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Department of Electrical Engineering

MASTER’S THESIS

Use of innovative High Voltage components in GOST standard market.

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ABSTRACT

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In Russia there are more than twenty thousand primary substations 35/110 kV and 10/110 kV. According to the Government Plan of Power Industry Development until 2020 year more than hundred new substations will be installed every year and even more renewed. The goal of this Thesis is to find out in this business environment what are the technology opportunities of prefabricated substation modules in new substations or in modernization of old substations in Russia.

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ABBREVIATIONS

IEA	International Energy Agency
MEDT	The Ministry of Economic Development and Trade of the Russian Federation
MIE	The Ministry of Industry and Energy of the Russian Federation
FTS	The Federal Tariff Service
RFSETAS	The Russian Federal Service for Ecological, Technical and Atomic Supervision
RAO UES	Unified Energy System of the Russian Federation
HVDC link	High-voltage direct current link
SA	Surge Arrester
SF6	Sulfur hexafluoride gas
WCB	Withdrawable circuit breaker
DCB	Disconnecting circuit breaker
LTB	Trolley mounted standard circuit breaker
HPL	Single pole operating standard circuit breaker
LEM	Line entrance module
IEC	International Electrotechnical Commission
ANSI	American National Standards Institute
PASS	Plug And Switch System
SBB	Single Bus Bar
CT	Current transformer
AIS	Air-insulated switchgear
GIS	Gas-insulated switchgear
DBB	Double Bus Bar
LCC	Life cycle cost
ISO	International Organization for Standardization
CENELEC	The European Committee for Electrotechnical Standardization
SNiP	Building codes and regulations
PUE	The rules for arrangement of electrical installation
GOST	Russian Government Technical Requirements

1. Introduction.

In open market conditions on decision making stage economic feasibility and innovative technical solutions are brought to the forefront now. Within recent decade power industry in Russia was in heavy economic circumstances what reflects on power industry development of the country, meanwhile outages and uninterruptible customers supplying issue become sharp as never before. At the present time, substantial sums are allocated from federal budget on power industry modernization and development. In connection with this, the topical question is to define perspectives and opportunities on GOST standard market as well as technical parameters, conformance to Russian government technical requirements and advantages and disadvantages of high voltage components produced abroad.

With this aim in view, modernization possibilities of typical bridge type substation 110 kV with innovative high voltage switchgear modules Compact, Combine, PASS and COMPASS are considered in this Thesis in full conformity with Russian government technical requirements, in the first instance, GOST and PUE.

2. Russian energy industry overview. Features and possibilities.

2.1 General energy system situation analysis in Russia.

Intensive development of fuel and energy industry in Russia during the period from the 60s to 80s of the 20th century (e.g. power stations, substations, thermal and electrical network systems, oil and gas pipe lines and etc.) promoted mighty base of power energy supply creation. At a later stage, renovation and modernization process of already existing energy key assets and installation of new ones considerably decelerated in relation with general economic situation and fell behind ageing of energy units constructed earlier so that the average level of deterioration of equipment exceeded 57,3 percents by 2007 year, see Fig. 2.1.

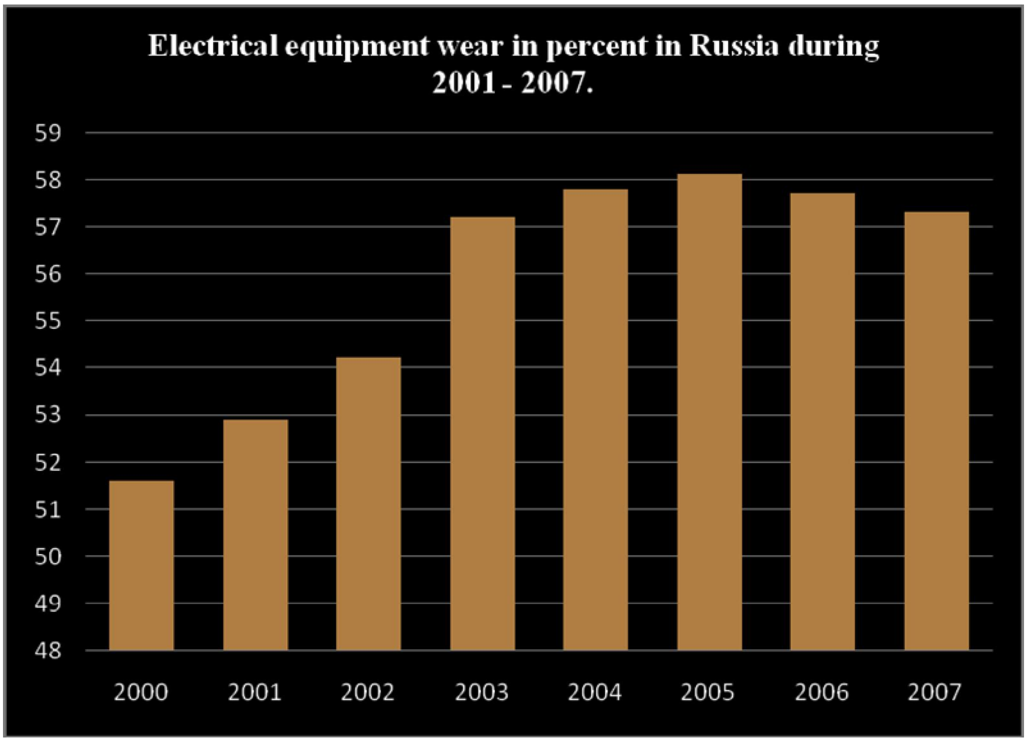

Figure. 2.1 The average level of deterioration of equipment in Russia in period 2001 – 2007.

According to the data from the All-Russian Institute of Heat Engineering the greatest portion of equipment runs now is the equipment that has being used for more than twenty years, about one third of it has being operated no less than thirty years and ten percent are under operation for more than forty years. Thus far depreciation of overhead lines and cable lines exceeds 55% and 53% respectively. Also a large-scale reconstruction of transmission and distribution networks and substations is needed urgently.

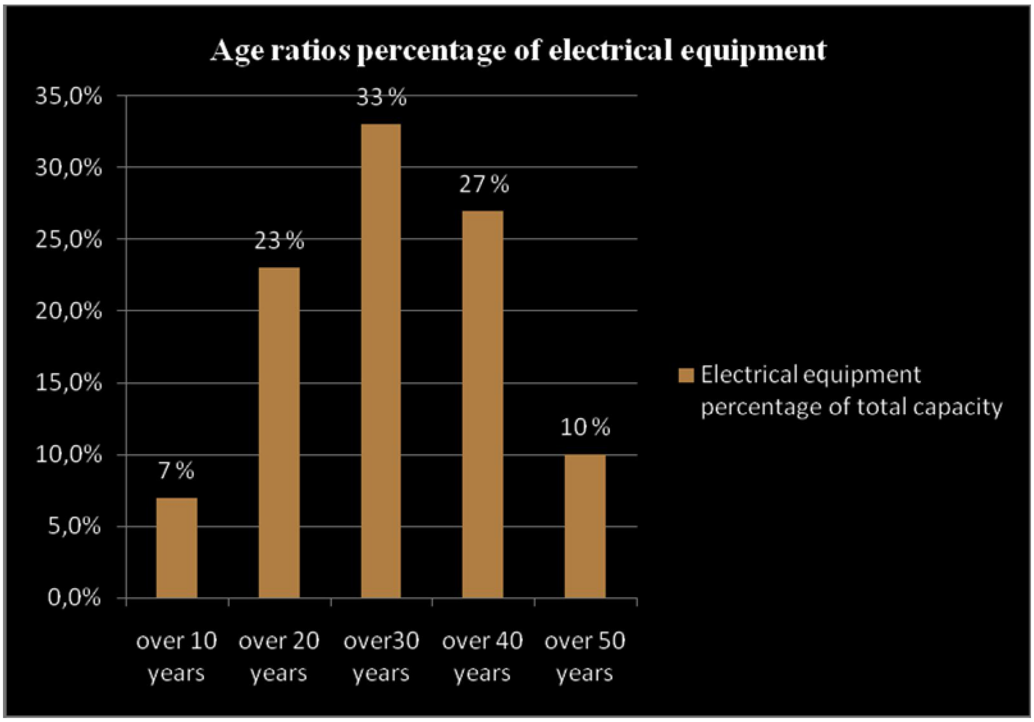

Figure 2.2. Age ratios percentage of electrical equipment.

A considerable gain in electricity consumption volume is one of the main long-term tendency in global economy development as well as in modern Russia which is going through respectable economic advance now the electricity consumption after lingering turn-down during 1990 – 1998 years grows steadily and according to the International Energy Agency (IEA) forecast has already reached in 2005 the consumption level of 1993 year. Although, generating capacity in Russia still surpasses its consumption needs the difference in generating and consumption level is getting smaller and smaller permanently. [4]

According to judgemental forecast from The Ministry of Economic Development and Trade of the Russian Federation (MEDT) the electricity consumption volume in Russia was expected to reach the level of 46-50 billion kWh during the period 2000 – 2006, but the real average gain in electricity consumption volume happened to be more than in 1,5 times higher and set on the level of 73 billion kWh. And to addition to it in many regions (e.g. Belgorod, Kaliningrad, Leningrad regions and, Moscow and Moscow region) the level of electricity consumption has already exceeded this forecast in several times what in such a condition due to progressing wear and tear and the lack of new generating capacity installations create prerequisites for electricity deficiency.

In such a condition the state energy security has to be assured and special arrangements on wear and tear dynamic correction have to be made urgently to prevent from possible breakdowns of energy supplying and considerable damage in industry and public sector from unexpected outages.

Taking into account capital-using bias in technical progress, long payback period of an investment project and rather long period of new power capacity installation, distinct value of electricity for modern society to maintain comfort and high living standards, the early planning of reasonable investment program and diversification in further development of energy industry is required.

In consideration of the above described reality The Ministry of Industry and Energy of the Russian Federation (MIE) in consort with The Ministry of Economic Development and Trade of the Russian Federation (MEDT), The Federal Tariff Service (FTS) with the support of the Federal Agency for Nuclear Energy and The Russian Federal Service for Ecological, Technical and Atomic Supervision (RFSETAS) worked out "The General Plan of Power Energy Installation in Russia until 2020 year"

The Government of the Russian Federation in order N215-p from the 22nd of February 2008 approved "The General plan of power energy installation in Russia until 2020 year". For the period until 2011 it is planned to allocate a budget of 700 billion roubles for purchasing key electrical and heat and power equipment and 195 billion roubles for purchasing materials and equipment for network systems. Even for Soviet Union, let alone modern Russia, this program is considered as an unprecedented project.

Thus, according to "The General plan of power energy installation in Russia until 2020 year" it is planned to install no less than 41 GW of new additional capacity as well as to modernize old substations and to renew transmission and distribution networks.

It is expected that considerable part of electrical and, heat and power equipment will be bought on open market from Russian and foreign suppliers. The main principle of purchasing is fair tender as a main factor to intensify competitive market and active competition for orders so that RAO UES of Russia (Unified Energy System of the

Russian Federation) may secure favourable environment for its project and stimulate private business interest, making large-scale business buying with high transparent.

2.2 General plan of power energy installations in Russia until 2020 year.

General plan of power energy installation in Russia developed by The Ministry of Industry and Energy in association with The Ministry of Economic Development and Trade, Federal Tariffs Service and Russian Federal Service for Ecological, Technical and Atomic Supervision, is expected to bring electrical energy industry of Russia to a new leading edge level.

In its entirety, the General plan of power energy installations in Russia is based on prediction of gain in electricity consumption volume in the Russian Federation on the level of 4% per every year and allows for consumption in plan to settle on the level of 1426 billion kWh by 2015 (the base case) with possible increasing in electricity consumption volume within the prescribed period up to 1600 billion kWh (the case of maximum consumption level), nevertheless, the dynamic of gain in electricity consumption volume may differ significantly depending on region.

In the General plan of power energy installations in Russia takes cognizance of all plans on constructing nuclear and hear and power stations with a capacity of more than 500 MW as well as hydro power stations with a capacity of more than 200 MW.

Moreover, in this document were determined location and implementation deadlines for large interregional overhead lines on 110 kV and higher, transmission and distribution networks for fresh installed substations to avoid bottlenecks in the Unified Power System of the Russian Federation. [2]

The General plan of power energy installations in Russia until 2020 year is a well-balanced plan on constructing generating power stations and electric grid units within the prescribed period on the base of prediction of gain in electricity consumption volume in the Russian Federation as on the whole and in its regions separately to determine main goals, aims and basic undertaking to develop energy industry with highly improved efficiency. The main goal of the General plan of power energy installations in Russia is to achieve reliable and effective customer electrical power supply and to meet industry demand in electricity and heat energy.

The major goal of the General plan of power energy installations in Russia is to form on the base of already existing potential of energy industry and settled priorities in power energy development, reliable, economically effective and making the most of fuel resources reasonable structure of generating capacity and power grid units as well as creating necessary conditions to avoid predicted lack of energy and capacity in the most sufficient way.

Within the framework of the formally approved “red line” of the long-term state policy in energy industry the following main priorities of the General plan can be listed:

- priority development of energy industry and creating a reasonable economically feasible structure of generating capacity and power grid units for reliable and effective customer electrical and heat power supply;

- fuel balance optimization by means of applying maximum possible potential of development nuclear, hydro and heat and power generating station and natural gas usage decreasing in the fuel balance of the industry;

- creating net infrastructure developed in priority rates when comparing with power station development to ensure customers’ and companies’ full role in functioning of electricity market and to enforce energy system interconnections what would guarantee reliability of mutual deliveries of electricity and power between Russian regions with expanded export possibilities as well;

- minimization of fuel use per kwhr by means of implementation and application of modern high-efficiency equipment on solid and fluid fuel;

- to decrease unavoidable environmental impact of energy industry by means of the most effective usage of fuel and power resources, optimization of management structure in energy industry, technical retooling and removal outdated equipment from service, intensification of environmental protection measures and carrying-out a programme on renewable energy sources application;

Priority development of constituents of the Russian Federation in the Northern-West and the Central part of the country is concerned with mighty production possibilities and high scientific and technological potential. On the territories of these regions it is planned to extend already functioning industrial production and to construct the new ones including power-consuming industry technologies.

The predicted gain in electricity consumption volume can be explained foremost by considerable increase in electricity consumption of Tyumen region accounts almost a half of the total gain in electricity consumption volume by 2020 year in the Western Siberian province (the Western Siberian oil-and-gas province remains leading oil and gas basis of the Russian Federation), where oil and natural gas extraction, usage of electricity-consuming technologies in oil and natural gas extraction and development of transport infrastructure permanently increase. Growth of population in Tyumen region will increase electricity consumption volume in public and services sectors.

Large investment projects implementation on expansion of production, modernization and development of metallurgical production in Sverdlovsk and Chelyabinsk regions will bring to bear considerable influence on the whole economy situation of the Ural region.

In the Far East region the gain in electricity consumption volume within the period under review is expected to grow in 1,9 times at the same time, the region’s share in electricity integrated demand will grow slightly.

In near-term perspective the basic electricity demand in the Siberian region will be formed as a result of fast developing large-scale industry accounts more than a half of total integrated volume of electricity consumption predicted to reach by 2020 year. New large power-consuming aluminium plants, chemical gas and oil treatment plants on the base of gas condensate fields, metals smelters and several pulp and paper plants are planned to construct in the Siberian region in the nearest time.

Still electricity consumption volume may increase in the regions of Siberia and Far East by means of fast gain in electricity consumption concerned with expected priority economy development of those regions. Availability of large stock of natural resources – oil and gas, nonferrous metal ores, non-metallic materials and forest can become a base for expansion of production of power-consuming industry.

The planned gain in electricity consumption in Volga region is slightly low than average in Russia what can be completely explained by specific industry structure on that territory characterized by predominance of manufacturing activity including mechanical-engineering industry.

The planned electricity demand in the South Federal region depends on industry expansion by means of constructing new metals smelters and further development of infrastructure facilities including building new and reconstruction health resort, hotel and recreational complexes.

In the General plan is also determined the main goals of export-import energy policy of the Russian Federation.

The further increasing in electricity export to Finland within 2016 -2020 is planned with help of constructing on the base of Knyazhegubskaya substation 330 kV additional high-voltage direct current link (HVDC link) of capacity 500 MW and overhead lines 400 kV from the HVDC link to Pirttikoski (Finland) with length of 175 km to State frontier. This will facilitate electricity and power transmission in the volume of 3 billion kWh and 500 MW and electricity and power exchange Kol’skaay power-transmission system and power-transmission system of Finland.

After 2020 year it may be found possible to install another high-voltage direct current link (HVDC link) of 500 MW capacity and implement conductor stringing of the second line 400 kV that will make potential to transmit up to 1 GW of power and increase electricity transmission up to 6 billion kWh to power-transmission system of Finland.

Electricity and power delivery to Kaliningrad power-transmission system through Lithuania power-transmission system during the period 2007 – 2009 is found optimal.

Under the circumstances of possible electric power systems interconnection between Lithuania and Poland for higher reliability of electric power delivery to customers in Kaliningrad region the double-circuit power line construction 400 kV is foreseen to interconnect Kaliningrad and Poland power-transmission systems what will let either to regulate electricity and power between Kaliningrad and Poland power-transmission systems or transmit electricity and power superfluity to European countries.

Taking into account the predicted gain in electricity and power consumption level in Russia and the lack of generating capacity within the period of fast expansion in energy units construction and because of their high capital-output ratio it is expected to import electricity and power from Kazakhstan and Ukraine power-transmission systems.

The planned large-scale electricity and power export to China will promote intensive economic progress and further energy industry development in regions of Eastern Siberia and Far East, installation of new power generating capacities working on local fuel resources and reinforcement of interstate connections and internal network of Unified Energy System.

The main goal of electrical energy industry within considered period of time until 2020 is to create efficient and thoroughly reasoned structure for reliable heat and power energy delivery of all customers.

In the General plan the base principles to form rational structure of generating capacities are the following:
Development of generating capacities, reliable heat and power energy delivery of all customers with permanent control if the settled technological conditions and standard figure of merit of electrical energy are satisfied.

