Slide 1

Good morning.

For those of you who don't know me I am professor Samorodov from Russia, Siberian Research Institute of Power Engineering.

I've divided my presentation into two parts. First of all, I'll give you an overview of Complex Tests of Half-Wave Transmission System. Secondly, I'll talk about Introduction of Half-Wave Technology in the near future in Russia.

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In connection with natural and economic features of Russia the problem of Power Delivery over very long distances 2000 - 4000 km has developed during many years. Researches of our Institute have shown that this problem can be solved on the basis of half-wave transmission systems (HWTSs).

The basic advantage of HWTSs is simplicity of their schemes and equipment. At the same time normal and emergency conditions of this TSs have unusual character. And that forces to reconsider the point of view which has developed for long TSs on the questions of stability, overvoltage protection, relay protection, system automatics, et cetera. Unusual properties of HWTSs were revealed by both theoretical methods and experiments on physical simulators (models). However for the solution of the questions which have arisen at research and development of such TSs, realization of field tests was required.

Therefore the decision on realization of field tests in the 500 kV network of the European part of Russia was accepted. It was necessary to lead tests without decrease in operating reliability of Power Systems involved for experiment.

In the accepted test scheme energy from the Volga HPP via 500 kV transmission system Volgograd – Moscow – Chelyabinsk should be transferred in Power System of Urals. The whole length of the line reached 2858 km. Its electrical length made 173º that is a little less than half-wave. In Brazil lines with length a little more than half-wave name often HWL+. By analogy lines with length a little less than half-wave we will name further HWL-.

However it was possible to consider equivalent electrical length of the transmission system equal to 187° if to pay attention to reactance of sending transformers and reactance of receiving system.

The preliminary analysis showed, that at the given electrical length and the big resistance of HWL- there was a danger of parametric instability (self-oscillation) at the transferred power exceeding about half of natural power.

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The commission on realization of the tests was guided by the following purposes:

- check of loading characteristics;
- Investigation of self-oscillation and its liquidation ;
- review of the transients leading to overvoltages.

Tests were bound to the certain technical risk because of unusual scales of the field tests covering huge territory.

To reduce this risk to a minimum and to raise efficiency of tests, preliminary researches on physical simulators were carried out. This researches allowed to develop recommendations on normal and emergency conditions for the period of tests.

The tests were led under direction of the Central Dispatching Office for the United Power System of the European part of Russia. The direct communication of the Central Dispatching Office with all basic test points was organized. Special automatics from the

Volga HPP started up oscillographs and under the set program necessary commutations (switching-in and disconnection of circuit breakers) at all points were carried out.

On the tested transmission system autotransformers, shunting reactors and arresters were disconnected from long lines. For restriction of overvoltages the protective spark gaps were installed at a number of points. On HWTS the existing relay protections were used.

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For the first energization the HWL- was shunted at the Arzamas point through the circuit breaker. Such scheme allowed to guarantee the least transient overvoltages. HWL- shunted at the Arzamas point was energized from the Volgograd substation. In transients the maximal overvoltage took place at the Lipetsk point and made 1.64. Then HWL- was switched-in at the Chelyabinsk substation. In transients observed maximal voltages were close to rating value.

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Greater transient overvoltages were received at energization of open-ended HWL-. At switching-in from the Chelyabinsk substation overvoltages at the open end of HWL- reached almost 2.0. Similar transient overvoltages took place also at energization from the Volgograd substation.

Opening of not loaded line from a source passed easily. Voltage after disconnection of HWL- oscillated with the frequency close to network frequency. The voltage between contacts of the circuit breaker which was disconnecting HWL- changed slowly not exceeding double value.

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Successful current synchronization was made. The line put into operation by disconnection of the shunting circuit breaker. Frequency instability of generators because of their small loading did not allow to carry out exact synchronization at the minimal current in the shunting circuit breaker. Disconnection of the shunting circuit breaker occurred at a frequency difference and current in the shunting circuit breaker shown on the slide 6. Appreciable, but quickly fading swings arose. Active power at the Volga HPP reached 950 MW, time of increase of it was about three periods of industrial frequency. The swing period was equal about 1.0 s, swings faded for 5 s. Overvoltages at the Arzamas point in transients reached the maximal value of the order of 1.25 practically simultaneously with the first maximum of reactive power.

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Usual synchronization was made at the Volgograd substation. The HWL- was put under voltage from the Chelyabinsk substation. Synchronization was not exact but generators of theVolga HPP joined for parallel work with Power System of Urals. Overvoltages at the Arzamas point in transients were less than in the previous case of current synchronization.

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Without loading HWTS worked steadily. Load increase was carried out by small steps of the order of 100 MW. The restriction of reactive power at the Volgograd substation was satisfied with the joint coordinated regulation of active power and voltage.

