Slide 1

Good morning.

I am professor Samorodov from Russia, Siberian Research Institute of Power Engineering.

I am going to talk to you today about HWTSs for power delivery over very long distances 2000 – 4000 km.

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In the countries with extensive territory there is a problem of power delivery over very long distances from energy complexes to load centers.

Special interest to this problem exists in Russia. Questions of very long power delivery are also considered in Brazil and China to harness future Hydro Power Plants.

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The given problem can be solved by employing TSs on both DC and AC. On AC there are two variants: Compensated TS and Half Wave TS.

Greater need for compensating devices does Compensated TS noncompetitive in comparison with DCTS.

Application of Half Wave TS is the most effective solution of the considered problem. Half Wave TS includes terminal substations and Half Wave Line (HWL).

Its length depends on industrial frequency and makes approximately 2500 km at 60 Hz and 3000 km at 50 Hz. No compensating devices are required for HWTS.

HWL has the number of unusual properties which distinguish it from long lines.

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You well know, that a uniform long line can be replaced by circuit of lumped parameters such as the equivalent Π circuit. The equivalence is only valid for one frequency and only for the terminal conditions.

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The traditional Π circuit well reflecting physical processes for lines no more a quarter of wave, for very long lines creates the number of inconveniences. So, for Half-Wave Line longitudinal active resistance turns out negative, and transversal conductance has super large value.

The substantiation of the equivalent Π circuit for Half-Wave Line demands the special approach. The offered approach is based on introduction in the equivalent Π circuit of the ideal transformer with negative unit transformation ratio, named by the half-wave transformer.

The slide shows the equivalent conversion of Half-Wave Line. It is subdivided into two elements in cascade connected, namely the half-wave transformer and the modified Half-Wave Line consisting, in turn, from the half-wave transformer and Half-Wave Line.

Introduction in the equivalent Π circuit of the half-wave transformer gives to parameters the values having clear physical sense.

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If the length of Very Long Line is less than half wave it can be presented in the form of two equivalent Π circuits in cascade connected. The first represents the equivalent Π circuit of modified Half-Wave Line, and the second does equivalent Π circuit of a complementary line with negative electric length.

Parameters of equivalent Π circuits follow from the equivalent transformations and are defined by the formulas on the slide.

By means of tuning equipment the Very Long Line is led to Half-Wave Line as the slide shows.

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If the length of Very Long Line is more than half wave it can be presented also in the form of two equivalent Π circuits. The first represents the equivalent Π circuit of modified Half-Wave Line, and the second does equivalent Π circuit of a complementary line with positive electric length.

Parameters of equivalent Π circuits are defined by the formulas on the previous slide.

By means of compensation equipment the Very Long Line is led to Half-Wave Line as the slide shows.

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Property 2. In Long Line the power angle and transmitted power are connected by the power angle formula. In HWL end voltages are in opposite phase regardless (independent) of transmitted power.

In HWL transmitted power can be changed only due to voltage module regulation on its ends as well as in DC line.

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Property 3. When a power station operates through HWL to an infinite busbar, the static stability limit is defined only by the station parameters, as well as in the case of the zero line.

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Property 4. It is known, that in Long Line the reactive power balance at its ends takes place under natural load. Under conditions less than natural load, line generates reactive power and under conditions more than natural load line absorbs it. At ends of HWL the reactive power balance takes place under any active power.

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Property 5. Voltage deviation in the middle of Long Line makes only some percent from nominal value when transmitted power is changed within a wide range. Directly proportional dependence of voltage from transmitted power takes place in the middle of HWL.

Voltage increase in the middle of HWL is the main limiting factor for transfer capability of HWTS.

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Property 6. At shunting of the middle point of HWL currents at its ends are equal to zero, that is such shunting is equivalent to switching off HWL at its ends. Therefore, supplying HWL with the shunting circuit breaker in its middle part is useful to commute Line.

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The list of unusual properties shows that decision of theoretical and practical questions of HWL demands the special approach.

Researches in the field of the Half-Wave Technology are spent in Russia for many years. As a result the reliable schemes as well as technical and economical parameters of HWTSs was substantiated.

This slide shows UHV HWTS. Used equipment is one intended for traditional ACTS. Transfer capability is within the limits of 6000 - 9000 MW.

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At a choice of scheme and parameters of HWTS the length of Very Long Line can be less than half-wave.

In this case it is necessary to mean following circumstance.

If the imaginery part of the short-circuit input impedance of Very Long Transmission System will be capacitive it is possible occurrence of self-oscillation in the scheme.

To rule out self-oscillation of generators of Power Plant the imaginery part of the input impedance should be inductive.

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Serviceability of HWTS was corroborated with the field tests in the 500 kV Russian Grid. Thus, HWTS is a well developed (investigated) object expecting a practical introduction.

More in detail I shall tell about this experiment at following lecture.

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In connection with increasing the frequency of blackouts in the world, the great importance is attached to Power System Reliability.

As a rule, system blackout is initiated by primary outage of a separate element with cascade development of failure. And the collapse of all system is possible. The most part of dangerous contingencies originates in Transmission Systems. Especially it will relate to Very Long Transmission Systems.

Very Long TS because of its outages can have essential effect on Power System Reliability. Therefore, at development of such TS not only economic efficiency but also reliability should be under careful consideration.

Reliability of Power System has two aspects namely Adequacy and Security. The concept of Adequacy means that Power System has to have sufficient installed capability to satisfy the consumer demand. Security is the ability of Power System to withstand the impact of sudden changes which may result in major disturbances.

World experience shows, that rather high reliability of power systems is provided, if at their designing and operation the N-1 criterion is satisfied.