The highest possible development of generating capacities which do not use organic fuel resources – is nuclear and hydro power stations.

The General plan is oriented on implementation the most sufficient and progressive equipment for power stations and substations modernization. The equipment mounted during retooling and modernization and installation new power stations and substations must provide high reliability and sufficiency and also to improve environmental impact.

Network 750 kV evolvement in the European part of the Russian Federation is allowed for enforcement of Unified Energy System on the whole and interconnection between Northern-West and Central power-transmission systems in particular whereas networks 500 kV will be employed for enforcement of the bulk electricity system and to develop interconnection tie lines.

Network 330 kV will keep carrying out backbone power transmission functions and transmit electricity and power from large substations to customers supplying from Central and Northern-West power-transmission systems with enforcement interconnections between over mentioned systems and installation additional electricity transmission lines 330kV.

The main tendencies in evolvement network 220 kV will be in strengthening distribution functions and energy supplying from large substations to customers.

In isolated electricity system of several regions (e.g. Far East, the Komi Republic and Arkhangelsk region) power-transmission systems 220 kV will carry out backbone power transmission functions.

The main direction in development network 110 kV is to extend and spread it all over Russian territory in order to improve reliability of customers supplying with installation considerable amount of new and far-reaching modernization of overage retrofit substations 110 kV.

According to the base case of predicted electricity consumption volume for electricity and power transmission in the nearest time it is needed to construct no less than 25,7 thousand km of overhead super grid lines to transmit electricity and power from fresh installed and modernized generating power stations, 22,3 thousand km of overhead power-transmission system lines 330 kV and higher to improve reliability of customers supplying and 16,1 thousand km of overhead power-transmission system lines for enforcement of Unified Energy System and inter state connections as well.

In summary, within considered period of time the total capital investments requirement for energy industry development in the base case is estimated on the level of 11,6 trillion roubles. And total capital investments demand for construction electric-power units within 2006 - 2020 in the base case is estimated on the level of 9,3 trillion roubles. [3]

2.3 Technology opportunities of prefabricated substation modules in new substations or in modernization of old substation in Russia.

In these latter days funding for energy industry in Russia increased essentially. Energy companies gather momentum in modernization and installation new generating capacities and transmission and distribution networks. That is why research for shortcut methods, possibilities what may shorten designing time, accelerate the pace of constructing and implementation period is actual more than ever. In solving this problem a new leading edge approach may help what is in elaboration and promotion of prefabricated engineering solution on the base of typical substations on the market.

It is crucially important especially in circumstances of high competition to suggest customers already developed and prefabricated engineering solution where must be

reflected the most frequently used engineering solution on installation and modernization typical substations.
In case when natural or others circumstances may not require special correction changes in installation or modernization process, design engineers having systematized previous working experience can provide customers with demonstration of prefabricated engineering solutions for typical substations to choose. These engineering solutions must be worked out well, confirmed by State Authorities and do not require additional coordination what will save a lot of time.

Main advantages of prefabricated engineering solutions for typical substations:

- Reduction of installation period of substation in several times;
- Reduction of time for administrative decision-making;
- Minimization time of equipment delivery due to beforehand order of primary equipment what usually requires rather long period according to typical projects after the main electric circuit has been chosen;
- Reduction of time for project adaptation;
- Volume reduction of building and construction works, wiring and commissioning works acceleration;
- Decreasing of environmental impact using compact solutions, sharply diminishing quantity of building waste, due to application of prefabricated engineering solutions construction engineering impact becomes lower.

In summary, installation time of substation 110 kV owing to prefabricated engineering solutions declines considerably.
Main features of electric power supply units design.

- Design of electric power supply units is based on requirements to secure reliable and sufficient operation of every electrical installation.
- As a rule, design solution is based on typical projects.
- Following to up-to-date established state standards design engineers has to make an optimal decision for each case paying attention to particular working conditions, wiring plan and layout, creeping distances and etc.

- Determination of the main points concerning electrical and mechanical requirements, as well as accident prevention and safety requirements and admissible environmental impact.

2.4 Summary.

Intensive development of fuel and energy industry in Russia was during the period from the 60s to 80s of the 20th century.

Renovation and modernization process of already existing energy key assets and installation of new ones considerably decelerated due to general political and economic situation.

In the whole statistic data analysis brings to a conclusion that the greatest portion of equipment runs now is obsolete equipment. So far depreciation of overhead lines and cable lines exceeds 55% and 53% respectively, the average level of deterioration of equipment already exceeded 57,3 percents by 2007 year. If gain in deterioration of equipment keeps growing in further, it can reach a critical level what makes possible breakdowns of energy supplying and considerable damage in industry and public sector from unexpected interruptions.

In such a condition the General plan of power energy installation in the Russian Federation was developed by The Ministry of Industry and Energy in association with The Ministry of Economic Development and Trade, Federal Tariffs Service and Russian Federal Service for Ecological, Technical and Atomic Supervision to bring electrical energy industry of Russia to a new leading edge level.

The General plan of power energy installations in Russia is based on prediction of gain in electricity consumption volume in the Russian Federation on the level of 4% per every year and allows for consumption in plan to be settled on the level of 1426 billion kWh by 2015 (in base case) with possible increasing in electricity consumption volume within the prescribed period up to 1600 billion kWh (in case of maximum consumption level)

The construction and modernization volume of energy industry equipment multiplies considerably in the nearest time.

In summary, within the period of 2006-2020 the total capital investments requirement for energy industry development in the base case is estimated on the level of 11,6 trillion roubles. And total capital investments demand for construction electric-power units within 2006 - 2020 in the base case is estimated on the level of 9,3 trillion roubles.[3]

Market demand on modernization and constructing projects will grow significantly. Experts expect that considerable part of electrical and heat and power equipment will be bought on open market either from Russian and foreign suppliers with the main principle of fair tender as the main factor to intensify competitive market and active competition for orders.

In such a condition of high competition it becomes absolutely necessary to suggest customers already developed and prefabricated engineering solution based on the most frequently used engineering solution on installation and modernization typical substations to promote and gain competitive advantages on the market.

3. Introduction of ABB innovative HV modules. Features.

3.1 Compact.

Switchgear is a basic component of every substation, where electrical voltage is switched and regulated. Compact switchgears are applied for the primary network. According to the conception of further development compact switchgears are scalable and combined with other equipment revealing unique concept of flexible, modular compact switchgears. [5]

3.1.1 Withdrawable and disconnecting circuit breakers for compact air-insulated switchgear, 72.5 – 420 kV. Overview.

Due to its mechanical complexity, the circuit breakers, traditionally for substation solutions, were previously the devices that needed the most working expenditures and maintenance. The latest advances in product development for circuit breakers have improved their technical performance to such a state when the breakers are nearly maintenance-free and the need for maintenance has been decreased.

Typically, in traditional substations, in order to be disconnected during maintenance disconnectors are still installed at both side of the circuit breaker. The contacts of conventional disconnectors also require the most maintenance as they are not shielded from the influence of the surrounding environment.

To improve operational availability innovative combined units have been created with the special capability for substations designing without conventional disconnectors.

Figure 3.1 Compact 72.5 kV switchgear assembly. .[7]

Thus, a new compact switchgear assembly 72.5 kV with circuit breaker (CB), surge arresters (SA), instrument transformers and earthing switches on one frame has been developed.

Depending on bay connected to the busbar directly and type of bay itself this new module could be equipped with different high voltage apparatus on request. Comparing to a conventional switchyard layout, innovative compact switchgear assembly being mounted on a common solid frame is able to save space up to 25 %.

Even those disconnectors that require intensive maintenance and connected directly to a busbar could be eliminated and replaced with new compact switchgear assembly, what reduces the time when it is needed the busbar to take out of service and allows the solutions to be far more simpler. On a base of SF6-insulated innovative circuit breakers, new alternatives and opportunities can be offered. [6]

3.2 Combine.

WCB - withdrawable circuit breaker is intended to be a part of a complete type-tested bay of substation and being trolley-mounted it can be easily driven with use of motorized operating mechanism between the both positions when it is connected and disconnected. The fixed primary contacts do not require intensive maintenance.

DCB is the other alternative disconnecting circuit breaker, where the contacts of breaker, being protected in the breaking chamber with SF6 insulation, also guarantee the switching function.

Thus, DCB is intended to replace the conventional combination of surrounding disconnectors at both side of the circuit breaker. Combination of a motorized grounding switch, fail-safe interlocking system and clear contact position indication provide comprehensive safety.

In the interest of maximal safety the circuit breaker is fitted with earthing switches and the breaking chamber has the integrated disconnecting function in. For overvoltage protection the combine circuit breakers are equipped with surge arresters. Also both capacitive voltage transformer and current transformer are used.

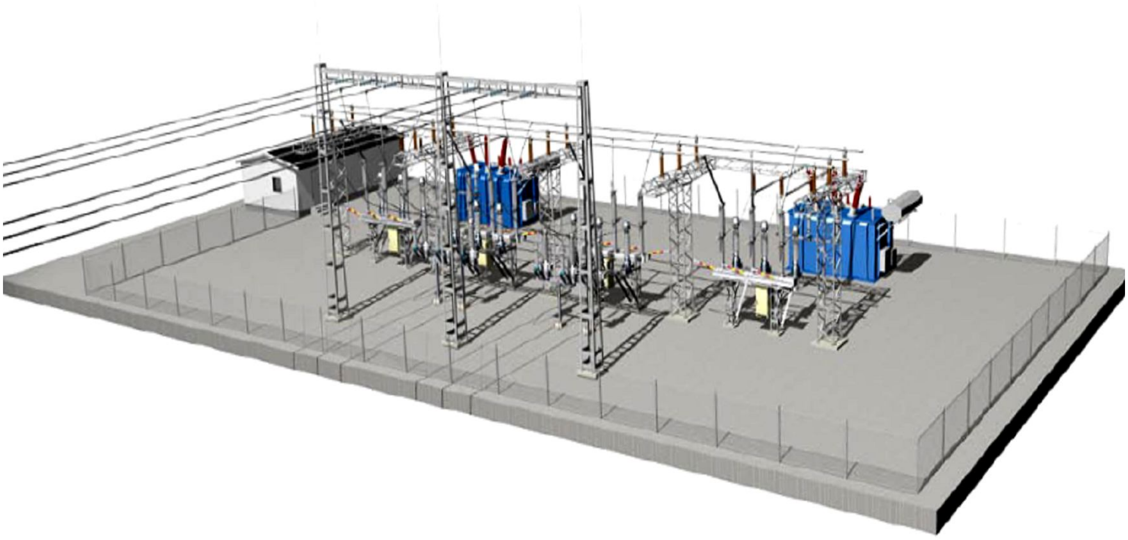

Figure 3.2 Substation without conventional disconnectors. [6]

New opportunities are got for compact substations design by means of withdrawable and disconnecting circuit breakers which simplify single, double or other configurations busbar layouts. These modules require less effort within period of installation and maintenance and stand out for less impact on the environment as a result of small substation surfaces and low material requirements.

3.2.1 WCB – withdrawable circuit breaker for 72.5 – 300 kV.

The withdrawable circuit breaker or WCB 72.5 – 300 kV is composed of LTB or HPL type trolley-mounted standard circuit breaker. Motorized, spring operating mechanisms are used for switching - opening and closing operation. The overhead line connection and connection to busbar are performed contacts not requiring intensive maintenance. Motor unit performs movement from the connected to the disconnected position and when the circuit breaker is closed motor unit becomes interlocked.

Figure 3.3 Withdrawable circuit breaker for 72.5 – 300 kV [6].

For some reasons two configurations of withdrawable circuit breakers have been designed: high-built and low-built withdrawable circuit breakers solutions. The former is applied for air insulated outdoor substations and the latter for indoor, usually SF6-insulated substations.

Thorough type-tests in compliance with international standards are carried out for the circuit breaker bay including busbar. All essential functions for a circuit breaker bay are included in this high voltage equipment. The withdrawable circuit breakers LTB 72.5-145 kV are performed with spring operating single-pole mechanism, three-pole operation motor drive is represented in withdrawable circuit breakers on higher voltage level.

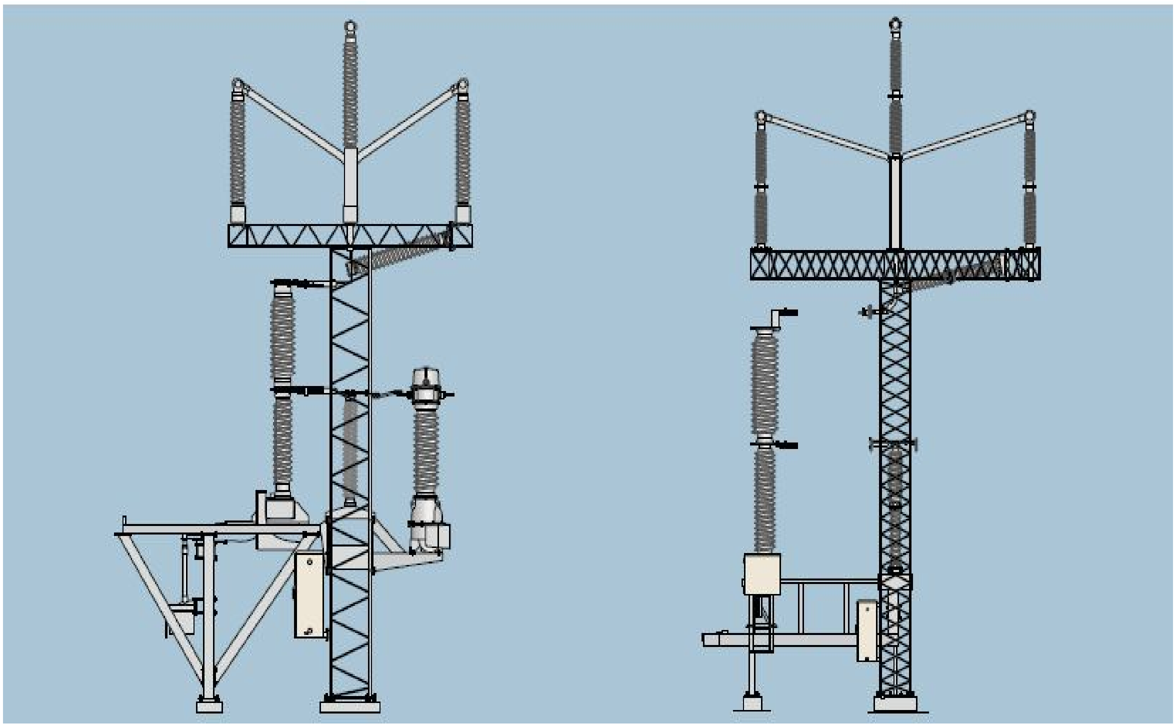

Figure 3.4 Withdrawable circuit breaker LTB 72.5 – 145 kV [6].

A circuit breaker bay includes the following equipment:

- Trolley with moving mechanism
- Maintenance-free fixed and movable primary contacts. [6]

The following options are available:

- IMB- type current transformer with oil insulation, which is installed on the common module’s frame with circuit breaker
- High-built solution for outdoor substations

- Low-built solution for indoor substations
- Controller for adjustable switching - opening and closing operations.

Line entrance modules (LEM) can include a capacitor voltage transformer with oil-insulation, surge arrester and grounding switch.

Table 3.1 Technical data for withdrawable circuit breakers. [6]

	WCB LTB 72,5 - 145	**WCB LTB or HPL 245**	**WCB HPL 300**
Type of operation	Single- or three-pole	Single pole	Single pole
Standard	IEC, ANSI	IEC, ANSI	IEC, ANSI
Rated voltage	72,5 – 145 kV	245 kV	300 kV
Rated current	3150 A	3150 A	3150 A
Rated breaking current	40 kA	50 kA	50 kA
Ambient temperature	-30 – +40 °C	-30 – +40 °C	-30 – +40 °C

Withdrawable circuit breakers may also be supplied for other ambient temperatures, upon request.

3.2.2 Combined - disconnecting circuit breaker DCB for 72.5 - 420 kV.

Substantially, the disconnecting circuit breaker (DCB) is a circuit breaker of standard LTB or HPL- type. Disconnecting circuit breaker is also type-tested in compliance with international disconnector standards and expected to replace the conventional combination of separate disconnectors at each sides of circuit breaker. It brings advantages of compact substation layout with increased level of availability due to low maintenance requirements.

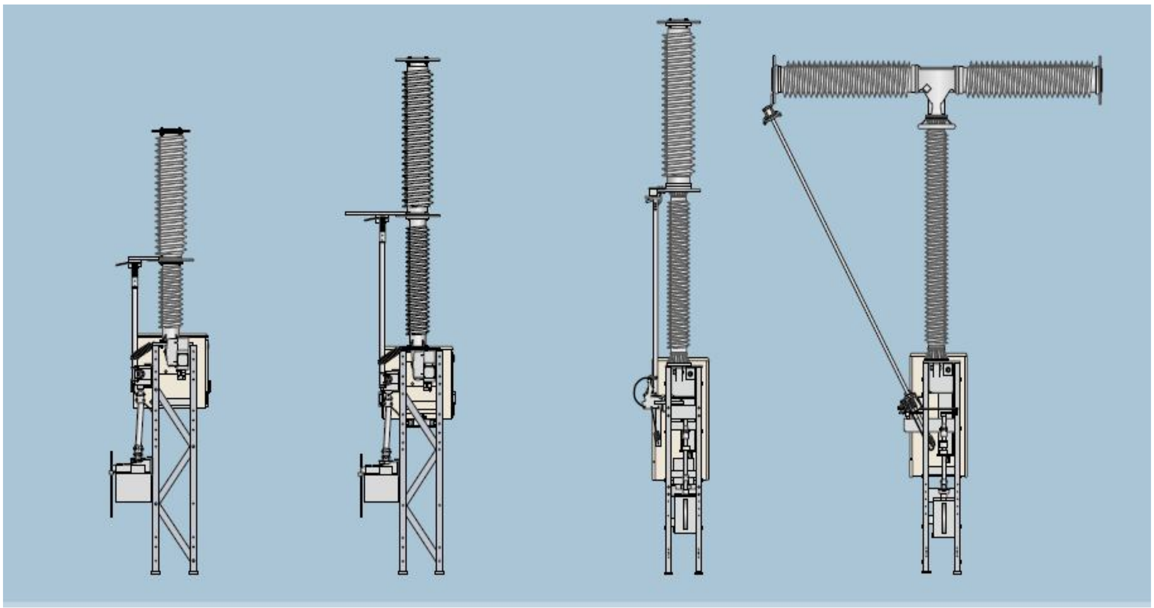

Figure 3.5 Disconnecting circuit breaker (DCB) for 72,5 – 420 kV [6].

