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DESIGN, TESTING AND OPERATION OF HIGH VOLTAGE BUSHING OF 1150 kV AND THE WAYS OF ITS UPDATING

Evgueni E. Ust'yantsev, Sergey D. Kassikhin, Moscow A. Barkov "Izolyator" Plant

In the USSR the AC transmission lines (electric power lines – EPL) were desined, manufactured and put into operation of voltage 500 kV - in 1959 and 1150 kV - in 1985 by the first in the world. An implementation of EPL with voltage of class 750 kV began in the USSR in 1967 (in Canada – in 1966) and in seventies - eighties the construction of EPL of 750 kV assumed mass type. The dependence of power line capacity from voltage of 500, 750, 1150 kV is defined by doubling of power capacity in going to next class of voltage. It is reasonable to apply the EPL with voltage of 1150 kV at power of 4000-6000 MW and distances of 500-1000 km.

The aerial transmission lines with rated voltage of 1150 kV were developed for the purpose of strengthening of interconnection ties between the electric power systems of unified electric power system (UEPS) east zone of the USSR and power transfer(about 5 GW) of large-size Ekibastuzskii and Kansko-Achinskii fuel and energy complexes. The development of large-size industrial Siberia -Kazakstan- Ural EPL of 1150 kV by common length more than 2000 thousand km was supposed. The first site of this EPL Ekibastuz-Kokchetav (494.3 km) with electric power substations (ESS) in Ekibastuz and Kokchetav was put into operation in the middle of 1983 and the power transmission was switched over rated voltage of 1150 kV when putting into operation the autotransformers (AT) of 1150/500 kV by power 2001 MW (3 phases x 667) in Ekibastuzskaya ESS and Kokchetavskaya ESS in August,1985. In April, 1988 the Kokchetav-Kustanai (395.5 km) with interconnect switch-gear (SG) of 1150 kV and autotransformer group of power 2001MVA in Kokchetavskaya EPS was put into operation. As a whole at Ekibastuzs- Kustanai site of EPL was installed:

Ekibastuzskaya ESS - 1 group of single-phase AT of 667 MVA (3 bushings) and 2 groups of shunt reactors of 300 MVA (6 bushings);

Kokchetavskaya ESS - 2 groups of single-phase AT of 667MVA (6 bushings) and 4 groups of reactors of 300 MVA (12 bushings);

Kustanayskaya ESS - 1 group of single-phase AT 667 MVA (3 bushings) and 1 group of reactors of 300 MVA (3 bushings).

The Ekibastuz-Barnaul power line of 1150 kV (697 km) was put into operation in March 1988.

The last site of Siberia - Kazakstan – Ural power transmission of 1150 kV as a part of Barnaul - Itat line (448 km) and Barnaul ESS of 1150 kV Itatckaya ESS was scheduled to complete in 1995. The complete equipment of AT and reactors of 1150 kV and part of other electric equipment of 500 kV were installed. Since 1996 till the present time EPL at geometry of 1150 kV have been operated with voltage 500 kV for such reasons as disintegration of the USSR and significant lowering of required power capacities.

It should be remarked that up to seventies in the USSR the development of construction of grid for voltage classes of 500 kV and 750 kV occurred with the development of grids in the advanced industrial countries - USA, Canada, Japan and others. As a result of Ekibastuz - Kustanai and Ekibastuz - Barnaul first EPL of 1150 kV construction the USSR is in advance of other countries much more and till now Russia has real experience of their operations incomparable to researches of EPL experimental sites

of 1000, 1100 kV in other countries.

The parent organization on construction of all electric equipment complex of 1150 kV was the All-Union electrotechnical institute (AUEI). Among the high-voltage electric equipment for EPL of 1150 kV the power transformers and shunt reactors are the most complicated elements and their construction represented the serious scientific and technical problem.