First marks of self-oscillation (cumulative hunting) appeared at active power about 400 MW. Generators of the Volga HPP worked with the proportional voltage regulators. At 500 MW intensive self-oscillation began.

For increase of power transfer more than 500 MW the forced voltage regulators were put. Then up to transferred power 935 MW self-oscillation were eliminated.

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For elimination of self-oscillation at greater loading one 500 kV line at the Chelyabinsk substation was disconnected. As a result equivalent reactance of receiving system was increased and the increase of transferred power was continued. At full loading 9 generators and total power 1043 MW conditions was steady. Note that the natural power at voltage 525 kV is equal about 1000 MW. Thus despite of unfavorable circumstances (the length of HWL- was a little less than half-wave, rather big resistance) a high level of static stability of HWTS was provided.

Active power losses made 225 MW including corona losses.

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The slide 10 shows data under some registered conditions and their comparison with calculated ones. There is closeness of experimental and calculated data. Some deviations were caused by an error of measuring transformers. Other reason of discrepancies consisted that calculated data were received without taking into account corona losses.

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To find-out influence of zero sequence on transient overvoltages three experiments of single-phase short circuit were performed: single-phase short circuit at the Volgograd substation, at the Lipetsk point and at the Chelyabinsk substation. This slide shows duration of single-phase short circuits.

The greatest registered overvoltages in transient made: at the Volgograd short circuit – 1.75 (at Lipetsk), at the Lipetsk short circuit – 1.82 (at Chelyabinsk), at the Chelyabinsk short circuit – 1.95 (at Chelyabinsk).

Overvoltages in transient on buses of the Volgograd substation reached values of the order of 1.20. The steady-state voltages under emergency conditions were of the order of 1.1.

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Possessing rather great margin of dynamic stability HWTS at the same time is sensitive to swings of connected systems because of proportional dependence of voltage at the middle of half-wave line from transmitted power. The more the angle of swing, the more voltage increase in the middle of HWL-. For check of dynamic characteristics the experiments were performed under load conditions at single-phase short circuit at the Arz. point and at the Volgograd substation.

Single-phase short circuit at Arzamas was performed after power increase at the Volgograd substation up to 640 MW. It led to power decrease on the Volga HPP approximately equal to 200 MW. After disconnection of short circuit swings were observed. The first amplitude of active power at the beginning of HWL- was 990 MW. Through 5 s swings stopped practically. The greatest switching overvoltage equal to 1.6 in transient was observed at the Lipetsk point. The greatest swing overvoltage registered was nearby 1.3.

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Experiment of single-phase short circuit at the Volgograd substation was accompanied by power decrease nearby 200 MW. The greatest switching overvoltage equal to 1.95 in transients was observed at the Lipetsk point.

At disconnection of short circuit arose swings of active power. The first maximum at the beginning of HWL- was 850 MW. The greatest swing overvoltage registered was nearby 1.2.

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Last experiment was directed on creation of limiting overvoltages sufficient to break-down spark gaps. With this purpose rough current synchronization was carried out.

Disconnection of the shunting circuit breaker occurred at a frequency difference and current in the shunting circuit breaker shown on the slide. During swings protective spark gaps were broken down and HWTS was disconnected. The greatest registered overvoltages were of the order of 2.3 .

On it tests ended.

Slide 15, 16. Conclusions to the part 1

1. The planned test program of HWTS Volgograd – Moscow – Chelyabinsk was successfully and completely executed. It was not observed difficulties in operation of the 500 kV commercial equipment.

2. Tests confirmed theoretical conclusions that HWTSs are efficient and can serve as means of energy transfer over very long distances.

3. Results of field tests have great value for the further development of the HWTS theory. The phenomenon of parametric instability of generators (self-oscillation) was investigated.

4. Ways of energization and synchronization of HWTS were tested. Results of tests showed, that these modes passed successfully without special measures of damping of swings and restrictions of internal overvoltages.

5. Regulation feature of normal conditions of HWTS was checked up and the opportunity of self-oscillation suppression at length a little less than half-wave was confirmed by use of forced voltage regulators.

6. The performed series of emergency conditions in the loaded HWTS showed its rather high stability at dynamic transitions. Internal overvoltages arising in these modes, and also in modes of single-phase short circuit did not surpass insulation level of 500 kV transmission system.

7. Use of existing schemes of relay protection and automatics and a number of additional measures enable to provide disconnection of HWTS under emergency conditions. At the same time it is necessary to develop special relay protection and safeguarding automatics.

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UHV of 1150 kV was brought to a commercial level in last quarter of the last century in the former Soviet Union. As a result UHV transmission line Siberia - Kazakhstan - Urals with the total length about 2400 km was constructed. On the basis of accomplished R&D the complex of the UHV equipment was made. This equipment was installed on three substations in Kazakhstan.