A visible motor-operated grounding switch standing out for its considerable mechanical strength and low maintenance requirements is installed on the disconnecting circuit breaker and spring operating mechanism can be single- or three-pole operating with digitally controlled operating mechanism. The circuit breakers on voltage level up to 245 kV have one breaking chamber per phase and two breaking chambers per phase on higher voltage level 362–420 kV, consequently. [6]

Disconnecting circuit breaker can be called equal in terms of ratings for voltage and current with the LTB and HPL circuit breakers. The disconnecting circuit breakers completely satisfy the IEC and ANSI standards requirements for disconnectors and circuit breakers and successfully tested in accordance with the IEC standard refers to testing of disconnecting circuit breakers. It was also verified through type test that serviceable life for the disconnector or circuit breaker contacts is on approximate level of 10,000 mechanical operations.

The personal safety is assured by visible grounding showing that the disconnected part of the substation is not energized. Locally padlocked and remotely controlled interlocking system brings an advance of preventing from accidental switching of the grounding switch and circuit breaker. The positions of the circuit breaker and the interlocking system are visually controlled by means of mechanically interlinked indications. The circuit breaker's composite insulators stand out, besides good dielectric properties, withstand external damage and various mechanical stresses.

In perspective, within the process of conventional disconnectors eliminating there will appear the unique opportunities of low maintenance requirements, reducing installation period and simplifying substation layouts and, decreasing service and maintenance costs what can be translated into reality by innovative switchgear module installations.

. *Table 3.2 Technical data for disconnecting circuit breaker (DCB) [6].*

	LTB Combined 72.5	LTB Combined 145	HPL Combined 170 – 300	HPL Combined 362 – 420
Type of operation	Three-pole	Three-pole	Single-/three-pole	Single pole
Standard	IEC, ANSI	IEC, ANSI	IEC, ANSI	IEC, ANSI
Rated voltage	72.5 kV	145 kV	170 - 300 kV	362 - 420 kV
Rated current	3150 A	3150 A	4000A	4000A
Rated breaking current	40 kA	40 kA	50 kA	50 kA
Ambient temperature	-30 – +40 °C	-30 – +40 °C	-30 – +40 °C	-30 – +40 °C

Disconnecting circuit breakers may also be supplied for other ambient temperatures, upon request.

3.3 PASS - Plug And Switch System.

PASS M0 is the innovative primary equipment created as a result of a different thinking on the substation as a complete integrated system.

The best functionality of the bay is achieved by limiting the number of equipment to really necessary units and a great range of all possible layouts of substation can be realized through its modular design.

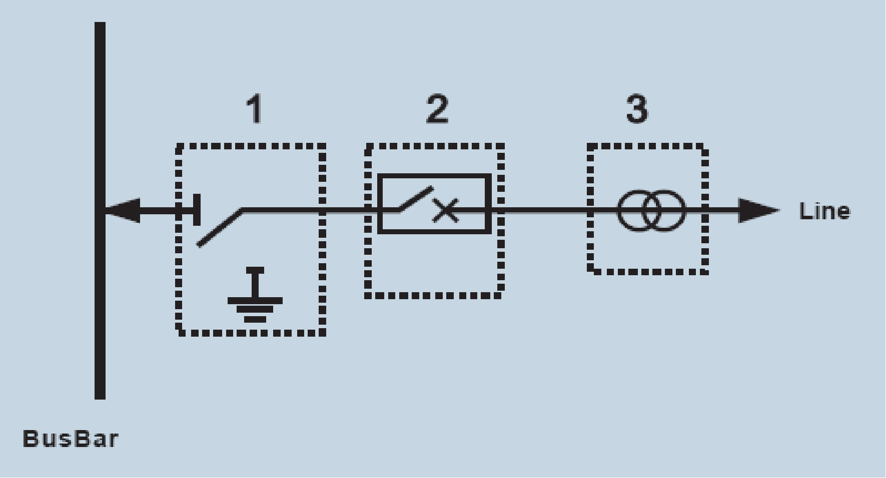

Figure 3.6 PASS M0 in its standard configuration (Single BusBar - SBB):

1: Combined disconnector/earthing switch

2: Circuit-breaker (CB)

3: Current transformer (CT). [8]

Large accumulated experience in air-insulated switchgear (AIS) and gas-insulated switchgear (GIS) design produced PASS (Plug And Switch System) or can also be interpreted as “Performance And Save Space”: demonstrating that almost any layout of substation can be organized to make use of available space more efficient.

Extensive experience in research and development, manufacture and operation management also assures a high performance of produced PASS switchgears. The main advantage of PASS over others is its modular design and compactness, what brings expanded number of functions implemented in one module:

- Bushings to connect either one or two bus bar systems
- One circuit-breaker
- One current transformer
- One or more combined disconnector/earthing switches [8].

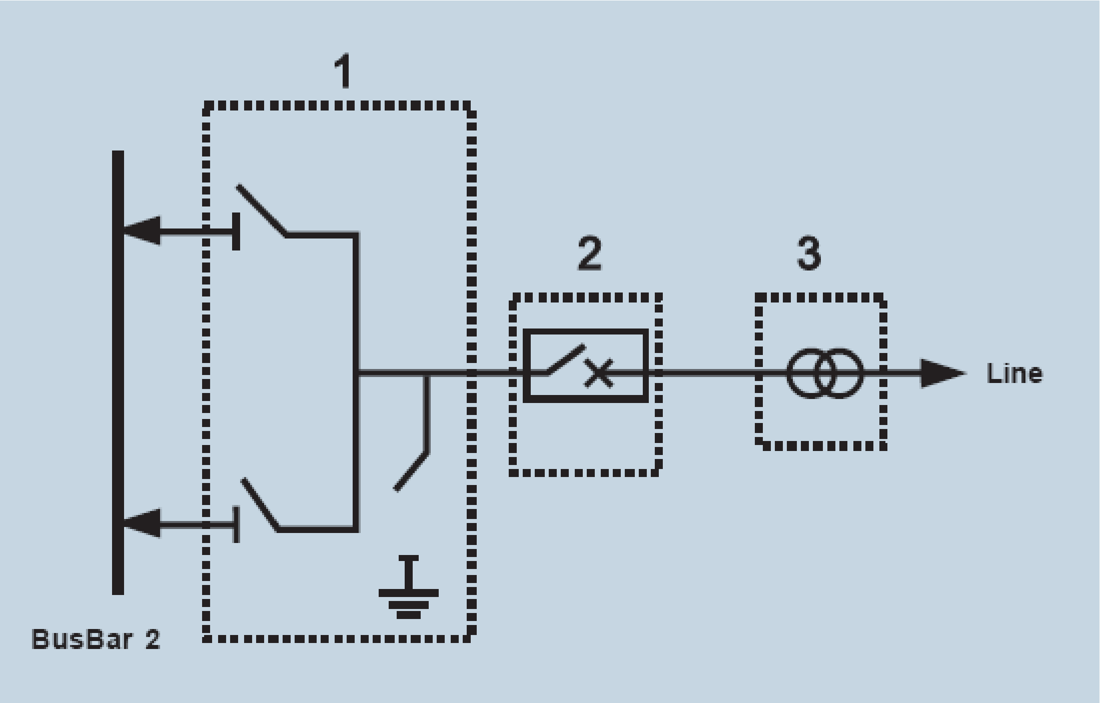

Figure 3.7 The diagram shows PASS M0 in Double Bus Bar (DBB) configuration.
1: Combined disconnector/earthing switch on bus bar 1 and bus bar 2.
2: Circuit-breaker.
3: Current transformer. [8]

Thanks to over listed functions PASS may be considered as an equivalent of a whole high voltage bay. In PASS M0 has a unique construction where all parts, not excepting busbar, are canned in a grounded aluminum tank with SF6 gas under pressure. To increase safety and reliability each pole is enclosured in construction made of welded aluminum. The connection of PASS M0 to a secondary busbar system is easily realizable with use of standardized components.

As it can be seen on the picture Fig. 3.7, PASS M0 configuration can completely replace several units in high voltage substation of either incoming or outgoing configuration:

- the first bushings can be connected to the power transformer;
- the second bushings can be connected to the outgoing line;
- the third bushings can be connected to the incoming line. [8]

The PASS M0 specialty is in that there is no such a thing as traditional Busbar what is realized by means of the first and second bushings.

In this configuration PASS M0 appears as a really innovative and breakthrough module and can be accepted as a perspective system concept for high voltage substation.

Figure 3.8 PASS M0 Double busbar. [8]

General description of PASS M0.

The PASS M0 circuit-breaker is a single pressure interrupter functioning on the well-proven self blast principle. To a certain degree arc itself is a supplier for the energy of interrupting currents, what consequently reduces the energy required for the operating mechanism and comparing with conventional puffer-type circuit-breaker about some 50% energy can be saved.

Table 3.3 General Ratings for PASS M0 [8].

Rated frequency	50/60 Hz	50/60 Hz
Rated voltage	170 kV	72,5/123/145/170 kV
Rated current		2500 A
Max. test voltage:		
a) Phase to ground:		
Rated short time power frequency withstand voltage, 1 min	325 kV	140/230/275/275 kV
Rated lightning impulse withstand voltage 1,2/50 ?s	750 kV	325/550/650/650 kV
b) Across isolating distance (circuit-breaker, disconnector):		
Rated short time power frequency withstand voltage, 1 min	375 kV	160/265/315/315 kV
Rated lightning impulse withstand voltage 1,2/50 ?s	860 kV	375/630/750/750 kV
Rated short time withstand current (3 s)		40 kA
Rated peak withstand current		100 kA
Ambient temperature		
Min.	-25 °C	- 30 °C
Max		+ 55 °C
Gas loss per year		< 1%
Weight		
Single BusBar		1900 kg
Double BusBar		2150 kg
Incoming - outgoing		2300 kg
SF6 pressures (20 °C) (absolute values)		
Filling pressure	700 kPa	680 kPa
First alarm level	660 kPa	620 kPa

Nominal insulating pressure (blocking pressure)	640 kPa	600 kPa

Table 3.4 Technical data for circuit-breaker PASS M0 [8].

Single interrupter	
Rated short circuit breaking current	40kA / 50 Hz
Rated short circuit breaking current	40kA / 60 Hz
Rated short circuit making current (close and latch)	100 kA pK
Line charging switching	63A
Cable charging switching	160A
Drive	3 poles spring operated / Single pole
Type	BLK 222 / BLK 82
Rated operating sequence	O-0.3 s-CO-1min-CO
Opening time	=<25 ms
Breaking time (50 Hz)	=<47 ms
Breaking time (60 Hz)	=<44 ms
Closing time	=<42 ms
Rated supply voltage of auxiliary circuits	110VDC (typical)

A three pole operated disconnector and earthing switch is combined and implemented to PASS M0. The operating principle is based on circular motion with three available positions: closed contact position, when contact is in the neutral position or when it is earthed. [8]

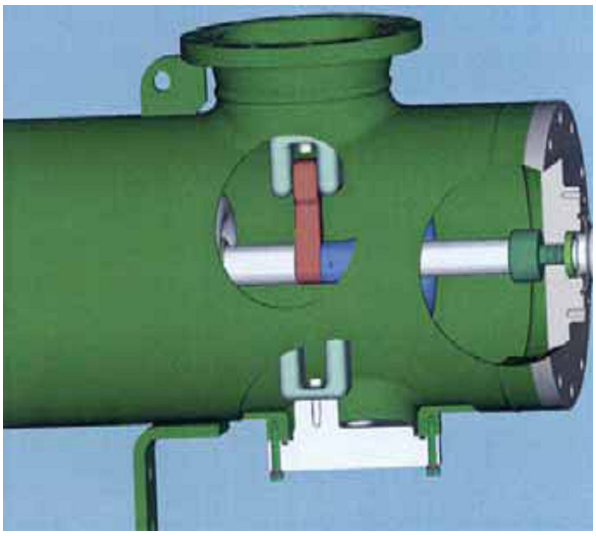

Figure 3.9 Combined disconnector/earthing switch for PASS M0 single busbar. The contact is closed on the busbar. [8]

Minimal numbers of mechanical components compose the mechanism and assure its distinctive reliability. This modular design of PASS M0 lets to avoid intensive maintenance and can be employed in different configurations - double busbar or single busbar configurations and on all the bushings.

Table 3.5 Disconnector/Earthing Switch. [8]

Drive	3 poles motor operated
Rated supply voltage of auxiliary circuits	110VDC
Switching time from line to earth	5.5 s
Emergency manual operation possible (hand-crank).	
Contact position visible through porthole	

The position of the combined disconnector/earthing switch can be clearly seen as it is indicated constantly by an indicator in both cases of single busbar and double busbar. The indicator is mechanically connected to the shaft. In an emergency, the disconnector/earthing switch can be controlled manually.

In order to meet customer requirements, a conventional current transformer is implemented in PASS M0. For measurements and protection several combinations of cores are presented and up to five cores with different burdens can be implemented into the current transformer.

Busbar and overhead lines are connected to the PASS M0 by means of air bushings, where the main insulation is realized with help of compressed SF6-gas. Several important arrangements for the insulator e.g. an epoxy impregnated fiberglass tube with silicon rubber sheds, hydrophobic properties of silicon rubber sheds and etc ensure strength margin of a construction especially in extreme and unfriendly environment, sandstorm resistance, low weight in combination with low maintenance and give very good rain and pollution performance.

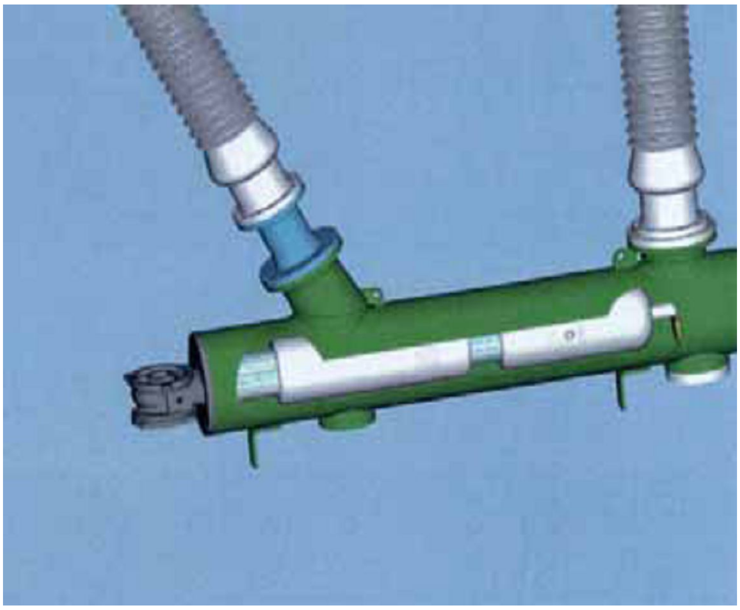

Figure 3.10 The operating mechanism is of the spring type. This type of drive stores energy in a spring which is discharged during operations. [8]

So far as dielectric strength in a homogeneous field of SF6 gas in some 2.5 times greater comparing at the same pressure and temperature with air dielectric strength in a homogeneous field, this provides the excellent insulation qualities and compact design of the PASS M0 module. The live components design is organized in such way that the field distribution is reached as homogeneous as possible, allowing the intrinsic insulating gas strength to be utilized most effectively.

Table 3.6 SF6 gas pressures of the PASS M0 module at 20 °C [8]

Filling pressure	680 kPa (abs)

First alarm level	620 kPa (abs)
Nominal insulation pressure	
(blocking pressure)	600 kPa (abs)

Filling pressure surpasses the nominal insulation pressure in about 15% to guarantee enough gas density for a long operational period. Accurate gas-tightness tests are carried out in the factory to ensure minimum gas losses during operation.

One important thing to note, that to control SF6 - gas density and detect leakage of it, a gas density relay should be installed so far the switchgear dielectric strength and the breaking capacity of SF6 circuit-breaker depend on the density of the SF6 gas.

PASS M0 innovative modules are environment friendly ones comparing with conventional air insulated solutions accomplishing the same functions. Global life cycle cost is reduced considerably by reducing of SF6 volume by 80%, maintenance cost by 38% and environment impact is got lower while the space reduced by 70% and total life cycle cost now is less than 60%.

