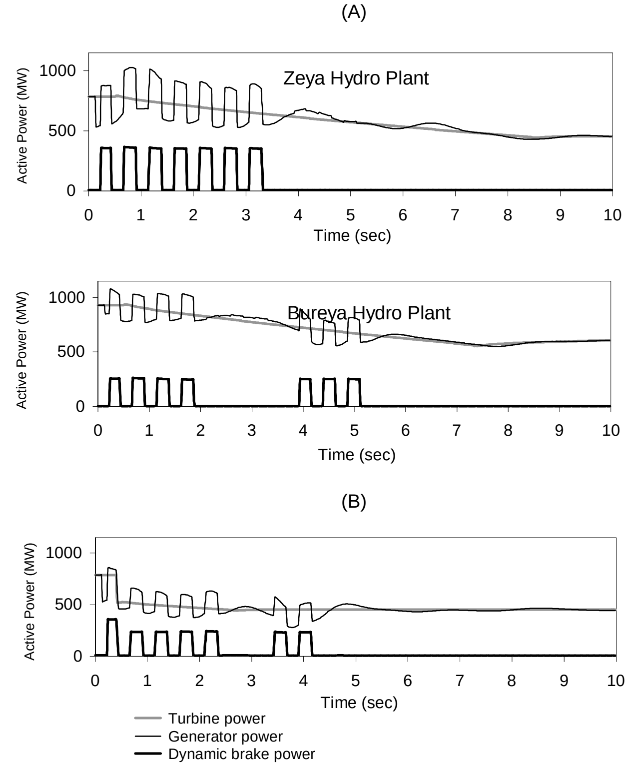

Fig. 4. Assessment of various controls: (A) repeated-several-times dynamic braking coupled with long-term hydro-turbine unloading and step-by-step generator tripping at the Zeya and Bureya Plants; (B) same at the Zeya Plant when controls are not used at the Bureya Plant.

Comparison of two cases when the Zeya and Bureya Plants have controls (A) and when only the Zeya Plant has ones (B) is displayed in Fig. 4. Here, an emergency loss of the Amurskaya Substation – Khabarovskaya Substation transmission line has been simulated. The number of braking resistors closures was limited to 7. This group of computing experiments was conducted under the following conditions: the total power of the Zeya Plant under initial conditions is 786 MW, the total power of the Bureya Plant is 915 MW; the transfer power capability limit of the transmission system under loss of the line is 1580 MW (active power of both the plants); the post-emergency stability margin was accepted equal to 20%.

Fig. 5 shows an example of application of repeated-several-times fast valving at the Primorskaya Plant with the control signal having one corrective pulse with the trailing edge providing long-term unloading of 30%. In this case an emergency loss of the Primorskaya Plant – Dalnevostochnaya Substation 500-kV transmission line has been simulated. The initial conditions were the following: the Primorskaya Plant was at full load, generating 1400 MW, the Primorskaya Plant – Dalnevostochnaya Substation line was carrying about 620 MW; almost all Primorskaya Plant's power output (1300 MW) was transmitted to the south of the system. There was simulated such event sequence:

Time (sec)	Event
0.01	single-phase fault
0.13	single-phase tripping
1.13	single-pole switching on fault
1.25	three-phase tripping
1.27	24%-load tripping in the Dalenergo Power System

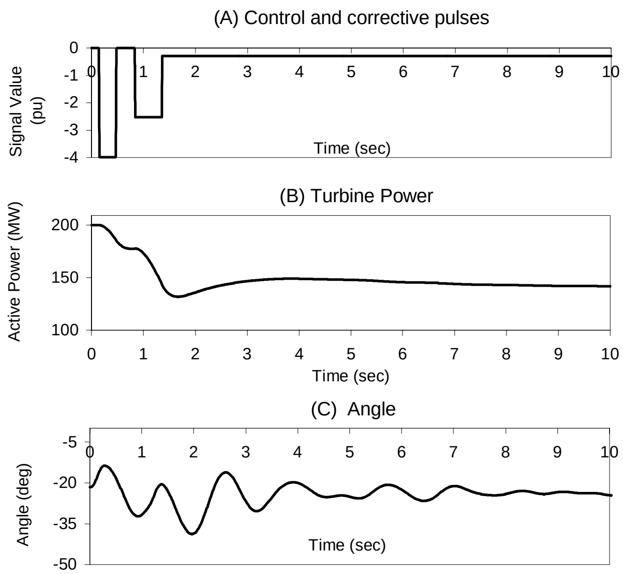

Fig. 5. Simulation of controls response at the Primorskaya Plant: output signal controls (A); active power of one of the turbines (B); rotor angle of one of the generators with respect to Komsomolskaya power plant's generator (C).