The high-voltage bushings of voltage class 1150 kV for single-phase AT of 667MVA and reactors of 300 MVA were designed and manufactured by Moscow factory «Izolyator» nowadays «Mosizolyator» Close Joint-Stock Company (fig. 1, 2). The bushings intended for installation at autotransformers such as АОДЦТ-667000/1150/500 kV of Zaporozhye transformer factory (ZTR) manufacture in Zaporozhye city and reactors such as РОДЦ-300000/1150 of Moscow electrical factory "Electrozavod" manufacture in Moscow city. In seventies the prototype models of industrial bushings of 1150 kV were tested in high-voltage laboratories of ZTR and MEF in Moscow and they were tested at bushing installation models according to special programs in All-Union institute of transformer construction (AUITC) in Zaporozhye city. The standard construction of HV bushings installations of 500-1150 kV is shown in fig. 3. In all transformers (autotransformers) and reactors of 500-1150 kV the winding BH is designed with bushing at middle and, hence, the lower shield of bushing is located near middle of winding that renders the appreciable influence to electric field intensities both in bushing shield area and inside of bushing. The most intense interval of HV bushing installation is usually the interval from HV bushing shield up to tank wall. The insulation cylinders are usually set in this interval. In HV bushing installation of 1150 kV in this interval the special «pocket» of electric-grade cardboard is located. In terms of analysis of electric field and results of tests the insulation distances to grounding parts are chosen. Using the first autotransformers the series of improvements was brought in design and technique. In 1983 the modernization of autotransformer was fulfilled and design of main insulation and the HV bushing installations of 1150 kV were essentially improved. The insulation of tapping and HV bushing of 1150 kV is fulfilled with the help of details of complicated configuration manufactured by the paper mass casting method and in the HV bushing shield the paper insulation a thickness of 10 mm is overlapped and the barriers are fulfilled of electric-grade cardboard instead of bakelite cylinders earlier used.

At a stage of development in seventies- eighties the first industrial samples were put into experimental operation in powerful test benches (PTB) in Tolyatti city and in «Belyi Rast» ESS near Moscow. The experimental AT of 210 MVA 1150/500 kV (manufactured in 1970) and three phases of AT of 667 MVA 1150/500кВ were subjected to long operation. For accumulation of experience of installation, operation, testing of internal insulation at long effect of operational voltage with switching overvoltage overlapping and also for development of routine tests methods the tests of the equipment were carried out in conditions, maximum approximated to operational conditions. The insulating strength of equipment was investigated at effect of voltage and also the mechanical performances of the equipment were studied. The tests of the equipment were carried out in different atmospheric conditions (fine weather, rain, snow, heavy fog) not only at long using of operational and heightened voltages but also at switching overvoltages.

The overvoltage protection system of EPL-1150 includes the spark connection of shunt reactors. The spark connection of shunt reactors is fulfilled by the special device — closer-breaker ensuring the reactor inertialess switching-on at overvoltages and also the normal commutations of reactor necessary for regime conditions. The greatest overvoltages in the equipment were observed at reactor cutting-off by the cut-out switch or closer-breaker; they reached up to 1800 kV. Overwhelmingly the overvoltages were limited with the help of arresters. In tab. 1 the data about equipment operating time at normal voltage and

higher voltage are shown and the number of commutations fulfilled in equipment at tests is specified. It is necessary to note that the successful twelve-year operation of the experiment-industrial AT 210MVA of 1150 kV took precedence of putting into operation of EPL 1150 kV.

' The data of tests at PTB were used which were mentioned in report of I.Bortnik Doctor of Engineering Science (AUEI) at conference « ELELKTRO-87». Moscow.

Table.1

Name of equipment	Operating time of energized equipment, hours		Number of made commutations
	Rated voltage, U_R	(1,05-1,15) Rated voltage, U_R	
Autotransformer №1	7656	-	365
Autotransformer №2	6002	-	336
Reactor №1	5926	2866	573
Reactor №2	1437	742	14
Reactor №3	574	225	18
Air circuit breaker	3459	-	362
Closer-breaker	6317	-	409
Arresters№1	10298	558	418
Arresters №2	7108	742	203

Choosing higher voltage classes the more and more heavy limitation of overvoltages from 2,5 line-ground voltage in systems of 500 kV up to 2,1 line-ground voltage in systems of 750 kV and up to 1,8 line-ground voltage in systems of 1150 kV is required from the point of view of technical and economic expediency.

According to results of laboratory, factory and operation tests the autotransformer of upgraded construction for limiting level of switching overvoltages 1,8 line-ground voltage and the arresters for outdoor switch-gear of 1150 kV are developed.