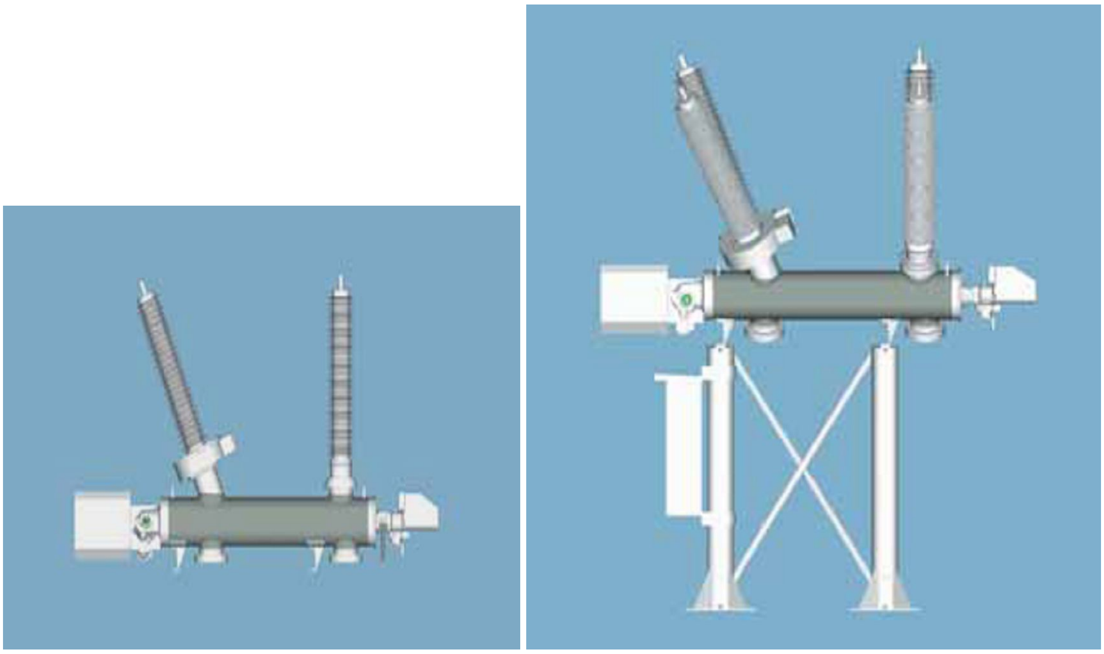

Figure 3.11 PASS M0 145 kV SBB Transportation Position (left) and Operation Position (right). [8]

The global life cycle cost (LCC) for PASS M0 is expected to be less than 30% when compared with conventional bays for H layout of bridge-type air insulated substation. In addition to it, PASS M0 has been executed for a numerous tests comprehensively covering environmental aspects within the whole period of the product life.

Thanks to its modularity and compactness no special arrangements for packaging, shipping and transportation, besides a standard truck container, are required. It can be brought from compact transportation position to final layout by simple 30° rotation of the outer poles, as it can be seen from Figure 13 showing PASS M0 145 kV in transportation (left) and operation (right) positions, Fig 3.11.

Standards

PASS M0 fulfills all the requirements set out by the following documents:

- IEC (all relevant standards - see technical data)
- ISO 9001 and 14001.
- CENELEC EN 50052 (standard for pressure vessels). [8]

Table 3.7 Standards requirements for the PASS M0 module. [8]

PASS switchgear is produced according to the following standards:	
•For pressure vessel construction:	CENELEC EN 50052
For quality assurance:	ISO 9001, 14001
For switchgear and associated equipment:	
High voltage switchgear	IEC 60694
SF6 switchgear	IEC 62271-203
Bushings	IEC 60137

Current transformers	IEC 60044-1
Disconnect/earthing switch	IEC 62271-102
Circuit-breaker	IEC 62271-100

3.4 COMPASS.

Compass high voltage switchgear modules are allocated for air-insulated both outdoor and indoor high voltage substations up to 170 kV rated voltage. Having such features as pre-fabricated bays or self-supported bus bars compass switchgear module compare favorably with conventional air-insulated switchgears. Minus 25° C for Compass is lower outdoor temperature limit corresponds to IEC 56 temperature class.

It suffices to implement these modules within the limits of the city as the square for switchyard layout is required much lower than usually. The time necessary to construct the substation reduces considerably as well as interruption in supplying end customers due to special arrangements for protection and control by means of digital protective relays and computers.

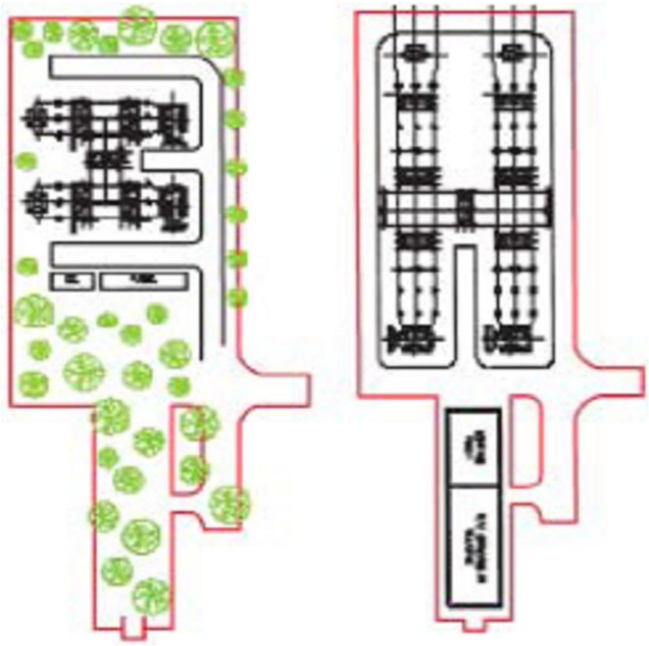

Figure 3.12 COMPASS H configuration (left) vs. conventional H configuration (right).

Conventional H configuration:

- *Total area: 2600 m2/sqm.*
- *Earthing area: 3700 m2/sqm*

COMPASS H configuration:

- *Total area: 1200 m2/sqm*
- *Earthing area: 1000 m2/sqm [9]*

As a whole the global substation consistency is achieved also by agreeable to the standards and appropriate design of the earthing grid and flexibility of circuit-diagram before everything else. Consequently, the erection process of a COMPASS switchyard becomes very fast and simple procedure taking far less time.

Substation constructed on base of Compass switchgears can be also characterized as relocatable and having low environment impact in accordance with the recommendation ISO 14040, following the Environment Priority Strategy method.

The possible bay adjustments or inspection can be carried out on site, that is, operating personnel can complete tasks while standing on ground inside, as it is called, Faraday cage - an earthed structure assuring satisfactory safety and effectiveness. In case of serious breakdowns the major maintenance could be easily performed due to the mobility of the bay. The complete bay can be entirely replaced in less than three hours. This reduces the maintenance and assures reliability and less duration of outages and related additional damages.

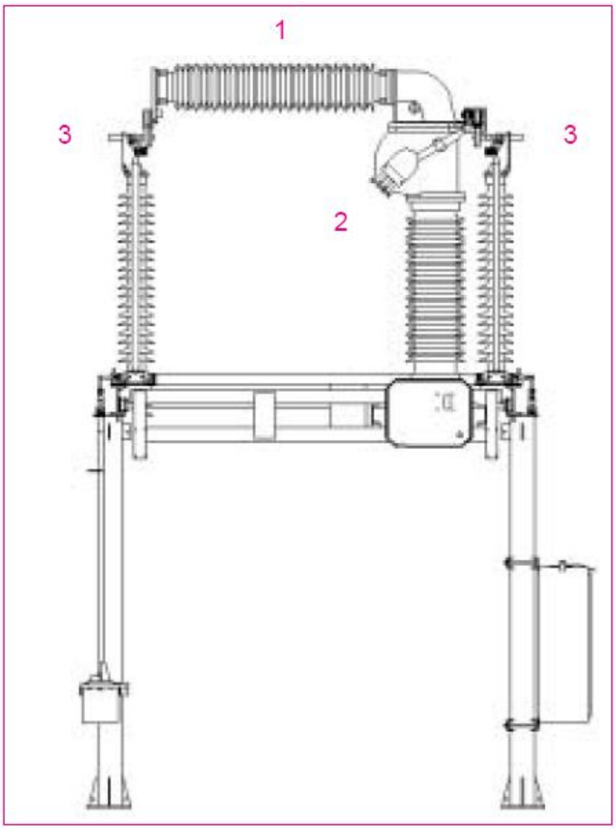

Figure 3.13 Structure of the module

1. CB chamber

2. Current transformer

3. Disconnectors [9]

The COMPASS module consists of several major components, a circuit-breaker with a breaking chamber specified as LTB and spring operated drive designed in two alternative modifications BLK 82 for one and BLK 222 for three pole operation in line-bays, and electromagnetic type multi-cores current transformer with SF6 insulation

The above mentioned components are designed on the one frame of the apparatus, where the breaking chamber is supported by the current transformer: in order to simplify road transportation the COMPASS is arranged that the breaking chamber has horizontal position so that the apparatus' profile is similar to the Greek letter Γ (gamma).

Disconnectors: a truck on which is installed the Γ apparatus, can be driven with a motor operated warm screw, so that it could be either energized or just the opposite isolated from the main circuit. A fixed frame supports post insulators, the terminals are on the top of them and therefore the draw-out Γ apparatus is equivalent to following scheme: circuit-breaker + current transformer + upstream and down-stream disconnectors.

On any or both of post insulators the earthing switches can be installed, however, the post insulators could be replaced by surge arrestors to install on the module. Surge arresters for rated voltage up to 145 kV are placed on the side opposite to the current transformer, whereas 170 kV surge arrestors due to their size are installed on a bracket supported by the frame of the module itself.

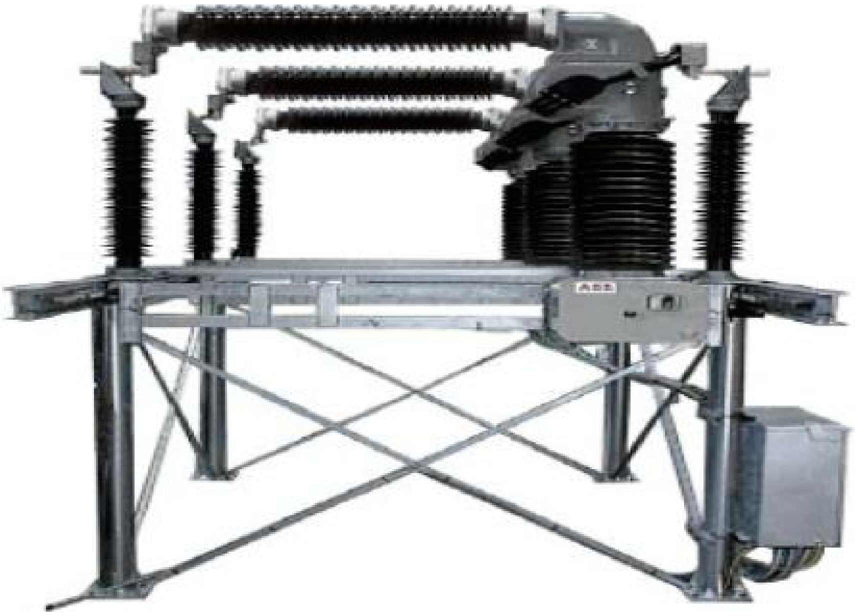

Figure 3.14 COMPASS solution for High Voltage substation. [9]

In accordance with the recommendation ISO 14040, following the Environment Priority Strategy method checking the facts about the environmental burden of a product from early stage of design through the stages of raw material procurement to production and final disposal. The COMPASS impact on the environment has been carefully studied and comparing COMPASS with conventional outdoor solutions has lead to the fact that the life cycle assessment for COMPASS is only two thirds of the corresponding value for conventional air-insulated solutions.

Table 3.8 General characteristics of COMPASS. [9]

Rated voltage	123 145 170 kV
Rated insulation level	
Lightning impulse withstand voltage	
To earth & between phases	550 650 750 kV
Across the isolating distance	630 750 860 kV
Short duration power frequency withstand voltage	
To earth & between phases	230 275 325 kV
Across the isolating distance	265 315 375 kV
Rated frequency	50 (60) Hz
Rated normal current	1600 A
Rated short-time withstand current	40 kA
Rated DC supply voltage of closing and opening devices and auxil. circuits	110 V(DC)
Rated AC supply voltage of closing and opening devices and auxil. circuits	400/230 V
Degree of protection of enclosures	IP44
Seismic withstand factor	0.3 g
Mechanical stress on terminals	according to IEC

3.5 Summary.

Modern society highly depends on electricity and requires safe and uninterruptible electrical supply. Thus, the reliable generation, transmission and distribution of electrical energy at the desired quality and cost level and with minimal environmental impact and risk to people became the main purpose of electrical power systems.

All too often, the most common reason for energy supply interruptions or for removing a whole substation or parts of it from service is maintenance operations for definite devices. Thus, it is necessary to reach an optimal availability so that maintenance shutdowns at a substation could be planned long before in low load period and alternative connections can be arranged to provide important loads with electricity and power.

The substation design must also take into account the accidents requiring urgent disconnection of substation parts what causes unplanned interruptions, so that the disturbances in one part of substation would not affect its other parts. Only leading edge equipment based on innovative technologies and principles is able to meet all these divers challenges.

So far, today’s open market circumstances keep changing, the substation remains the main element to satisfy end users demands successfully. The operational life of many already existing substations is close to the end and replacement of conventional air insulated substation components like circuit-breakers and disconnectors on the principle of one-to-one is not economically viable.

The reducing of occupied space, low environmental impact and availability not the only tough requirements from the today’s problems list what the modern substations have to fulfill.

It follows thence, according to the concept of further substation development the main emphasis should put on switchgears improvement to get them scalable and combined with other equipment revealing unique concept of flexible, modular switchgears.
The answer in front of the changing world for what concerns the energy market could be innovative high voltage modules. New high voltage modules described over have their own specialties and design advantages.

On a base of AIS and GIS-insulated innovative modules, new alternatives and opportunities presenting a lot of advantages for customer can be attained:

- reduction of occupied space;
- short installation period;
- simplified substation layouts can be consisted of three main parts: high voltage switchgear module, for example PASS M0, power transformer, middle voltage feeders;
- low environmental impact;
- reduction of short circuit current;
- substation is completely transportable;
- reduced commissioning time of the whole substation;
- reduction of losses (high voltage substation can be brought closer to the end user and the number of them can be substantially increased);
- reduced life cycle cost. [7]

High voltage innovative switchgear modules in this overview are presented by air insulated modules Compact WCB – withdrawable circuit breaker for 72.5 – 300 kV, Combined DCB - disconnecting circuit breaker for 72.5 - 420 kV and COMPASS and gas-insulated module PASS M0. Compact WCB – withdrawable circuit breaker consists of a standard trolley mounted circuit breaker with motorized, spring operating mechanisms, interlocking motor unit, oil-insulated current transformer and line entrance modules (oil-insulated, capacitor voltage transformer, grounding switch and surge arrester).

The differential peculiarities of this module are maintenance-free contacts and two possible alternative busbar arrangements for high-built, outdoor and low-built, indoor substations.

Combined DCB - disconnecting circuit breaker is equipped with a visible motor-operated grounding switch, spring operating mechanism, or with new digitally controlled operating mechanism named Motor Drive™, one breaking chamber per phase up to 245 kV with disconnecting circuit breakers. The main distinctive features are advanced logical interlocking system that can be remotely controlled and locally padlocked and grounding switch makes the disconnection visible.

The COMPASS module consists of several major components, a circuit-breaker with a breaking chamber, spring operated drive designed in two alternative modifications for one and three pole operation in line-bays and electromagnetic type multi-cores current transformer with SF6 insulation. All these components are installed on the one common frame. COMPASS has such an arrangement that the breaking chamber having horizontal position so that the apparatus' profile is similar to the Greek letter Γ (gamma).

The PASS M0 SF6- insulated module is equipped with bushings for connection to one or two busbar systems, one circuit-breaker, one or more combined disconnector/earthing switches and one current transformer. The distinctive characteristics of PASS M0 are its compactness and modular design which allow to realize several functions in one module at the same time. PASS M0 configuration is a really breakthrough one as there is no traditional busbar, what is performed within the module by means of the first and second bushings.

Further development is considered to improve achievements in high voltage switchgear module design. The goals of it to assure the best functionality of the bay and low failure rates; to simplify substation layouts and maintenance, to decrease environmental impact and life cycle cost, serious research for more flexibility without changing the main components and etc.

4. Typical substation overview. Classification and requirements.

4.1 Distribution substation overview and classification.

Distribution substation is called an electric installation what is meant for electricity transformation and distribution and contained switchgear apparatus, collecting and connecting bus, pilot and support devices (compressors, motor drives, storage battery rooms and etc.) and also circuit protection, automation and measurement devices.

There are usually several different voltage levels connected by transformers or autotransformers on substation. Distribution substation can be divided into two groups - open-type-bus-and-switch arrangement and indoor bus-and-switch arrangement. [11]

Open distributive system is called an open-type-bus-and-switch arrangement all or almost all important parts of which are situated on open air as an outdoor installation. Open distributive system is mainly used on higher 35 – 110 up to 750 kV voltage levels. Comparing with indoor bus-and-switch arrangement open distributive system has a number of considerable advantages:

- less volume of building and construction operations;
- substantial saving of constructional materials (steel, concrete and etc.);
- less installation costs and construction duration;
- decreased risk of damage propagation thanks to relatively large distances between high voltage apparatus;
- huge scenic corridor for good visible substation control;
- large possibilities for modernization and unit replacement to new one even with larger clearances;
- possibility of easier rig-down and rig-up operations.

However, open distributive systems when compared with indoor solutions have also a number of disadvantages: [11]

- less comfortable maintenance as every manual switching operations, refreshment and apparatus overseeing have to be carried out rain or shine on open air;
- more space is required;

- considerable contrary environmental conditions impact, sharp temperature changing, humidity and etc.;
- dust pollution exposure what requires using more expensive apparatus with special arrangements for outdoor installation and more intensive maintenance.

After the manner of construction distributive systems can be divided on unit-to-unit switchboard or factory-assembled switch-gear and station-type cubicle switchgear systems.

Unit-to-unit switchboard is built on the base of separate elements and nodes (cubicles, bays, panels and etc.) have been produced and completed at factories and special manufactories. The bigger constructional unit the easier further design and implementation are. [10]

Use of prefabricated innovative modules such as PASS M0 what includes several important units within one frame can completely fulfill this requirement.

Unit-to-unit switchboard construction is performed completely or almost completely on direct place of substation construction, where constructing base with associated hardware, operating personal and technical management is organized.

However, apparatus with small clearances and weight can be an exception. Unit-to-unit switchboard construction is produced at installation companies and delivered to the construction place as separate parts.

Station-type cubicle switchgear systems is completed with closed cubicles or bays with integrated measurement, protection and automation devices available either as separate major components to construct or completed and ready for operation unit. [10]

4.2 Open distributive system. PUE and GOST general requirements.

According to GOST and PUE standards requirements open distributive system on equality with other power grid units must fulfill the following requirements:

- working reliability,
- operation availability and safety,
- efficient performance,
- fire safety,
- low environment impact.