IV. SOME CONCLUSIONS

Computer simulations of the Far-Eastern interconnected power system dynamic behavior for the system planned for the year 2003 similar to those shown in Figs. 3-5, allow to make some conclusions:

1. The interconnected power system dynamic performance under a disturbance caused by opening of the Zeya Plant - Amurskaya Substation, the Amurskaya Substation - Khabarovskaya Substation, and Primorskaya Plant – Dalnevostochnaya Substation 500-kV transmission lines, is conditioned by many factors. The most affecting are the methods of these power plants power output emergency control.
2. Multiple dynamic braking and step-by-step generator tripping and also long-term unloading of hydro turbines used jointly at the Zeya and Bureya Plants may become a reliable means of controls coordination. Using local measurements of transient parameters allows automatically coordinate the action of the Zeya and Bureya Plants' control complexes.
3. Dynamic brake switches must permit at least 5-7 closures, and braking resistors must allow total duration of application no less than 3-5 seconds during one operation cycle. The braking resistor capacity must be 25-30% of the generator's rated power capacity.
4. Providing possibility of successful high-speed reclosing of the 500-kV transmission lines or providing conditions for long-term unloading of hydro turbines, in case that reclosing is unsuccessful or disabled, is to be considered the main purpose of the dynamic braking controls at the Zeya and Bureya Plants. Another important purpose of the dynamic braking controls is providing conditions of automatic "dosage" of generation tripping amount under all possible operating conditions of the transmission system.
5. Under the most heavy operating conditions, it is necessary to determine the number of generators per group for the first step of generation tripping to be applied at the Zeya Plant depending on the external, with respect to the Zeya Plant, conditions: the number of generators in operation at the Bureya Plant, directions and magnitudes of the intersystem power flows between the Siberian and Far-Eastern interconnected power systems, and between the Amurenergo and Yakutskenergo power systems.

V. WHOLE CONTROL SYSTEM REQUIREMENT

The block diagram of the offered control system and telecommunication concept for the Far Eastern interconnected power system are shown in Fig. 6.

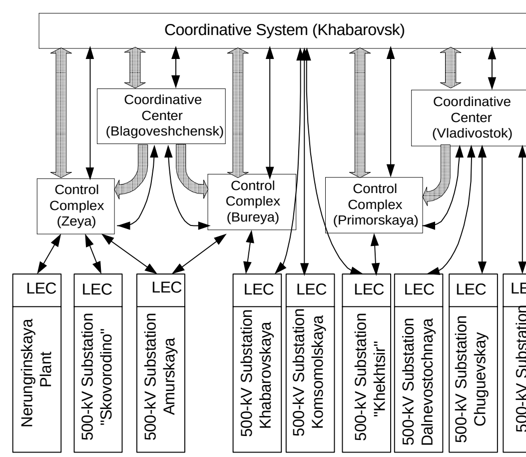

Fig. 6. Telecommunication concept: LEC stands for Local Emergency Controls; thick arrows stands for "data transfer"; thin arrows stands for "commands and measurements transfer"

The volume of long-term unloading of turbines is to be determined by the control complexes located at the plants which determine needed control actions following a disturbance. The emergency coordinative centers and emergency coordinative system (hereinafter, "coordinative centers" and "coordinative system") transfer data necessary to perform the tasks described in paragraph *Control Complexes Mission.* The optional duty of the coordinative centers and system is transferring the initial values of the control action prior to a disturbance to the control complexes.

The number of generators in the first group for tripping at the Zeya and Bureya Plants can be determined either by the coordinative center of the Amurenergo power system or by the control complexes. In the latter case, all necessary information must be provided to the power plants by the coordinative centers of the Amurenergo and Dalenergo power systems. This information can also be provided by the coordinative system of the Main Control Center of the Far-Eastern interconnected power system, if previously received from the coordinative center of the Amurenergo or obtained by means of computer simulation of the power system dynamics.

Thus, the effectiveness of the control system of the Far-Eastern interconnected power system under extreme and forced operating conditions depends on the effectiveness of interaction between its separate components, namely between the control complexes, coordinative centers and coordinative system.

Each of the three control complexes must represent a control system having three levels. The lower level of the control system fulfill multiple dynamic braking and turbine long-term unloading (repeated-several-times fast valving for Primorskaya Plant) control principles with feedback. The middle level keeps initial long-term unloading values and applies them immediately following a contingency. The upper level is responsible for communicational interchange with the coordinative centers and coordinative system. Immediately following a contingency, the upper and the middle levels of the control system must determine necessary corrective control actions within several seconds, if the initial actions applied were insufficient, or tens of seconds, in case that the initial actions were found excessive.

Communications between the coordinative system, coordinative centers, and control complexes is to be carried out via fiber-optic communication lines or via high-voltage overhead transmission lines using high-frequency communication channels or by means of the Russian power industry telecommunication network "Elektra", or via the Internet. Communication environment is to be chosen depending on the state of development of communication facilities in the power systems. Communication via low-orbit satellites being the most promising one.

VI. Conclusion

The Russian experience of multiple dynamic braking and step-by-step generator tripping at the Zeya Plant is the base for developing a new emergency control concept for spread power systems. This is provided by new communication technologies used in power systems.

The application of artificial neural network technologies may be used for determining the level of long-term unloading at the control complexes, corrective centers and corrective systems. The application of fuzzy logic may be used for choosing the number of generators per group for tripping at the control complexes. That appears to have a potential for improving the concept proposed in this summary. This is the subject of the future investigations.

VII. Acknowledgment

The author gratefully acknowledge the contributions of V. V. Kourilo and N. A. Borodina for their valuable assistance.

VIII. References

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IX. Biography

Andrey Grobovoy was born in Western Ukraine, on January 10, 1950. He graduated from the Far East Polytechnic Institute, Vladivostok, in 1973. After conscription, since 1975 his employment experience include the Siberian Electric Power Research Institute. Since 1992, he is director of the Power System Emergency Control Laboratory, Ltd. His special fields of interest include large power system emergency stability controls.