The operation of UHV section Ekibastuz - Kokchetav - Kustanai began in 1985. But in 5 years the operation stopped in connection with disintegration of the former Soviet Union. Because of the sharp economic recession the need of transfer of originally planned power disappeared and the transmission system began to operate under the compensated scheme at 500 kV.

At present this transmission line operates also at voltage 500 kV and its transfer capability makes no more than 800 MW.

The UHV equipment installed earlier became unfit for use and electrical industry for production of such equipment is absent now.

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However now there is imperative need of gain of transfer tie between IPSs of Siberia and Urals. One of ways to do it is a return to operation of transmission line Itat – Ekibastuz - Chelyabinsk at UHV.

At the decision of this question it is expedient to be guided by direct uniting IPSs of Siberia and Urals without connection to network 500 kV at intermediate substations.

Considering that total length of transmission line Itat – Chelyabinsk is close to half-wave length (2900 km) it is advisible to consider operation of this transmission line not only under compensated scheme but also under the half-wave one.

Increase in transfer capability of CTS and HWTS is considered up to 3000 MW. That is admissible on condition of reliable operation of UPS of Russia.

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Slide shows the scheme of UHV CTS Itat-Chelyabinsk. Two ATs by capacity 2000 MVA are installed at every end substation. For compensation of reactive power of TL and also for exception of voltages at the line over the maximum operating voltage 1200 kV it is necessary to install 18 shunting reactors (ShR) by capacity 900 MVar everyone.

The conditions analysis of CTS at change of transmitted power from no-load up to 3000 MW shows that for maintenance of voltage at the line within the admissible limits it is necessary alongside with usual ShRs application of controlled ShRs (CShRs). Their demanded number shown on slide makes about 60%.

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Slide shows voltage allocation along CTS under no-load and transfer of 3000 MW. Voltage at points of installation of CShRs is maintained so that voltage at any place of the line did not exceed the maximum operating voltage.

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Slide shows the scheme of UHV HWTS Itat-Chelyabinsk. The given scheme as well as scheme of CTS includes two ATs on each end of HWTS. Two tuning reactors need to install at Itat’s end connecting each with AT in series.

This HWTS includes also the phase-controlling device (PCD) for connection of 500 kV buses of HWTS with a shunting network at voltage 500 kV. By means of PCD the coordination of voltage vectors at Itat’s end of HWTS with 500 kV shunting network is carried out. Use of PCD allows to carry out various operating conditions in a wide range.

Feature of the given scheme is the significant need for capacitor banks. At each end of HWTS it accounts for 1200 MVar.

Slide shows voltage allocation along the line under no-load conditions and transfer of 3000 MW. Decrease of voltage in the middle of the line speaks about a significant margin on transfer capability for the given variant. Having installed one more AT on each end transfer capability of this HWTS could be brought up to 5000 MW. However transfer of such power via single-circuit transmission system is problematic on condition of reliability. Therefore if to start with the maximal transferred power 3000 MW the variant of 750 kV HWTS is feasible.

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Slide shows scheme of 750 kV HWTS. It includes three 750 kV ATs at each end of the line. One tuning reactor is included in series with every AT. Capacity of PCD is the same as in previous variant. Consumption of reactive power by the line under no-load conditions essentially decreases. Accordingly necessary capacity of capacitors on each end of HWTS decreases up to 300 MVar.

Slide shows voltage allocation along the line during no-load conditions and transfer of 3000 MW. As follows from this figure there is still a margin on transfer capability as voltage in the middle of the line does not reach the admissible level.

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In table comparison of technical and economic parameters UHV CTS, UHV HWTS and 750 kV HWTS is given.

750 kV HWTS is the most economic. Its capital cost is less in 2.5 times than UHV CTS. Efficiency of these variants are practically comparable.

UHV HWTS concedes appreciably to 750 kV HWTS on technical and economic parameters. Potential advantage of UHV HWTS as I said earlier consists in its greater transfer capability 5000 MW. But realization of this advantage is problematic on condition of operating reliability of UPS of Russia

Therefore on condition of economic efficiency and reliability the preference should be given to 750 kV HWTS.

Slide 24. Conclusions to the part 2

1. 750 kV HWTS in comparison with UHV CTS is essentially cheaper and more simple in realization as it does not demand development and production of the various UHV equipment. For realization 750 kV HWTS it is necessary to develop only 500 kV tuning reactors and the phase-controlling device.
2. 750 kV HWTS can place in service till 2020.
3. Advent of 750 kV HWTS Itat-Chelyabinsk will promote introduction of future Half-Wave Transmission Systems in Russia and abroad.