Working reliability of open distributive systems are determined to a large extend by general wiring diagram, quality and correctness of chosen equipment, operation speed of relay protection and other automation systems, effectiveness of protection from switching and lightning overvoltages, locking and holding devices operating availability, reliability of service and correct operation, in particular, regular implementation of routine check, preventive testing and repairing. At the same time, design and layout also significantly influence on open distributive systems reliability.

Operation availability and safety are provided by associated layout arrangement, dividing units with protecting walls, creating propitious conditions for visible control of disconnectors switching operations, implementation of disconnectors with stationary earthing blades to earth disconnected parts of unit, locking of incorrect operation with disconnectors, protective grounding and also the associated design and layout arrangements. [12]

Efficient performance requirements should be considered as final goal to minimize constructing, operational and maintenance costs with reliability and safety restrictions. All these requirements should be taken into consideration on design stage of open distributive system.

In the context of today's circumstances it is not necessary to design every open distributive system from scratch, just the opposite, it is quite evident that prefabricated and well-proven in real working conditions open distributive system solutions should be used preferably. Typical design and layout have been worked out for every widespread substation type by leading engineering design companies on the base of developed technologies and long-term experience. Typical design and layout can be applied to any wiring diagram, which are widely used nowadays at high voltage stations and substations.

Open distributive system equipment should be gradually replaced as and when necessary with newer and higher-end one. Typical open distributive system solution is considered as a base in certain stations and substations design.

An exception in using typical open distributive system solutions can be only made for hydro power plant substations as it is usually required special design and layout arrangements because of lack of space for distributive system installation and, in the first turn, distributive systems on generating voltage. [12]

On the stage of decision making, among a huge number of alternatives the final solution should be made comparing technical-and-economic properties of every prefabricated version.

Open distributive system is performed in strict accordance with operational code for electrical installations - PUE, Russian government technical requirements – GOST and building codes and regulations – SNiP. The main and most important requirements can be listed as following. [11]

Operating electrical equipment in normal conditions must not constitute a hazard to personal or other equipment at open distributive system, lead to equipment damage and fault inception.

In case of real working conditions different from normal conditions fault localization caused by short circuit fault current must be immediately assured as well as safe maintenance of de-energized parts of units or de-energized overhead lines without outages, dangerous impact and disturbances in neighboring circuits operating.

Distributive systems on 1000V and higher must be equipped with effective earthing systems providing bus bars and equipment grounding not using transportable grounding devices. Earthing blades are painted in black and their actuators in red color. [20]

Middle and high voltage disconnectors are installed with one or two stationary grounding blades interlocked with main grounding blades.

Electrical connections in distributive systems are performed, as a rule, with aluminum, steel or steel-cored aluminum conductors, profile pipes and bus bars made of aluminum and aluminum alloys for electrotechnical purposes.

Cage and other protection enclosure from live part of electrotechnical equipment must meet requirements on the height and for open distributive substations and open situated power transformers must be 1,6 – 2 meters in height and 1,9 meter in height for indoor distributive systems installed inside of building. Mesh size of cage must not exceed more than 25x25 mm. In addition to it, reliable locking system for cage should be foreseen. [20]

Metallic structure of distributive system and substation as well as underground parts of metallic and other concrete elements should be well protected from corrosion.

4.3 Open distributive system. Design requirements.

Clear distances between rough conducting parts and different elements of open distributive system must meet requirements in PUE and can not be less than distances presented in table 3.1 below. [11]

In case of flexible busbar if the clear distances between living parts and earthed ones and also between living parts situated in one horizontal plane must be not less than

$A^1_{ph-ph} = A_{ph-ph} + a$ and $A^1_{ph-e} = A_{ph-e} + a$

where $a = f \times \sin a$;

f - amount of deflection in meters, temperature t= +15°C;

$a = arctg\left(\frac{p}{Q}\right);$

p - wind pressure on overhead lines, N/m - newtons per meter;

$Q = mg$ - conductor weight, N/m - newtons per meter;

m - mass of conductor, kg/m;

$g = 9.81$ m/s^2. [20]

Wind speed is expected to be on the level of 60 % of wind speed value considered in building structure calculations

Flexible busbars must be adjusted for short circuit current influence, electrodynamic and thermal impacts, protected from possible electric cross of wires and dangerous overlapping in case if short circuit current exceeds 20 kA and more.

At open distributive systems 110 kV and higher a passway four meters in width and height along switchgear units should be foreseen to facilitate more easy access for mobile maintenance and repair on wheels stations and mobile laboratories.

Clear distances between free standing living parts and on wheel maintenance stations, mechanisms and transportable equipment should be observed in accordance with the operational code for electrical installations requirements. Clear distances are presented in Table 4.1.

Within open distributive system installation process explosion prevention and fire safety requirements, for oil-insulated equipment firstly, should be carefully fulfilled.

Table 4-1. Minimum clear distances between living parts and different open distributive system units for several high voltage levels. [20]

Clear distance, mm	Designation	Rated voltage level, kV			
		110	150	220	330
Phase-to-phase clearance distance.	A_{ph-ph}	1000	1400	2000	2800
Between living parts or energized parts of unit and:					
earthed constructions or permanent inside fences no less than 2 meters in height	A_{ph-e}	900	1300	1800	2500
permanent inside fences no less than 1.6 meter in height and transportable maintenance equipment	B	1650	2050	2550	3250
Between living parts of circuits located in different planes with operated lower circuit and non-disconnected upper circuit.	C	1650	2050	3000	4000
Between free standing living parts and earth or building roof with maximum conductor sag.	D	3600	4000	4500	5000
Between living parts of circuits located in different planes and also horizontal different circuits with one operated circuit and one non-disconnected circuit from living parts to the upper edge of an external fence, between living parts and buildings.	E	2900	3300	3800	4500
Between conductor and earthing blade in disconnected position and busbar connected to the second contact.	F	1100	1550	2200	3100

In accordance with PUE requirements oil receivers, oil sumps and drains must be organized for every oil-insulated power transformers, current-limiting reactors with oil quantity of 1000 kg or more and oil insulated circuit breakers 110 kV voltage level and higher to protect spreading behavior of oil and localize damage spreading in case of fire accident.

Distances and linear dimensions for insulation components which are under distributed voltage potential should be set with due account for actual value of voltage potentials distributed in different points on the surface. In default of necessary data the lineal law of voltage potential drop distribution along the insulation surface should be applied with rated voltage value as its maximum from living parts of equipment side down to zero from earthing parts side.

Distances between either living parts or insulation components from conducting parts side which are under voltage potential and power transformers during railway shipping is accepted on the level of value B see Table 4.2, but no less than A_{ph-e} distance.

4.4 Open distributive systems. Layout requirements.

Main principles determine the substation construction and layout can be listed as following:

- main wiring diagram,
- rated voltage level,
- type and dimensions of electrical equipment,
- number of connections and intercircuit connection arrangement,
- open distributed system expansibility and possibilities of various layouts implementation. [11]

The most widespread application have so called low type open distributive system where disconnectors are constructed as much close to the earth surface as it is possible. The height of installation is set by personal safety restrictions for maintenance and repairing operation safety within open distributive system territory. In such low type open distributed systems access to connecting bars and selector switch disconnectors is considerably simplified.

At the present time the most widespread typical wiring diagram is considered bridge type substation wiring diagram and also double busbar trunking system with one transfer busbar. Open distributive systems layout 110 – 500 kV for these wiring diagram were standardized and unified. Layout of unified open distributive systems 110 – 500 kV is shown in Figure 4.1 and all distances for unified open distributive systems 110 – 500 kV are presented in Table 4.2.

Connection between circuit breakers and current transformers over the passway to facilitate more easy access for mobile maintenance and repair operations is implemented by rigid bus bars.

Single-pole two-column disconnectors are mounted in every circuit with asymmetrical keel distribution of disconnectors under internal working bus bars systems.

It is possible to accompany explanations with illustrations of open distributive system 110 kV with help of Figure 4.2. Carrying an analogy, open distributive systems on 150 kV, 220 kV, 330 kV and 500 kV have the same layout arrangements with corresponding to the Electrical Installation Regulations distances.

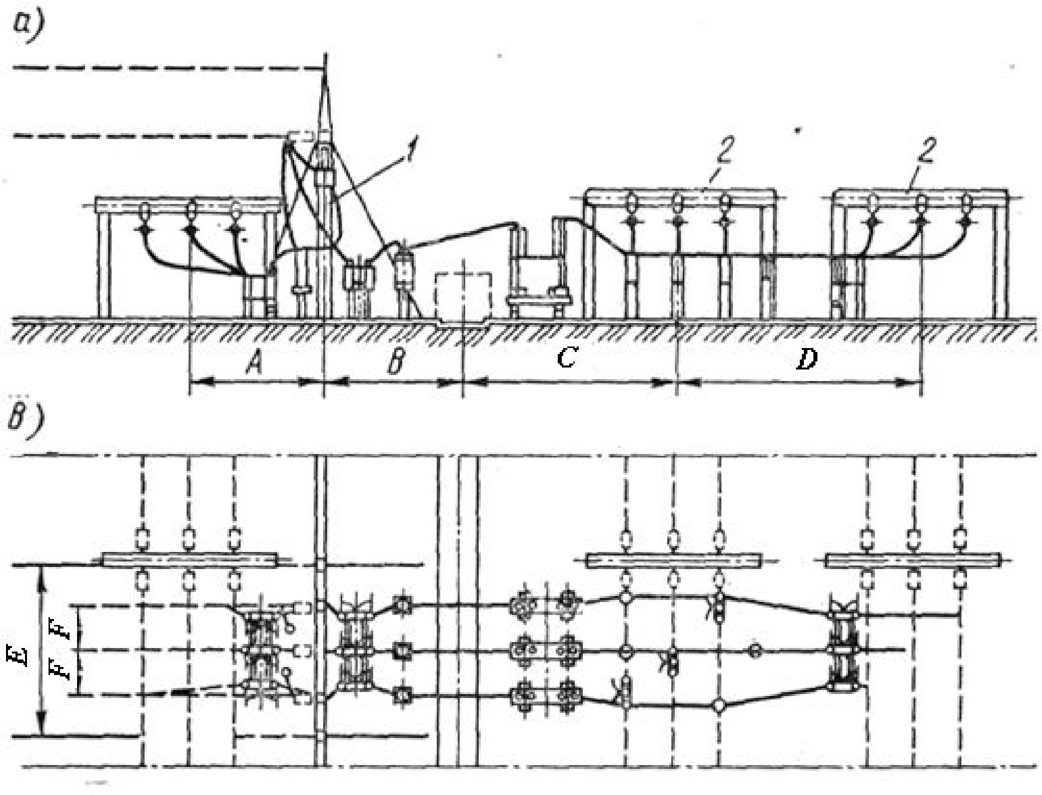

Figure 4.1. Layout of unified typical open distributive systems 110 – 500 kV with double busbar trunking system and one transfer busbar: a - sectional elevation and plan; b – layout structure; 1 – overhead lines portal; 2 – busbar portal. [11]

Table 4-2. Clearance distances of unified typical open distributive systems 110 – 500 kV in accordance with figure 3.1. [20]

Dimensions, m	Rated voltage, kV			
	110	*150*	*220*	*330*
A	8,0	11,5	11,75	29,0
B	9,0	9,5	12,0	26,8
C	12,5	15,0	18,25	29,0
D	10,5	16,0	20,5	45,0
E	9,0	11,1	15,4	31,0
F	2,5	3,0	4,0	11,0

4.5 Air- and SF6-insulated circuit breakers PUE requirements.

In accordance with the 7th edition of the Electrical Installation Regulations air-insulated circuit breakers must fulfilled the strictly determined requirements.

Insulation resistance measurements of rigid insulators, interrupting chamber insulators and breaker-isolating switches and circuit breakers air piping on any voltage level are carried out with insulation megohmmeter on 2.5 kV.

In case of need, insulation resistance measurements of rigid insulators, interrupting chamber insulators and breaker-isolating switches should be carried out with guard rings installation on the external surface. [20]

Insulation resistance must not be less than values presented in Table 4.3

Table 4.3 The lowest acceptable values for mounting insulation and insulation of moving parts of high voltage circuit breakers. [20]

Unit under test	Insulation resistance, MOhm, rated voltage of circuit breakers, kV		
	Uo to 10 kV	15 – 150 kV	220 kV and higher
Porcelain rigid insulators, air piping of circuit breakers and propulsion device.	1000 MOhm	3000 MOhm	5000 MOhm

Industrial frequency overvoltage test for insulation is obligatory only for middle voltage circuit breakers up to 35 kV. Rated testing voltage impulse duration is 1 minute. SF6-insulated circuit breakers can be accepted without industrial frequency overvoltage test for insulation if it is not expected the maintenance depressurization within whole lifetime period. [20]

Measurements have to be performed for contacts resistance of every interrupting chamber component, isolating switch as for separate unit of circuit breakers all voltage

levels. The greatest acceptable value of contact resistance of air-insulated circuit breakers 110 kV should not exceed 80 mcOhm. [20]
Main circuit resistance for SF6-insulsted circuit breakers should be measured both in the whole for current-carrying pole circuit and for every separate disconnected contour of arc quenching device. Measured values must correlate with factory of origin standards. Measurements do not perform for SF6-insulated circuit breakers if filled with SF6 at factory of origin and the maintenance depressurization within whole lifetime period is not expected. Measured values for winding resistance of controlling electromagnets and additional resistors in circuit breakers circuit must correlate with factory of origin standards. [20]

Electromagnet winding direct-current resistance of switching on and off electromagnet is set for every circuit breaker type separately accordingly to factory of origin requirements.

Air-insulated circuit breaker parameters measured in normal, minimal and maximal working pressure conditions must correlate with factory of origin requirements and standards.

On checking working ability, SF6-insulated circuit breaker parameters preassigned by factory recommendations should be determined and proven. Measurements results must correlate with factory of origin standards.

Test on minimal response voltage of circuit breakers.
Electromagnet of air-insulated circuit breakers must operate on voltage no more than 70% of rated voltage when supplied from direct-current power supply and no more than 65% of rated voltage when supplied from ac power supply through rectifying devices and maximal working pressure of compressed air in circuit breaker tanks. Testing voltage has an origin of sharp edge impulse. [20]

SF6-insulated circuit breakers must operate on voltage no more than 85% of rated voltage when supplied from direct-current power supply and no more than 70% of rated voltage when supplied from ac power supply with normal SF6 pressure in circuit breakers enclosures and maximum SF6 pressure in tanks of circuit breakers drive. Electromagnets are supplied with testing voltage what has an origin of sharp edge impulse. [20]

Multiple testing of air-insulated and SF6-insulated circuit breakers operating reliability means carrying out switch on and off operations and more complex cycles without time interval between operations. Multiple testing of circuit breakers operating reliability must be performed for every circuit breaker with wide range pressure parameters in tanks of circuit breakers drive and voltage parameters of controlling electromagnets to prove working order of circuit breaker.

The numbers of complex testing operations for circuit breakers operating reliability checking are set as following:

- 3 – 5 out switch on and off operations
- 2 – 3 cycles of every type of operations

SF6-insulated circuit breakers hermiticity is examined with help of gas leak indicator device. On checking the hermiticity of circuit breakers with gas leak indicator sealing area of butt joint and joint weld to be inspected thoroughly. Gas leak inspection result can be considered as satisfying one if gas leak indicator does not show SF6 escape. Gas leakage testing is carried out under SF6 normal pressure conditions. [20]

On the base of SF6 dew-point temperature moisture contents in SF6-insulation is detected before filling circuit breaker. Dew-point temperature should not exceed minus fifty Celsius degree.

Current transformers higher than 35 kV do not undergo basic insulation testing by boosted voltage.

Testing voltage value for secondary winding resistance with circuits connected to it is set on the level of 1 kV. Testing voltage applied duration is set 1 minute.

Magnetization characteristic is studied by stepping-up of a voltage on any one secondary winding till the voltage level when magnetic saturation begins, but not higher than 1800 V. If secondary winding has certain number of winding taps magnetization characteristic is studied on the operating winding tap. Studied magnetization characteristic is compared either with typical magnetization characteristic or magnetization characteristic of properly operating current transformer which are single-typed to those tested. [20]

Difference between typical magnetization characteristic and studied magnetization characteristic must correlate with factory of origin data and should not exceed as a rule 10%. It is assumed only three control points to study magnetization characteristic.

In accordance with PUE the following testing for high voltage disconnectors is foreseen. High voltage disconnectors, isolating switches and short-circuiting switches on 35 kV and higher may not undergo insulation testing by boosted voltage of industrial frequency.

Direct-current resistance measurements are performed between terminal lead points. Results of measured resistances must correspond to factory of origin data.
Maximum accepted direct-current resistance of disconnectors contact combination on rated voltage level 35kV – 220 kV can be no more than 220 mcOhm. [20]

Manual controlled apparatuses must be examined on operating reliability by performing 5 switching on and 5 switching off operations. Remote controlled disconnectors must be also proven on operating reliability by performing 5 switching on and 5 switching off operations with rated voltage level supplied on controlling electromagnets and electrical drives outputs. [20]

Blocking system must not let main blades operating when earthing blades are switched on and vice versa.

4.6 Summary.

Substation distributive system are used for transformation and transmitting power and electricity and include switching modules, collecting and connecting bus, pilot and support devices and also circuit protection, automation and measurement devices. There are two type of substation distributive system - open-type-bus-and-switch arrangement and indoor bus-and-switch arrangement. Substation distributive systems with open-type-bus-and-switch arrangement are used on 35 – 750 kV voltage levels.

In accordance with GOST and PUE standards requirements open distributive system on equality with other power grid units must meet the following requirements: working reliability, operation availability and safety, efficient performance, fire safety, low environment impact. All these requirements must be taking into account on designing level.

In modern condition it is more efficiently to design new distributive system on a base of previous experience and well-proven prefabricated solutions. Thus, typical substations were worked out and at the present time are wide spread.

The main factors determining open distributive system design and layout arrangements are general wiring scheme, rated voltage level, number and order of connections, type and dimensions of electrical equipment, open distributed system expansibility and possibilities of various layouts implementation.

At the present time the most widespread typical wiring diagram is considered bridge type substation wiring diagram and also double busbar trunking system with one transfer busbar. Open distributive systems layout 110 – 500 kV for these wiring diagram were standardized and unified.