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Let's consider ways to satisfy the N-1 criterion relative to single-circuit DCTSs under overwhelming single-pole faults.

For the 2-pole DCTS with one converting branch on a pole the N-1 criterion is met only 50&60%. It means that in post-fault conditions it is possible to transfer no more than 50&60 % of rated power.

The smaller figure concerns to operating conditions of long duration and is used at estimation of Adequacy.

The greater figure concerns to operating conditions of short duration (20 – 30 minutes) and is used at estimation of Security.

Reliability of DCTS depends in a greater degree on converting substation faults.

Use of the 2-pole DCTS with two converting branches on a pole raises the N-1 criterion at substation failures. However at line failures this criterion does not change.

Only use of the 4-pole DCTS allows having enough high level of reliability both at substation failures and at unipolar line damages.

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The traditional solution of the reliability problem relative to long ACTSs is the use of double-circuit line. With respect to Very Long TS the same solution is also possible.

However, it is expedient to use single-circuit line instead of double-circuit one for economic and ecological reasons. Such way is admissible if there is a technical solution to ensure just the same reliability for both variants when clearing the most probable single-phase faults. Such faults at UHV TSs make more than 98 %.

Extreme contingencies leading complete refusal are possible both in double-circuit and single-circuit TSs. However, there is their low probability in any variants. Naturally for each alternative special defensive measures must be developed in order to safeguard Power System against extreme contingencies.

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Let's consider ways to satisfy the N-1 criterion relative to single-circuit HWTS under single phase faults.

Substations possess high reliability and emergency outages of HWTS is defined basically by a linear part.

If all single phase faults were transient, the use of the SPAR would satisfy the N-1 criterion completely. However, the share of sustained faults can reach 30-50%. Therefore, the SPAR does not solve the reliability problem under sustained faults.

Clearing of single phase faults can more effectively be decided by introduction of 2-phase modes. In this case an emergency phase is disconnected and there is a transition to the 2-phase scheme. For this purpose it is necessary to put balancing devices into operation.

Under the 2-phase mode the N-1 criterion is satisfied on 50&60 % as it can be transmitted no more than 50 & 60 % nominal power.

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To the full the reliability problem is solved by using single-circuit line with RPh. RPh is put into operation instead of an emergency phase.

In addition, such design improves line maintenance as there is an opportunity of carrying out repair works by the phase. Also ecological influence of line decreases because a right-of-way for line diminishes. Obvious lack of line with RPh is underexploitation of its total cross section under normal conditions.

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Therefore, it is expedient to provide at a later date re-equipping the 3-phase TS with RPh into the 4-phase
one.

It increases transfer capability almost in one and a half time in comparison with a traditional three-phase line.

The 4-phase TS uses the 4-phase AC with the phase shift 90°. The distinctive features of the 4-phase TS are shown on slide.

The 4-phase TS improves economic and ecological parameters of ACTS and reliability as well. For the 4-phase TS the N-1 criterion is met on 80&100%.

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Transfer Capability of HWTS depends on nominal voltage and type of line.

At the given voltage the HWTSs with use of 4-phase compact lines have the greatest transfer capability.

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For delivery 4000 – 5000 MW over very long distances it is possible to be guided by application of the 3-phase 765 kV HWTS with use of ultra high voltage in the middle of HWL. We have so-called humpbacked scheme.

The analysis shows that technical and economic parameters of such HWTSs do not concede to corresponding parameters for the 3-phase UHV HWTS.

Delivery of the order of 6000-8000 MW at use of the 765 kV equipment is possible at orientation to 4-phase HWTSs.

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The economic efficiency estimation of variants without taking into account reliability shows, that the variant with the least reliability has an economic advantage.

Namely the 2-pole scheme with one converting branch on a pole and traditional 3-phase scheme.

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However, at comparison of the different types of the TSs it is necessary to take into account a reliability component in the resulted cost. This component considers cost for additional generating Reserve in receiving system. This additional reserve in all variants should provide the identical reliability of Power System, corresponding the ideal case when TS is considered absolutely reliable.

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In view of the factor of reliability total expenses of all AC variants appear practically identical. For the DC variants the account of reliability also leads to their practical identity on total expenses.

The best AC variant from position of reliability and economic efficiency is the scheme with Reserve Phase. The best DC variant is the 4-pole scheme. Both of variants are characterized by comparable levels of reliability. The technical and economic analysis shows, that at comparable levels of reliability the variant on AC has an appreciable advantage. Expenses for the UHV HWTS with Reserve Phase make about on 30 % less than for the 4-pole ±600 kV DCTS.

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On DC it is possible to provide some efficiency improvement by use of UHV TS with transfer capability 8000 - 10000 MW. As the analysis shows, in this case expenses decrease by no more than 15 %. It means, that use of UHV DCTS does not change the conclusion about the advantage of the Half-Wave Technology.

Besides, it is necessary to bear in mind development of the 4-phase UHV HWTS with transfer capability 8000 - 10000 MW. That leads to the further economic increase of the Half-Wave Technology.

Slide 28. Conclusions

1. Power delivery over very long distances is possible both on DC and AC. The special attention should be given to Reliability.

2. Economic and ecological reasons dictate the use of single-circuit TSs instead of double-circuit ones.

The N-1 criterion of reliability for HWTSs is practically met by using line with RPh and the 4-phase scheme in virtue of the fact that overwhelming number of faults are single-phase ones.

3. Comparison from position of reliability and economic efficiency of the variants on AC and DC for delivery of 6000 MW over 2500 - 3000 km has shown that expenses for the HWTS with RPh make about on 30% less than for the 4-pole DCTS.

4. The basic directions of technical progress in the field of very long electricity transmission on AC:

- Application of the Half-Wave Technology;
- Development of the 4-phase TS.