The development of norms and methods of tests [1] of electric strength of electric equipment complex of class 1150 kV was a result of large volume of researches and tests of external insulation with the help of different aspects and forms of voltage effects alongside with corresponding researches of internal insulation.

The manufacturer of the bushing – Moscow A. Barkov "Izolyator" Plant was established in 1896. Its main business area is the design and manufacture of high voltage bushings for power transformers, shunt reactors, high voltage circuitbreakers, complete SF6 insulated switchgears, manufacture of wall bushings, and also the import of electrical engineering equipment for the Russian power industry.

The Plant manufactures high voltage bushings for 20 to 1150 kV voltage classes and 150 to 20000 A currents with oil impregnated paper, SF_6 and solid internal insulation and with porcelain and composite outer insulation. The solid RBP and RIP insulated bushings product range consists of bushings designed for all voltage classes from 35 to 150 kV.

The Plant has a dominant status on the internal market of Russia and the CIS countries, being the manufacturer of OIP, RBP and RIP-insulated bushings with the optimal for the Russian consumers technical level and quality to price relation, and controls about 80% of the market.

The Plant is certified in accordance with the provisions of ISO 9001, ISO-9001-2000 and ISO-14000-2000 international standards.

The manufactured bushings characteristics conform to the requirements of IEC Publication 60137.

The bushings of 1150 kV are made according to specifications ТУ16-528.179-79. This specifications are approved on the 28th of March 1978 by AUEI as parent organization in the name of chief designer of equipment complex development of AC 1150 kV and coordinated with Department of Energy USSR, AUITC, ZTR, MEF.

In all excluding the prototype models 42 pieces of industrial bushings with height of the upper porcelain cover of 7.5 m and two experiment-industrial models with height of 9 m were made. The last bushing was made in 2004 for reserve phase of reactor and installed at «Itatskaya» ESS.

The overall dimensions and basic technical characteristics of bushing of 1150 kV such as ГМТ-20-1150/1250 У1 with broaching connection of transformer winding tape bushing cable are shown in

fig. 2 and in tab. 2.

* - Given testing voltage corresponds to level of switching overvoltages 1,6 operational line-ground voltage.

Rated voltage witch has impact on the insulation of the equipment during switching overvoltage can be determined by divisible number switching overvoltage $k.U_{(SW)R} = k\sqrt{2U_{ph}}$

Table. 2 Basic technical parameters of bushing ГМТ-20-1150/1250 У1

Name of parameters	Value
Voltage class, kV	1150
Rated current, A	1250
Internal insulation	OIP of condenser type
External insulation	porcelain
Installation height above sea level, m	500
Most operational line voltage, kV	1200
Most operational line-to-earth voltage, rms value, kV	693
Ratio of creepage distance to most line voltage, cm/kV	1,5
Test voltage of power frequency, rms value $U_{1\ min,\ 50\ Hz}$, kV	1150
Test voltage of power frequency, rms value $U_{1\ min,\ 50\ Hz}$, with level measuring of internal discharge, kV	900
Test voltage of full lightning impulse of positive and negative polarity at dried condition, maximum value, kV	2700
Gradual ascent of power-frequency voltage at dried condition and in the rain, kV or test with help of switching surge voltage, kV	1300 2100(1850*)
Test voltage concerning lifetime of insulation as for heat breakdown, $U = 1{,}1\frac{1200}{\sqrt{-}}$, kV	765
Test bending load, N	2500
Rated short time current, t = 5s., kA	7
Rated dynamic current, kA	17
Climatic version - У1 (ambient temperature), C°	-40 +40

Divisible number switching overvoltage

U_n, kV	500	750	1150	
k (without surge arrester)	2,5	2,1	1,8	Using for protection of arresters type PBMK (combined vent magnetic arrester)
k (with surge arrester)	1,75	1,75	1,6	Using for protection of ОПН (non-linear surge arrester)

When limiting level of switching overvoltages 1,6 line-ground voltage and atmospheric overvoltages up to 1,8 line-ground voltage the dimensions of tower and longitudinal insulation are reduced approximately to 20%. It is possible at use of non-linear surge arrester ОПН-1150 with limiting level of switching overvoltages 1,6 line-ground voltage. ОПН are made by joint-stock company «Kornilovskii» porcelain factory on ceramics basis with additive of zinc oxide having extremely high nonlinearity of current-voltage characteristic.