Minimal clearance distances between living parts and different open distributive system units are strictly determined in PUE and presented in this chapter for several high voltage levels.

Considering the minimal clearance distances between living parts and different open distributive system units on 110 kV voltage level, linear dimensions of electrical equipment, and typical layout of unified open distributive system of bridge type substation 110 kV in accordance with PUE it can be concluded that space required for conventional typical bridge type substation 110 kV approximately equal 2100 square meters what rather more comparing with bridge type substation 110 kV realized with innovative switchgear modules, for example using COMPASS switchgear modules only 1200 square meters are needed.

All switchgear apparatuses – circuit breakers and disconnectors with air or SF6 - insulation must fulfill several strict requirements which are set in PUE. The main testing requirements can be listed as following:

- industrial frequency overvoltage test for insulation is obligatory only for middle voltage circuit breakers up to 35 kV with rated testing voltage impulse duration is 1 minute. SF6-insulated circuit breakers can be accepted without industrial frequency overvoltage test for insulation if it is not expected the maintenance depressurization within whole lifetime period,
- electromagnet winding direct-current resistance of switching on and off electromagnet is carried out for every circuit breaker type separately accordingly to factory of origin requirements,
- multiple testing of air-insulated and SF6-insulated circuit breakers operating reliability must be proven by the number of complex testing operations
- SF6-insulated circuit breakers hermiticity is examined with help of gas leak indicator device. Gas leak inspection result can be considered as satisfying if gas leak indicator does not show SF6 escape. For circuit breaker moisture contents in SF6-insulation is detected and magnetization characteristic is studied as well.

5. Estimation of primary substation equipment.

5.1 Fault current calculations.

To choose primary equipment of substation, circuit breakers, disconnectors and surge arresters fault current calculation is required.

For that purposes calculation model is composed for substation 110kV working in normal operating conditions. The calculation model is shown in Figure 5.1.

Considering points of fault current are chosen in order to set primary equipment and conductors in the worst working condition in terms of fault current.

The calculation model is composed in full accordance with main wiring diagram of electrical connection including elements fault current flows through.

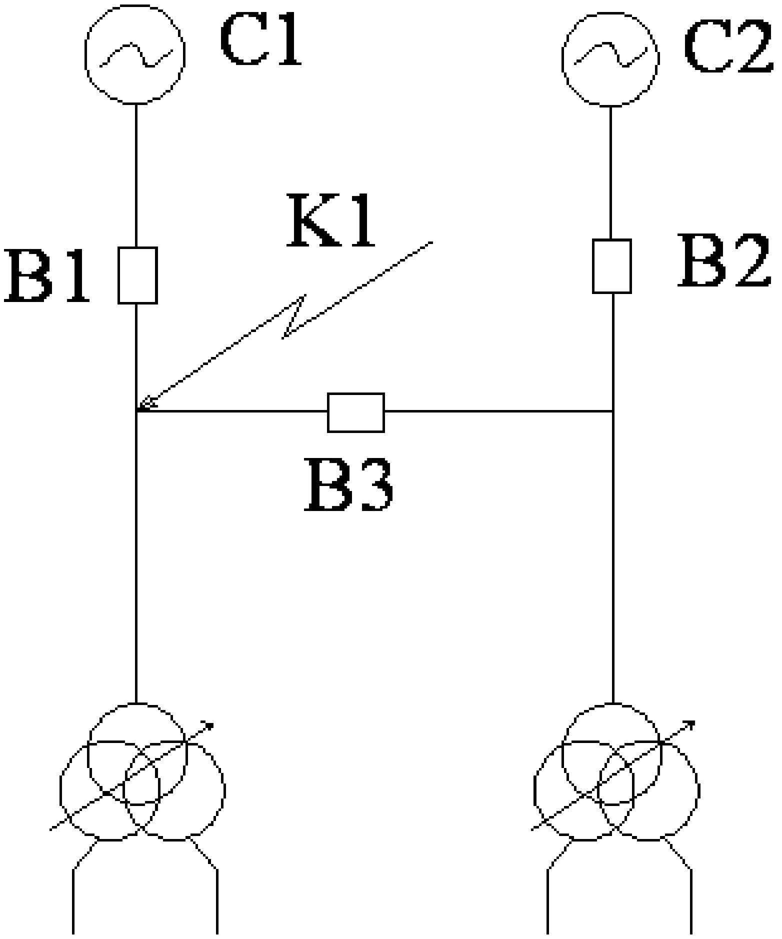

Figure 5.1 Fault current calculation model.

On fault current calculation a set of assumptions could be admitted:

- electromotive force of all sources match in phase;
- symmetry of all units of the system excepting fault current points;
- neglecting distributed capacitance of overhead lines;
- linearity of all units of the system, magnetic system saturation has not been taken into account;
- approximate dispatching, when the load can be considered as a constant inductive reactance;
- neglecting active resistance of all units of the system;
- neglecting excitation current;

Evidently, over mentioned assumptions lead to certain inaccuracy in calculation results, which, however, do not exceed 2—5 % (in some special cases the error of computation may reach 10 %).

For all chosen points of fault current it is necessary to compose an equivalent circuit (see Figure 5.2) where all units are electricity connected. Overhead lines and transformers are replaced with inductive reactance, and transient resistance of busbars, circuit breakers and current-conducting wires may be neglected.

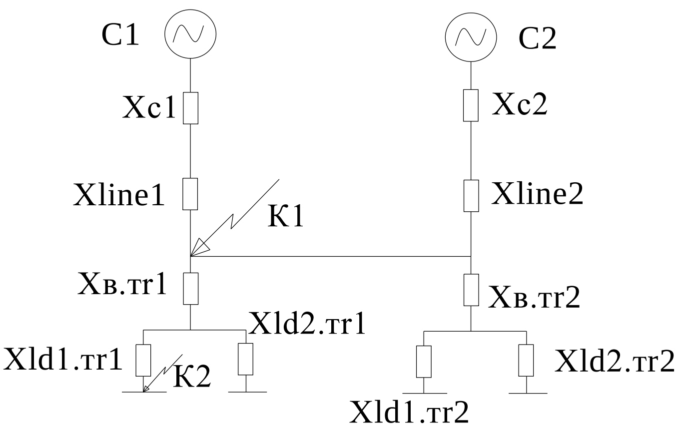

Figure 5.2 Equivalent circuit.

For computational convenience all resistances of short circuit should be expressed per unit value in basic terms.

Reduction all resistances to reference conditions in basic terms

As a basis capacity can be set a capacity S6 = 1000MVA.

Basis current can be obtained from following equation:

$$I_{b1} = \frac{S_{b1}}{\sqrt{3} \cdot U_{b1}} = 1560A \tag{5.1}$$

Where $U_{б}$ - a basis voltage is set as an average operating voltage of that level where short-circuit failure is expected to be. [10]

The resistance of the system:

$$Xc = \frac{S_b}{S''_C}; \tag{5.2}$$

Where S''_C - sub-transient short circuit capacity of the system in determined net point [11]

Overhead line or cable line resistance:

$$X_L = X_{yd} \times l \frac{S_b}{U^2_{cp}}; \tag{5.3}$$

Where X_{yd} - inductive reactance of overhead line or cable line per one kilometer, Ohm/km.

l – length of overhead line or cable line, km

U_{cp} –voltage average in place of considered unit is installed, kV. [11]

Transformer resistance:

$$X_B = X_{B-H} - \frac{X_{pac}}{2n}; \tag{5.4}$$

Where X_{B-H} - can be obtained from the following equation:

$$X_{B-H} = \frac{u_{k.B-H}}{100} \times \frac{S_b}{S_{NOM.T}}; \qquad (5.5)$$

where $u_{k.B-H}$ - short circuit voltage of transformer from [12]

$S_{NOM.T}$ - transformer rated capacity [10]

$$X_{pac} = k_{pac} \times X_{B-H} \qquad (5.6)$$

Where k_{pac} - current-limiting effect of transformer with split winding (for three phase transformer k_{pac} =3.5);

n – amount of split winding [10]

5.2 Calculation of equivalent circuit resistance in basis conditions terms.

Equivalent circuit resistance according to equation (5.2)

$$X_{C1} = \frac{S_b}{S''_{C1}} = \frac{1000}{4000} = 0,25$$

$$X_{C2} = \frac{S_b}{S''_{C2}} = \frac{1000}{6000} = 0,166$$

Equivalent circuit resistance of overhead line:

For single-chain overhead line on 110 kV rated voltage:

X_{yd} - 0,4 Ohm/km

$$X_{L1} = X_{yd} \times l_1 \frac{S_b}{U^2_{cp}} = 0,4 \times 5 \times \frac{1000}{115^2} = 0,151$$

$$X_{L2} = X_{yd} \times l_2 \frac{S_b}{U^2_{cp}} = 0,4 \times 3 \times \frac{1000}{115^2} = 0,091$$

Transformer resistance in accordance with equations (5.4) – (5.6):

$$X_{B-H} = \frac{u_{k.B-H}}{100} \times \frac{S_b}{S_{NOM.T}} = \frac{11.5}{100} \times \frac{1000}{63} = 1.825$$

$$X_{pac} = k_{pac} \times X_{B-H} = 3{,}5 \times 1{,}825 = 6{,}38$$

$$X_B = X_{B.T1} = X_{B.T2} = X_{B-H} - \frac{X_{pac}}{2 \times n} = 1{,}825 - \frac{6{,}38}{2 \times 2} = 0{,}23$$

$$X_{Ld} = X_{Ld1.Tr1} = X_{Ld2.Tr1} = X_{Ld1.Tr2} = X_{Ld2.Tr2} = \frac{X_{pac}}{2} = 3{,}19$$

Other equivalent circuit resistances can be accepted as follows:

$X_1 = X_{C1}$, $X_2 = X_{C2}$, $X_3 = X_{L1}$, $X_4 = X_{L2}$ $X_5 = X_6 = X_B$ and
$X_7 = X_8 = X_9 = X_{10} = X_H$;

5.3 Electric circuit transfiguration, determination of resulting resistances and short current analytical calculation.

Supply from generators is not considered assuming that equivalent resistance of generators far more bigger than remaining resistances in electric circuit.

Initial sub-transient short circuit current:

$$I''_{p0} = \frac{E''}{X_{res}} \times I_b; \tag{5.6}$$

Where E'' - sub-transient electromotive force,

X_{res} - resulting resistance until the point short circuit is occurred,

I''_{p0} - periodic component of short circuit current, кA. [10]

Surge short circuit current:

$$i_y = \sqrt{2} \times k_y \times I''_{p0}; \tag{5.7}$$

Where $k_y = 1 + e^{\frac{-0,01}{T_A}}$; - surge coefficient,

and T_A - response time of circuit. [10]

Short circuit current calculation in point K1.

First of all, calculation model of electric circuit is required to simplify as it is shown in Figure 5.3:

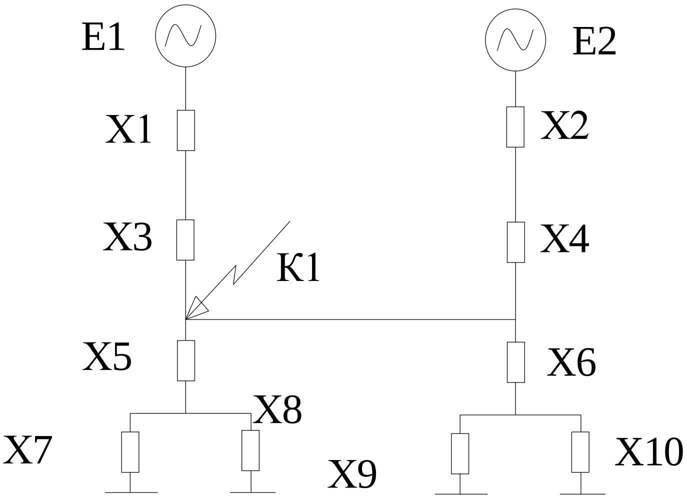

Figure 5.3 Calculation model of electric circuit for point.

Hereafter, on carrying out the re-expression of series resistance and parallel circuit resistance the equivalent resistance can be obtained (Figure 5.4):

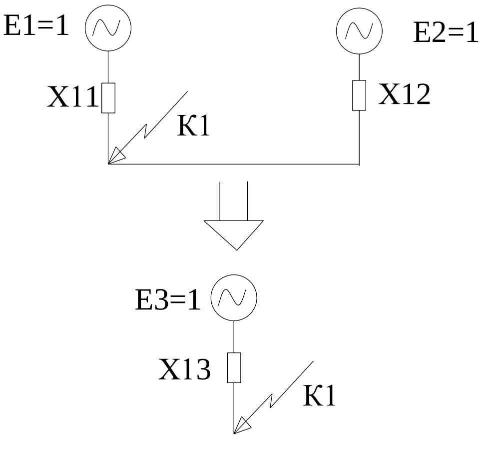

Figure 5.4 Calculation model transfigurations with respect to point K1.

The average operating voltage of that level where short-circuit failure is expected can be assumed as basis voltage:

$U_b = 115$ kV, then it follows from equation (5.1) the basis current can be determined:

$$I_{b1} = \frac{S_b}{\sqrt{3} \cdot U_b} = \frac{1000}{\sqrt{3} \times 115} = 5{,}02 \text{ кА}$$

Equivalent resistance of calculation model is derived as follows:

$$X_{11} = X_1 + X_3 = 0{,}25 + 0{,}151 = 0{,}401$$

$$X_{12} = X_2 + X_4 = 0{,}166 + 0{,}091 = 0{,}257$$

$$X_{13} = \frac{X_{11} \times X_{12}}{X_{11} + X_{12}} = \frac{0{,}401 \times 0{,}257}{0{,}401 + 0{,}257} = 0{,}157$$

In what follows, initial sub-transient short circuit current can be calculated in point K1 according to equation (5.6):

$E''_3 = 1$:

$$I''_{p0 \cdot K1} = \frac{E_3''}{X_{13}} \times I_b = \frac{1}{0{,}157} \times 5{,}02 = 31{,}97 \text{ кА}$$

Surge short circuit current in point K1 is found using equation (5.7):

$$k_y = 1 + e^{\frac{-0{,}01}{T_A}},$$

For busbar 110 kV as directed by GOST P IEC 60898.2—2006 point 4.7 “About response time” in electrical circuits with short circuit current value higher than 1500 A the response time is considered to be sufficient on the level of 4 ms. Thus, for $T \le 4$ ms the response time can be equal $T_A = 0{,}03$ ms, what is led from Figure (5.5):

$$k_y = 1 + e^{\frac{-0{,}01}{0{,}03}} = 1{,}717$$

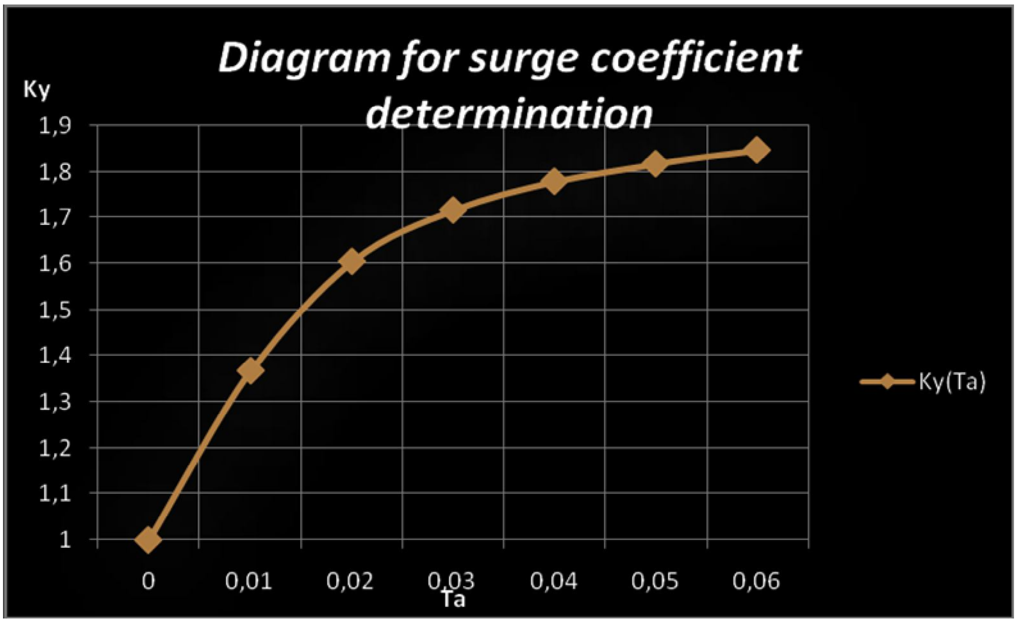

Figure 5.5. Diagram for surge coefficient determination. [10]

$$i_{y.K1} = \sqrt{2} \times k_y \times I''_{p0 \cdot K1} = \sqrt{2} \times 1{,}717 \times 31{,}97 = 77{,}62 \text{ кА}.$$

Short circuit current calculation in point K2

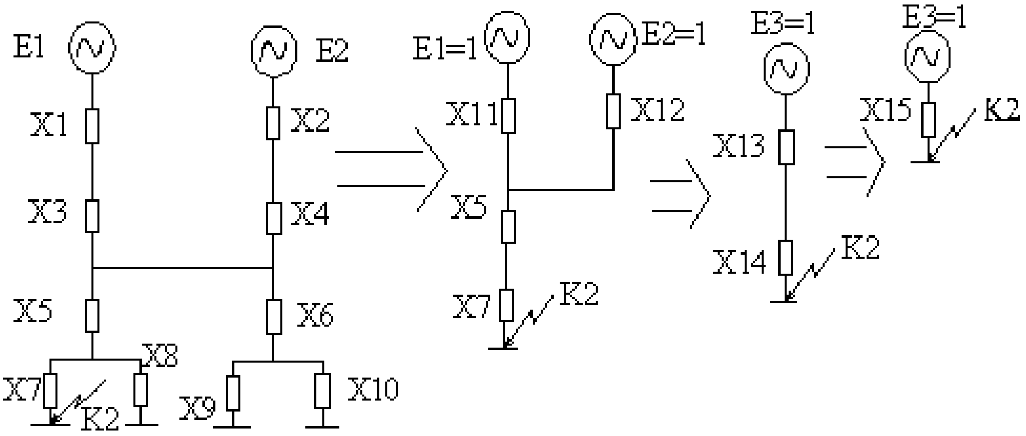

Figure 5.6 Calculation model transfigurations with respect to point K2

The average operating voltage of that level where short-circuit failure is expected can be assumed as basis voltage:

$U_b = 10{,}5$ kV, then it follows from equation (5.1) the basis current can be determined:

$$I_b = \frac{S_b}{\sqrt{3} \cdot U_b} = \frac{1000}{\sqrt{3} \times 10{,}5} = 54{,}98 \text{ kA}$$

Equivalent resistance of calculation model is calculated as follows:

$$X_{11} = X_1 + X_3 = 0,25 + 0,151 = 0,401$$

$$X_{12} = X_2 + X_4 = 0,166 + 0,091 = 0,257$$

$$X_{13} = \frac{X_{11} \times X_{12}}{X_{11} + X_{12}} = \frac{0,401 \times 0,257}{0,401 + 0,257} = 0,157$$

$$E''_3 = 1$$

$$X_{14} = X_5 + X_7 = 0,23 + 3,19 = 3,42$$

$$X_{15} = X_{13} + X_{14} = 0,157 + 3,42 = 3,577$$

Further, initial sub-transient short circuit current can be calculated in point K2 according to equation (5.6):

$$E''_3 = 1$$

$$I''_{p0 \cdot K2} = \frac{E''_3}{X_{15}} \times I_b = \frac{1}{3,577} \times 54,98 = 15,37 \text{ кА}$$

Surge short circuit current in point K2 is found with help of equation (5.7):

$$k_y = 1 + e^{\frac{-0,01}{T_A}},$$

From table for the response time of short circuit current aperiodic component can be defined as $T_A = 0,075$. [11]

$$k_y = 1 + e^{\frac{-0,01}{0,075}} = 1,87$$

$$i_{y.K2} = \sqrt{2} \times k_y \times I''_{p0 \cdot K2} = \sqrt{2} \times 1,87 \times 15,37 = 40,65 \text{ кА.}$$

The initial sub-transient short circuit current with respect to high side of substation can be found in accordance with equation (5.6):

$$I''_{p0.K2.B} = \frac{E''_3}{X_{15}} \times I_b = \frac{1}{3,577} \times 5,02 = 1,4 \text{ кА.}$$

The calculated values of short circuit current can be tabulated as follows:

Table 5.1. Summary table of short circuit current values.

Short circuit point.	Source	$I^{(3)}{}_{p0}$, kA	$i^{(3)}{}_{y}$, kA
K1	Power grid	31,97	77,62
K2	Power grid	15,37	40,65
K2 with respect to high side	Power grid	1,4	-

5.4 Substation equipment selection. General requirements.

Substation equipment selection is carried out for continuous normal operating conditions; verification is performed for short circuit conditions.

All apparatus and live parts undergo thermal and dynamical short circuit current influence; three-phase short circuit can be admitted as a case for further calculations.

Loading current verification of equipment:

$$I_{norm} = 0{,}7 \times \frac{S_{NOM}}{\sqrt{3} \times U_{NOM} \times 2}; \tag{5.8}$$

$$I_{p.y.} = 1{,}4 \times \frac{S_{NOM}}{\sqrt{3} \times U_{NOM} \times 2}; \tag{5.9}$$

$$I_{norm} \le I_{NOM} \text{ и } I_{p.y.} \le I_{NOM} \tag{5.10}$$

где I_{norm} - maximal current of normal conditions,

I_{NOM} - installation rated current,

$I_{p.y.}$ - - maximal current of breakdown and post emergency states,

S_{NOM} - installation rated power,

U_{NOM} - installation rated voltage,

Where figure of two involved reciprocally – split low-voltage winding coefficient of transformer. [11]

Electrodynamical withstandability verification:

$I_{p.0} \le I_{DIN}$ and $i_y \le i_{DIN}$ (5.11)

where I_{DIN} - root-mean-square value of periodic component of let-through short circuit current.

i_y - electrodynamical withstandability current, peak value. [12]

Thermal withstandability verification:

For thermal withstandability verification it is necessary to determine the value and estimate heat impulse intensity of short circuit current what is characterized by heat quantity released in electric apparatus during short-circuit clearance time.

$B_{k.pac} \le I^2{}_{\scriptscriptstyle TEP}{}_R \times t_{TER}$, (5.12)

Where $B_{k.pac}$ - heat impulse of short circuit current,

I_{TER} - root mean square value during flow of short circuit current, thermal withstandability current. [12]

t_{TER} - thermal withstandability current flow time. [12]

Heat impulse is found from equation:

$B_{k.pac} = I_{p.0}{}^{"2} \times (t_{Sw.Off} + T_a)$, (5.13)

Where $t_{Sw.Off} = t_p + t_{C.B.}$ and t_p -

где $t_{Sw.Off} = t_p + t_{C.B.}$, t_p - operating time of main relay protection, s.

$t_{C.B.}$ - total break time of circuit breaker, s. [11]

Breaking ability verification.

Firstly, verification is performed for balanced breaking current:

$$I_{\Pi.\tau} \le I_{Sw.Off.NOM} \tag{5.14}$$

Where $I_{\Pi.\tau}$

Where $I_{\Pi.\tau}$ - periodic breaking current by the disconnection moment of arcing contact circuit breaker.

In case of long distance short circuit:

$I_{\Pi.\tau} \le I''_{\sum} = I''_{p.0}$ [10]

Verification the possibility to disconnect aperiodical component of short circuit current:

$$i_{a.\tau} \le i_{a.NOM} = \frac{\sqrt{2} \times \beta_H \times I_{Sw.Off.NOM}}{100} \tag{5.15}$$

Where $i_{a.NOM}$ - rated admissible aperiodical component value containing in short circuit current for time τ ,

β_H - specified value of aperiodical component contained in disconnected current in accordance with catalogue [12],

$i_{a.\tau}$ - aperiodical component of short circuit current in the moment τ when contacts break,

τ - basic time from the moment of short circuit till the moment of arcing contact breaking:

$$\tau = t_{3.\min} + t_{C.B},$$

In this equation $t_{3.\min} = 0.01\text{c}$ – basic time of relay protection operating,

$t_{C.B}$ - opening time of circuit breaker. [11]

$$i_{a.\tau} = \sqrt{2} \times I''_{p.0} \times e^{-\frac{\tau}{T_a}} \tag{5.16}$$

Where $I''_{p.0}$ - initial value of short circuit current periodical component in the circiut breaker's circuit, kA [10]

Full short circuit current verification: [11]

$$(\sqrt{2}\times I''_{p.0}+i_{a.\tau})\leq\left(\sqrt{2}\times I_{Sw.Off.NOM}\times\left(1+\frac{\beta_{NOM}}{100}\right)\right) \tag{5.17}$$

Making capacity verification:

$$i_y\leq i_{Sw.On} \text{ and } I''_{p.0}\leq I_{Sw.On} \tag{5.18}$$

where i_y - surge short circuit current in the circuit breaker's circuit

$i_{Sw.On}$ - making current peak value [12],

$I_{Sw.On}$ - making current rated value,

5.5 High voltage equipment selection by the example of high voltage switchgear module PASS M0 145.

General properties

Rated frequency...50 Hz

Rated voltage...110 kV/150 kV

Rated current..2500 A

Thermal withstand current (1 sec)...40 kA

Electrodynamical withstand current...100 kA

Ambient temperature

Bottom value..-45°C

Peak value..+55°C

SF6 gas leakage per year...< 1 %

Circuit breaker

LTB-D type, with single arc-interruption chamber,

Rated short circuit breaking current...40кA

Rated short circuit making current (close and latch)..................................100 кА

Line charging switching..63 A

Cable charging switching...160A

Drive... 3 poles spring operated / Single pole

Type...BLK222

Opening time.. =<25 ms

Voltage level verification:

$$U_{yct} \le U_{NOM}$$

$$110kV \le 115kV$$

Loading current verification of equipment:

$$I_{norm} = 0{,}7 \times \frac{S_{NOM}}{\sqrt{3} \times U_{NOM} \times 2} = 0{,}7 \times \frac{63}{\sqrt{3} \times 115 \times 2} = 0{,}11\,\text{кА}$$

$$I_{p.y.} = 1{,}4 \times \frac{S_{NOM}}{\sqrt{3} \times U_{NOM} \times 2} = 1{,}4 \times \frac{63}{\sqrt{3} \times 115 \times 2} = 0{,}221\,\text{кА}$$

$I_{norm} \le I_{NOM}$, that is $0{,}11 \kappa A \le 2{,}5 \kappa A$

$I_{p.y.} \le I_{NOM}$, that is $0{,}221 \kappa A \le 2{,}5 \kappa A$

where $S_{NOM} = 63$ MVA.

Breaking ability verification:

$$I''_{p0.K1} \le I_{Sw.Off.NOM}$$

$$t_{C.B} = 0{,}025\,\text{s}$$

$$\tau = t_{3.\min} + t_{CB} = 0{,}01 + 0{,}025 = 0{,}035\,\text{s}$$

$$i_{a.\tau} = \sqrt{2} \times I''_{p.0K1} \times e^{-\frac{\tau}{T_a}} = \sqrt{2} \times 31{,}97 \times e^{-\frac{0{,}035}{0{,}03}} = 14{,}08\,\text{kA}$$

$$\beta_{pac} = \frac{i_{a,\tau}}{\sqrt{2} \times I_{\Pi.\tau}} = \frac{14{,}08}{\sqrt{2} \times 31{,}97} = 0{,}31 \text{ or } 31\%$$

$$i_{a.NOM} = \frac{\sqrt{2} \times \beta_{NOM} \times I_{Sw.Off.NOM}}{100} = \frac{\sqrt{2} \times 23 \times 40}{100} = 13{,}01 \,\text{kA}$$

Full short circuit current verification:

$$\sqrt{2} \times I_{\Pi.\tau} + i_{a.\tau} = \sqrt{2} \times 31{,}97 + 14{,}08 = 59{,}2 \text{ kA}$$

$$\sqrt{2} \times I_{Sw.Off.NOM} \times \left(1 + \frac{\beta_{NOM}}{100}\right) = \sqrt{2} \times 40 \times \left(1 + \frac{23}{100}\right) = 69{,}6 \,\text{kA}$$

Making current verification:

$$i_y \le i_{Sw.On} \text{ and } I''_{p.0} \le I_{Sw.On}$$

$$i_y = 77{,}62 \le i_{Sw.On} = 100$$

$$I''_{p.0.K1} = 31{,}97 \le I_{Sw.On} = 40 \,\text{kA}$$

Electrodynamical withstand verification:

$$I''_{p.0.K1} \le I_{DIN} \text{ and } i_{y.K1} \le i_{DIN}$$

$$I''_{p.0.K1} = 31{,}97 \le I_{DIN} = 40 \text{ kA}$$

$$i_{y.K1} = 77{,}62 \le i_{DIN} = 100 \,\text{kA}$$

Thermal withstand verification according to equation 5.12 and 5.13:

$$B_{k.pac} = I''^{2}_{p.0.K1} \times (t_{Sw.Off} + T_a)$$

$$B_{k.pac} \le I^2_{TER} \times t_{TER}$$

Breaking time for LTB-D type $t_{Sw.Off.B} = 0{,}047\,\text{s}$

$$t_{Sw.Off} = t_{C.3} + t_{Sw.Off.B} = 0{,}1 + 0{,}047 = 0{,}147 \,\text{s}$$

$$B_{k.pac} = I_{p.0.K1}^{''2} \times (t_{Sw.Off} + T_a) = 31{,}97^2 \times (0.147 + 0.03) = 180{,}9 kA^2 \times \sec$$

$$I^2_{TER} \times t_{TER} = 40^2 \times 0{,}177 = 283{,}2 kA^2 \times \sec$$

Summary verification of circuit breaker properties.

Table 5.2. Calculated and catalogue values.

Calculated value	Selection condition	General ratings from catalogue.
$U_{YCT} = 110$ kV	≤	$U_{NOM} = 115$ kV
$I_{MAX} = 0{,}221$ kA	≤	$I_{NOM} = 2{,}5$ kA
$I''_{p.0.K1} = 31{,}97$ kA	≤	$I_{DIN} = 40$ kA
$i_{y.K1} = 77{,}62$ kA	≤	$i_{DIN} = 100$ kA
$\beta_{pac} = 31\%$	≤	$\beta_{NOM} = 23\%$
$I_{\Pi.\tau} = 31{,}97$ kA	≤	$I_{Sw.Off.NOM} = 40$ kA
$\sqrt{2} \times I_{\Pi.\tau} + i_{a.\tau} = 59{,}2$ kA	≤	$\sqrt{2} \times I_{Sw.Off.NOM} \times \left(1 + \frac{\beta_{NOM}}{100}\right) = 69{,}6$ kA
$B_{k.pac} = 180{,}9 kA^2 \times \sec$	≤	$I^2_{TER} \times t_{TER} = 283{,}2 kA^2 \times \sec$

According to selection condition, value of short circuit current aperiodical component does not satisfy GOST standard 687-78E requirements. In this case full short circuit current verification is allowed and in accordance with it circuit breaker fulfils GOST standard requirements completely.

Summary.

Fault current calculations are carried out for primary equipment of substation to choose and prove circuit breakers, disconnectors and surge arresters. Calculation model is composed for substation 110kV working in normal operating conditions.

Fault current points for calculations are chosen in order to set primary equipment and conductors in the worst working condition in terms of fault current. The calculation model is composed in full accordance with main wiring diagram of electrical connection including elements fault current flows through.

In accordance with GOST and PUE following the equations presented in this chapter circuit diagram transformation, equivalent resistance determination and short current calculation analysis are carried out successively.

High voltage equipment and busbars selection is performed for continuous normal operating conditions. Operational verification is carried out for short circuit conditions. Three-phase short circuit is considered as a base case for further calculations.

Substation equipment verification includes loading current verification, electrodynamical and thermal withstand verification, full short circuit current verification and breaking ability verification.

On the base of calculation results summary verification of circuit breaker properties table is composed to compare general ratings from catalogue and calculated values.

By the example of switchgear module PASS M0 145 full calculation and equipment selection procedures for bridge type substation 110 kV were carried out. PASS M0 145 verification results are considered as satisfying the PUE requirements.

6. Lightning protection of bridge type substation 110kV.

In circumstances when uninterruptible supplying of end-customers becomes one of the main goal of generating, transmission and distribution systems, lightning protection arrangements are considered as the crucial point of such operations well-protected from impulse wave action coming from overhead lines to substation. *[17]*

In this chapter the basic lightning protection questions are considered successively: equivalent circuit of bridge type substation 110 kV transformations, finding of places with the most casualty effect, determination of years of uninterrupted operation and lightning-surge proofness index of high voltage equipment at open distributive system, and lightning protection results analysis.

Control for lightning protection is performed by special Energonadzor Authorities and its regional divisions, and also by local fire guard Authorities and Ministry of the Russian Federation for Civil Defense, Emergency Management and Natural Disasters Response.

Lightning protection control, evidently, is exercised also by insurance companies as the cost of insurance for units without lightning protection arrangements grows considerably and in certain cases insurance is impossible at all.

Lightning protection installation is compulsory procedure for promotion of safety of every substation unit and the whole substation itself. For evasion of lightning protection regulations money sanctions up to forced operation halt are foreseen. *[17]*

6.1 Main provisions on lightning protection of high voltage equipment at open distributive system.

Lightning discharges are the main source of external overvoltages in high voltage overhead lines. The most casualty effect on live elements of power grid is brought by lighting current of level 100 kA and even higher flowing in cases of direct lightning strike.

In the point of lightning impact an impulse of tens kilovolts appears what sure enough and leads to insulation flashover for even heavy-forced insulation up to highest voltage levels.

Dangerous impulses with the most casualty effect coming from overhead lines to substation may appear as a result of shielding failure and back flashover in case of lightning stroke in tower transmission line or overhead ground-wire cable within lightning protection zone. *[16]*

Evidently, those continuous improvements of shielding effectiveness of certain overhead lines as well as the whole power grid are main goal to protect lines and substations from expected number of failures concerned with lightning impulses.

However, lightning protection arrangements are well worked out and quite effective, the main undesirable effects are brought by arriving waves coming from overhead lines to substation

Lightning protection issues assume particular applicability in those cases where traditional methods do not bring the intended effect:

- overhead lines section with intensive local lightning activity
- high resistivity of ground

- very long spans over water or other huge obstacles

Overhead lines striking effect can be divided into two different modes:

- backflashover
- shielding failure

Main principles of lightning protection can be realized with following arrangements:

- overhead ground-wire cable
- line tower earthing contact resistivity R_{res};
- surge protection devices: valve-type lightning arresters and surge arresters.

Lightning-surge reliability can be estimated with help of mathematical expectation M – period between two lightning strokes in tower transmission line or overhead ground-wire cable.

$$M = \frac{1}{\beta};$$

Where β - lightning-surge proofness index– probable amount of lightning incidents per year. *[14]*

$$\beta_{pr} = N_{DLS} \times P_{pr} \times P \times (U > U_{PV});$$

$$\beta_{BF} = N_{DLS} \times (1 - P_{pr}) \times P \times (U > U_{PV});$$

Where,

U_{PV} - permissible voltage

P_{pr} – disruptive discharge probability

$(1 - P_{pr})$ – back flashover probability

6.2 Substation layout and initial data.

In this section high voltage overhead wires and overhead ground-wire cable parameters at open distributive system of bridge type substation 110kV are considered as well as typical bridge type substation layout with use of new innovative switchgear modules PASS M0.