Voltage class of 1150 kV

k =1,8	$U_{(SW)R} = 1{,}8\sqrt{2}\cdot 693 = 1760\text{kV}$
k =1,6	$U_{(SW)R} = 1{,}6\sqrt{2}\cdot 693 = 1570\text{kV}$

Testing voltage of switching impulse is determined by cumulative coefficient K_k=0,85, covering comulative effect and aging of insulation during operation $U_{sw} = \frac{U_{(SW)R}}{K_k}$, then for k=1,6

$$U_{SW} = \frac{1570\text{kV}}{0{,}85} = 1850\text{kV}.$$

Consequently the height of the upper cover should be not less than 7,5 m.

To provide the reliable operation of insulations which were designed before 01.07.93 creepage distances for three types of apparatus for outdoor switch-gear were defined by GOST 9920-75.

Type of apparatus	А	Б	В
Creepage distance (cm/kV), not less than	1,5	2,25	3,1

Actual creepage distance L_x for bushings of 1150 kV with the height of the cover of 7,5 m is not less than 1880 cm, i.e.

Actual creepage distance

$$d_{sc} = \frac{L}{U_R} = \frac{1880\text{cm}}{1200\text{kV}} = 1{,}57\text{cm/kV}.$$

Nowadays GOST 9920-89 and IEC Publication 137 Standart defined four environment contamination

degrees for witch the following creepage distances are corresponded:

Environment contamination degree	Creepage distance (cm/kV), not less than
I - light degree of contamination	1,6
II - medium degree of contamination	2,0
III - heavy degree of contamination	2,5
IV – very heavy degree of contamination	3,1

In a view of the above even providing the necessary creepage distance for I degree of contamination the height of insulation will be 7,5 m if it is installed on the support with the height of 2,5m.

The design of bushing with paper oil insulation (OIP) is hermetic and under the gage pressure of transformer oil. The gage pressure and temperature changes compensation of oil volumes are carried out with the help of remote tanks of pressure inside which the steel welded diaphragms thick with gas. The immediate contact of gas to oil is absent. The internal insulation was made by the cable paper tape winding. The grading layers of aluminium foil for regulation of an electric field were loaded at defined diameters. For the best cooling and improvement of thermal stability the insulation was fulfilled from two sections divided with the help of oil channel. After drying of insulation in thermal vacuum furnaces the assembly of bushing, vacuum handling, filling by transformer oil and leakage test by pressure 0,33MPa was made. The porcelain covers of necessary height were made of separate parts by gluing with the help of epoxide compound. The overhanging length of upper cover edge is 90 mm. The covers were made from silicate porcelain (mass fraction Al_2O_3 up to 30%) corresponding to the requirements of GOST 20419-83 subgroup 110. The durability of glazed models not less: flexing strength -70 MPa, tensile strength - 35МПа. Is possible to note that in common the manufacturing technology and high requirements to oil and thermal vacuum handling are similar for all large bushings for voltage classes of 500, 750 and 1150 kV. The differences connected with different dimensions essentially have respect to duration of technological operations. So for example the duration of insulation drying for bushing of 500 kV is 19 day and common cycle of input manufacture of 1150 kV is about two months.

Underway the internal insulation design procedures were specified, the calculation of an electric field around of bushing was executed. The validity of calculations and correctness of the main scientific-technical and constructive decisions are confirmed by successful tests during the industrial electrotransmission of 1150 kV and powerful test beds (PTB) in Tolyatti city and «Belyi Rast» ESS.