All overhead wires and overhead ground-wire cable parameters required for lightning protection arrangements are presented in table 6.1

Table 6.1 Overhead wire and ground-wire cable parameters of bridge type substation 110kV. [16]

Equipment	Wire				
	Type	h, m	r, mm	n_p	r_p, m
Busbar	AC-120	8	7,6	2	0,2
Overhead line	AC-120/19	19.06	7.6	2	0,2
	Ground-wire cable				
Overhead line	Type	r, mm	h, m	n_p	r_p, m
	C-50	4.5	24.67	2	2.5

6.3 Equivalent model.

Equivalent circuit is composed on the base of substation main wiring diagram and substation layout. All equipment is replaced with equal localized capacitance one to one consequently. As a rule, main wiring diagram is happened to be too complicated and needs in simplification. Thus it suffices to simplify the main wiring diagram and bring it to view of equivalent circuit taking into account some following recommendation:

- determination of main nodes of wiring diagram should be saved from further wiring diagram simplification
- as a main nodes cab be accepted the nodes which satisfy the following conditions:

1. connection points to surge protection devices and tapping points to them,
2. power transformers connection points,
3. tapping points from busbar to power transformers,

4. coupling capacitor connection points or disconnector connection points to overhead lines whence the lightning impulses come,
5. other connection points where it is preferably to study lightning over voltages.

Equivalent circuit transformation.

All electrical equipment: disconnectors, circuit breakers, current transformers and etc can be presented in view of localized equal capacitance imitating spur lines. Localized equal capacitances are spaced apart between equivalent circuit connecting points according to torque principle, in other words, in inverse proportion to distances between connection point of certain localized equal capacitance and the nearest main nodes of equivalent circuit at both sides as it is shown in the Figure 6.1.

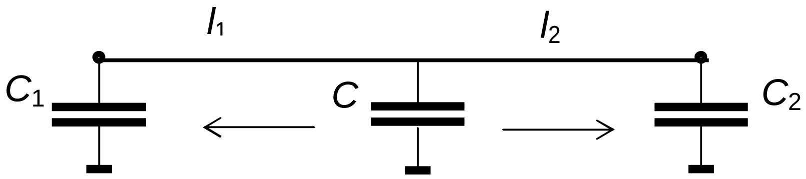

Figure 6.1. Spacing apart of localized equal capacitance according to torque principle. [14]

Localized equal capacitance can be estimated as following:

$$C_1 = \frac{l_2 C}{l_1 + l_2}; \qquad C_2 = \frac{l_1 C}{l_1 + l_2}; \qquad C_1 + C_2 = C\,.$$

It might be admissible to unite closely-spaced tapping point connecting lines, transformers of disconnectors, but only in way that keeps the distances between power transformer and the nearest surge protection devices unchangeable.

Values of localized equal capacitance for different substation units in the main nodes of wiring diagram are presented in the Table 6.2.

Table 6.2 Values of localized equal capacitances. [15]

Equipment	Rated voltage				
	110 kV	150 kV	220 kV	330 kV	500 kV
Power transformers and autotransformers, pF	800 - 1600	975	2000	3000	4200
Electromagnet voltage transformers, pF	300	470	300	300	500
Air insulated circuit breakers VNB, pF	-	300	-	250	250
Air insulated circuit breakers VVB, pF	130		150	250	250
Oil insulated circuit breakers (switched on), pF	800		800	-	-
Oil insulated circuit breakers (switched off), pF	500		500	-	-
Oil insulated circuit breakers VMT, pF	40		60		
Disconnectors (switched on), pF	60	190	100	150	200
Disconnectors (switched off), pF	40	100	60	100	150
Surge arresters, pF	60 (100)	100 (300)	80 (200)	100 (360)	150
Current transformers, pF	150	430	150	900	900
Busbar per one meter, pF	8	8	10	10	10

More detailed data gathered from different independent sources for substation 110 kV is presented in the Table 6.3.

Table 6.3 Values of localized equal capacitances for substation 110 kV.

Equipment	Sources				
	[14]	[15]	[16]	[17]	[18]
Power transformers (with capacitive compensation of high power), pF.	1600	800	800	1500	1000-1500
Power transformers (without capacitive compensation of low power), pF.	-	-	-	500	-
Autotransformers, pF	1600	-	-	-	-
Shuntings reactors	-	-	-	-	-
Coupling capacitors and standard-voltage dividers for power takeoff	6400	-	-	-	-
Electromagnetic voltage transformers	300	300	-	300	-
Air-insulated circuit breakers VNV	-	-	-	-	-
Air-insulated vacuum circuit breakers VNB	130	-	-	-	-
Oil-insulated circuit breakers (switched on)	800	500	-	500	-
Oil-insulated circuit breakers (switched off)	500	300	-	300	-

Disconnectors (switched on)	60	60	-	60	-
Disconnectors (switched off)	40	40	-	40	-
Surge protection devices: valve-type lightning arresters and surge arresters	60	-	-	-	-
Current transformers	150	300	-	-	-
Condenser-type leading-in insulators.	-	-	-	200	-
Non-condenser-type leading-in insulators.	-	-	-	150	-
Busbars (per 1 m. length)	8	-	-	-	9

Note, that all sources whence data was taken are listed in References.

Free ending busbars connected to tapping points distant from main nodes can be replaced with localized capacitance equal to input capacitance to ground.

For substation 110kV as a base can be accepted data from the second column source, where busbar substation capacitance equal to 8 pF per meter and average value of lightning activity can be admitted on the level of 30 hours per year, what corresponds to territory of European Part of Russia and Central Asia and Kazakhstan. *[14]*

On estimation probability direct lightning strike to substation equipment or high voltage overhead lines it should be started with point that there is an objective probability of direct lightning strike exists within certain territory not depending on whether it has been built up or not.

These maps of thunderstorm activity for the European Part of Russia and Central Asia and Kazakhstan are shown in Figures 6.2 and 6.3.

Figure 6.2 Thunderstorm activity map for Central Asia and Kazakhstan. [13]

Average number of direct lightning strikes per one square kilometer for certain territory can be found from thunderstorm activity maps. These maps are worked out for the huge territory of the Commonwealth of Independent States on the base of more than 40 years observation.

However, it should be taken into account that those maps are almost without update for the recent 10 years. Thus, to make lightning protection more reliable newer updated regional maps should be used.

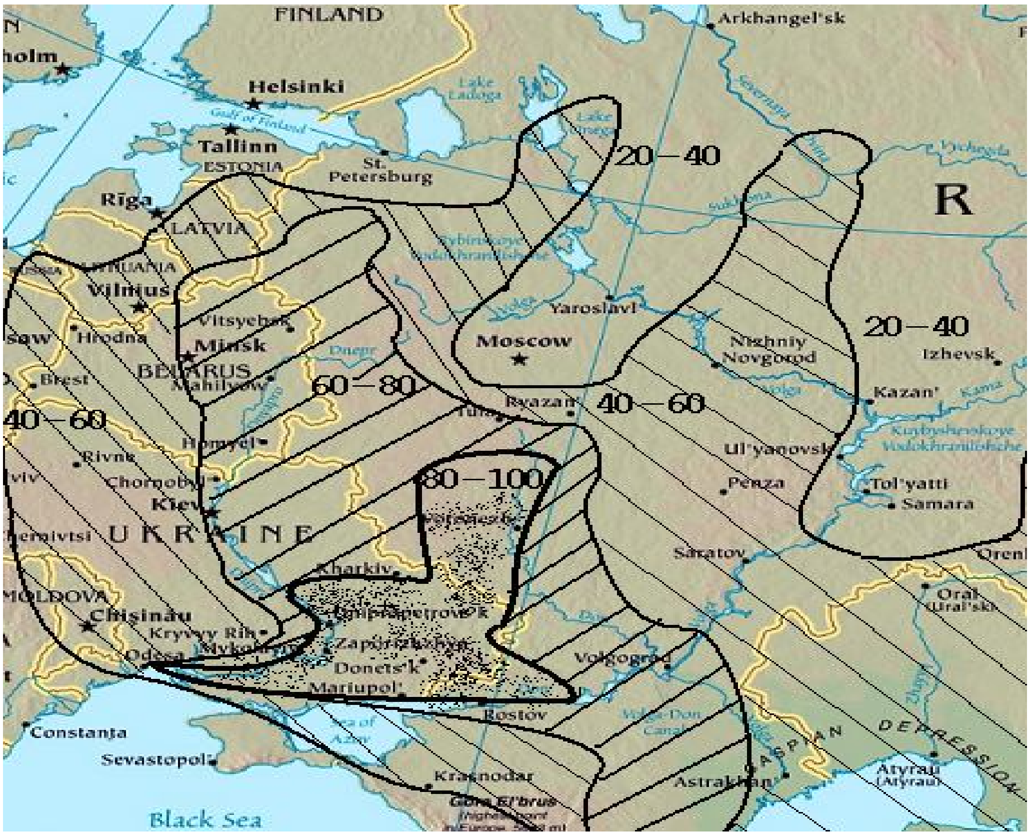

Figure 6.3 Thunderstorm activity map for the Ciscaucasian Russia territory. [13]

It can be easily seen from maps of thunderstorm activity that previous assumptions got from [15] concerning average number of direct lightning strikes per one square kilometer for the Ciscaucasian Russia correlate with map values quite well.

6.4 The node of wiring diagram estimation example.

A part of substation is taken for example of equivalent circuit diagram.

Every element of substation equipment is replaced with equal localized capacitance of this element and after that as a result of it an equivalent circuit diagram without notice of parameterization can be obtained as it is shown in Figures 6.4 and 6.5.

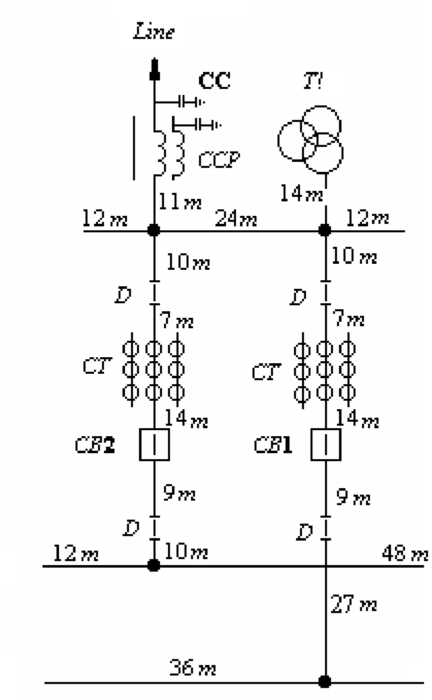

Figure 6.4. The node of wiring diagram example. [14]: CCP - carrier-current protection, CC - coupling capacity.

Hereafter, the equal localized capacitance is spaced apart with respect to main nodes of wiring diagram as it was described before. And, finally, equivalent circuit diagram with distributed and lumped parameters is obtained and presented in Figure 6.5.

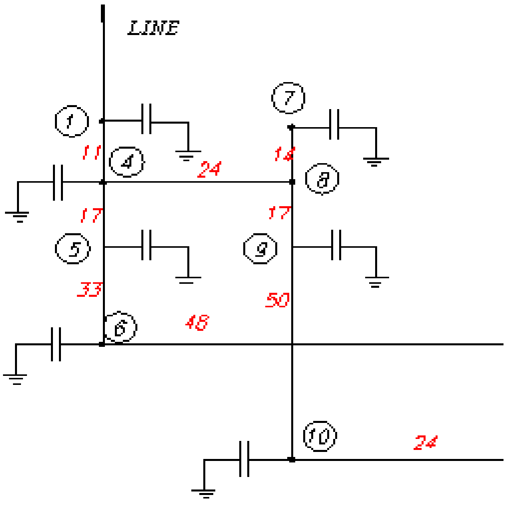

Figure 6.5 Equivalent circuit diagram with distributed and lumped parameters. [14]

6.5 Main provisions on equipment.

Initial data for open distributive system is set equal for all typical bridge type substations 110kV. Overhead lines supported by metal tower are protected, as a rule, by one or two overhead ground-wire cables which are hung over phase conductors and able to get the main impact of lightning impulse.

Applying overhead ground-wire cable to protect overhead lines from shielding failure decreases induced overvoltage amount in approximately one third. Nevertheless, rope protection does not completely except that induced high potentials on phase conductors may appear because back flashover from overhead line tower to phase conductors and also, although with less probability, direct lightning strike to phase conductor.

A lighting stroke leads as a rule, to insulator set overlapping what causes a dangerous impact on phase conductor of single-circuit tower and leads further to single line-to-ground fault of overhead line. *[17]*

Back flashover of twin-circuit tower causes a short failure between two circuits what must be completely excepted.

Applying surge arresters as a main surge protection device improves reliability of lightning protection for line insulation fail-safe operation. Surge arresters are installed directly on overhead power line towers.

Being a main surge protection device at typical substations 110 kV surge arresters installation let to solve the following problem: so far, comparing surge arrester with valve-type lightning arrester and finding the parameters of the former much better for deep voltage limitation, one question appears whether it is possible to remove overhead ground-wire cables or at least to decrease the length of protected zone. *[16]*

The minimal needed length for reliable lightning protection is determined also by value of tower footing resistance. The average value of tower footing resistance for considered territory can be set at level of 30 Ohm. However, in real circumstances the average value of tower footing resistance might vary depending on different environmental conditions and matter of soil. Average values of tower footing resistance can be accepted as 30 Ohm for normal conditions and 60 Ohm for heavy conditions. *[14]*

The current-voltage curve for *PEXLIM P120-XH123* surge arresters is assumed as base curve. Technical data in general for *PEXLIM P120-XH123* surge arresters is presented in Table 6.4.

Table 6.4 Technical data for PEXLIM P120-XH123. [19]

I, kA	with current wave 30/60 ?s (slow-front/switching)			with current wave 8/20 ?s (fast-front/lightning)		
	0,5	1,0	2,0	5,0	10	20
U, kV	228	234	243	260	274	300

The voltage level corresponds to surge arrester's nominal "opening" voltage level or in other words, the voltage level of the moment when surge arrester starts to react to lightning influence, can be found from equation:

$U_0 = \mathrm{U}_{\max} \times \mathrm{k}$

Where $\mathrm{U}_{\max}$ - maximum operating voltage

$\mathrm{k} = 1{,}6 - 1{,}7$

$U_0 = 152{,}3 kV$ can be accepted. *[14]*

6.6 Summary.

High voltage impulse is able to bring out of operation a number of substation units. Lightning strike into overhead line is extremely dangerous. Power cables are placed on the way of charge spreading in the ground also may become a path for fault current destroying interconnected substation equipment.

In most cases lightning charge creates a mighty electromagnetic field radiation which causes surge overvoltage in conductor – power surge of microsecond duration with peak value of several kilovolts. Although destructive power of such lightning charge impact is much more less than immediate lightning strike impact, but it spreads on considerable distances causing heavy and serious losses. According to PUE for 110 kV voltage level the recommended mathematical expectation value M - period within two dangerous lightning strikes occur –is set equal to 300 – 400 years.

The most expensive elements in main wiring diagram are of great importance to protect them from lightning overvoltage. For typical bridge type substation 110 kV before everything else the power transformer, potential and current transformers should be protected.

So far, dangerous surge impulses come from overhead lines because of high tower footing resistance equal 60 Ohm, resistance should be possibly decreased down to 20 – 30 Ohm as such tower footing resistance us a rule does not lead to dangerous surge impulses occurring. If it could not be done, at entrance of overhead line to the substation another additional surge arresters should be installed.

Lightning strike to power transmission tower or lightning protection cable line does not lead to dangerous surge impulses and back flashover if tower footing resistance is equal or less 10 - 20 Ohm. In case of shielding failure, line insulation overlapping occurs and surge arresters installation is reasonable only on top phases.

Lightning strike to lightning protection wire or power transmission tower with tower footing resistance more than 10 - 20 Ohm leads to back flashover from power transmission tower to bottom phase. Additional surge arresters installation on the bottom phases in those cases should decrease probability of to back flashover occurrence.

On lightning strike to power transmission tower or lightning protection wire area close to power transmission tower surge arresters undergo considerably more lightning energy deposition than on lightning strike to overhead line. Consequently, lightning strike to power transmission tower or lightning protection wire area close to power transmission tower has a decisive influence for surge arresters installed on bottom phase on lightning protection equipment selection.

Hereby, it is possible to implement a number of reliable solutions of surge arresters installation on power transmission towers depending on earth resistance value, thunderstorm activity and complementary requirements on overhead lines fail-safe operating.

However, the main principles could be formulated as following:

- A required amount of surge arresters with low capacity should be installed to protect overhead lines from lightning strike immediate to power transmission tower or lightning protection wire area close to power transmission tower;
- For overhead lines protection a required amount of surge arresters with high capacity should be installed on top phases to protect from immediate lightning strike to overhead lines;
- For economically feasible and reliable overhead lines protection from surge overvoltages caused by thunderstorm activity it is advisably to install surge arresters with both high and low capacity.

7. Conclusion.

Fast economical growth in Russia observed nowadays promotes auspicious opportunities for new power industry installations and modernization out-of-date equipment what became a long overdue necessity during two recent decades.

In this Thesis the current situation in power industry in Russia has been described and further perspectives for electrical equipment produced abroad have been determined. At the present moment the market conditions are estimated as favorable for such an equipment innovative technology utilization and meeting all Government Technical Requirements, GOST and PUE above all.

Switchgear innovative modules have been also examined in details and their advantages defined comparing with conventional primary substation equipment. For switchgear innovative modules the possibility of application within typical bridge type substation 110 kV conditions - minimal clearance distances, design and layout, air- and SF6-insulated circuit breakers and disconnectors requirements and other PUE and GOST requirements have been also considered.

Fault current calculations have been performed for primary substation equipment - circuit breakers, disconnectors and surge arresters selection.

By the example of switchgear module PASS M0 145 full calculation and equipment selection procedures for bridge type substation 110 kV have been carried out. PASS M0 145 verification results are considered as satisfying the PUE requirements.

An assumption is admitted for typical bridge type substation 110 kV widespread throughout the country and general and the most important technical requirements are described. However, technical requirements may vary depending on region: thunderstorm activity, earth resistance, force of wind and etc. In this case special technical requirements can be determined considering every substation separately.

In whole, finally, switchgear innovative modules utilizing leading-edge technology fulfill main technical requirements and it might be concluded that circumstances for innovative high voltage components on GOST standard market are favorable more than ever.

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