Now the design of bushing can be essentially modernized. First of all the upper and lower porcelain covers can be subjected to modernization. Besides last years Moscow A.Barkov "Izolyator" Plant manufactures the bushing up to 500 kV without remote tanks of pressure. At that as compensator in the upper part the gas cushion by analogy with bushing emitted western firms is used. In this case there is immediate contact of gas to oil that brings to subsolution of gases in oil up to balanced condition. Such decision is possible and for bushing of superhigh voltage of 750 kV and 1150 kV. However for climatic conditions of Russia with sharp temperature differences for bushing with gas cushion working at low pressure the reducing of internal insulation electric strength is possible. It is connected with opportunity of gas bubble formation in oil at sharp decrease of temperature. In Russia there was a negative experience of current transformers operation of some of Western firms with use of gas cushion. Now Moscow A.Barkov "Izolyator" Plant has designed the high-voltage bushing of 750 kV of two constructions: with gas cushion and with use of steel welded diaphragms. For development of high-reliable bushing with gas cushion of 750 kV and 1150 kV the additional researches with the help of full-scale specimens are necessary.

Taking into account the experience of exploitation it is possible to come to the conclusion that the most preferable is the design of the 1150 kV bushing under pressure with the remote tanks.

Literature:

1. Guiding Document РД 16.556-89. An electric

equipment of alternating-current for voltage of 1150 kV. The requirements to insulating strength and methods of tests, Moscow, publishing house of standards, 1989.

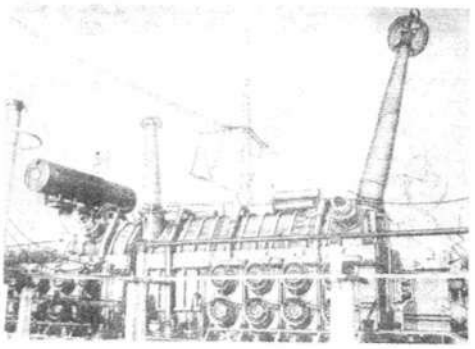
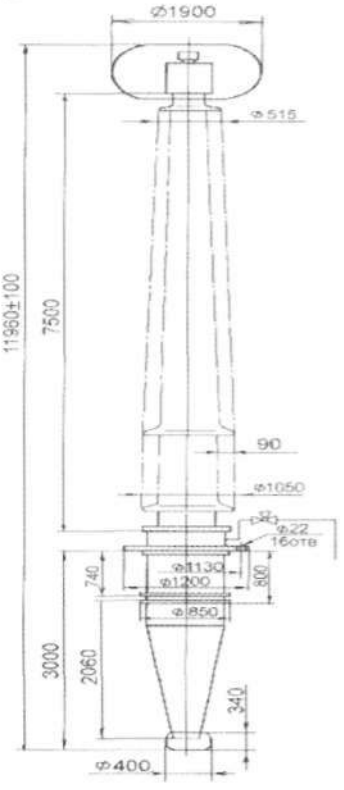
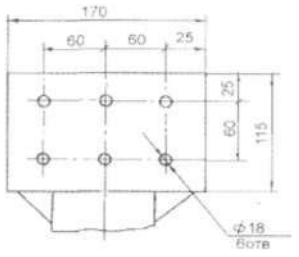
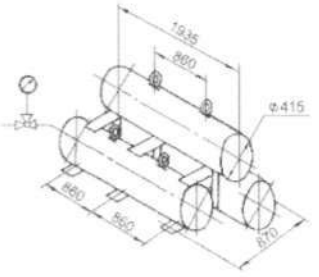


Fig. 1 Autotransformer for 1150 kV





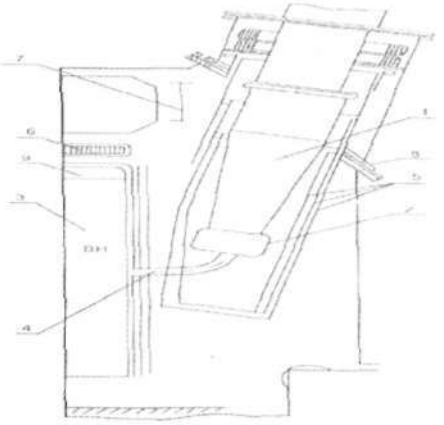
Connection clamps



Weight of bushing – 8130 kg

Weight of remote tank of pressure – 1130 kg

Fig. 2 Dimension, installation, connection and weight of bushing type ГМТ-20-1150/1250 У1



1- bushing; 2- bushing shield; 3- winding BH; 4- tap lead; 5- insulating cylinders; 6- moulding ring; 7- console; 8- edge of jet; 9- capacitance ring;

Fig. 3 Standard construction of bushing installation of 500-1150 kV