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SUBSTATION SWITCHYARD MODERNIZATION ANALYSIS AND WEB DESIGN DEVELOPMENT

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Abstract- The paper devoted to the analysis of optimal ways for substation modernization taking into account the requirements for electrical installations, carbon dioxide emission, and costs. The best up-to-date solutions in Russia and some other countries were examined. The key points affecting the effectiveness of the 500 kV switchgear retrofitting by installing the disconnecting circuit breakers and fiber optic sensors are highlighted. Corresponding to the purpose of the research, the high voltage switchgear of a conventional 500/220 kV substation was investigated within the scope of equipment cost analyses, digital substation technologies, future of the substation industry, and modernization applications. As the subject of the research, possible ways of modernizing the switchgear with different calculation methods are compared. The developed web page interface for online substation design is represented. According to the report generated from the interface, proper values for the equipment selection are defined and possible equipment for modernization are selected. The accuracy of the interface and the commercial structure of the web page are underlined.

Keywords: Substation, Switchgear, Disconnecting Circuit Breaker, Current Transformer, Voltage Transformer, Fiber Optic sensors, Web Design.

1. INTRODUCTION

The future of power engineering is shaped according to some main factors, such as: the unstoppable population of the world, globalizing technology, increasing energy demands, growing industrial needs, and the aidless planet trying to provide all important elements while carrying all the pollution that is created meantime. Between each of those factors, there is a complicated net of connections that may light the way of possible improvements to lead the design and development procedure more efficiently. Nowadays, the increased energy consumption and generation consequently, the greenhouse gas emissions followed and governments have started to initiate the reduction of carbon footprint, with the encouragements about a series of policy measures to stop climate change.

The share of renewable energy production worldwide recorded the fastest in the last decade. And the trend for the development of green energy is spreading to an increasing number of countries. Over the past five years, the part of renewables in total energy sources was estimated about 60% of the rapid growth in global production, while the use of wind and solar energy has more than doubled [1]. The installed capacity of renewables in the total energy production of the world increased significantly. Not only but also, grid businesses, the core business of the electricity industry, actively respond to climate change, establish energy conservation and emission reduction efforts, and promote the development for decrease in carbon footprint economy in the power industry [2-4]. Thanks to the policies that encourage a levelling of the net load curve, electricity costs and greenhouse gas emissions may be reduced by maximizing the use of variable renewable energy sources. Such policies can also optimize and modernize existing generation, transmission, and distribution capacity, easing grid reinforcement [5]. Despite the rapid share of electricity generation by renewables, the annually increased power demand caused by population growth and technological progress, may not be covered without burning fossil fuels for now. The modernizing of existing generation, transmission, and distribution systems equipment is the way to reduce the impact of oil, gas and coal as a source of power.

Digitalization of power industry and decarbonization are the most important goals of today's energy sector. Achieving the great results in this direction is possible by complete modernization or retrofitting the existing electrical installations. Political and economic issues influence to fulfilling ambitious plans for making the power engineering eco-friendly, more efficient, and with extremely high indexes of availability and reliability.

According to scientific studies of IEA, modernizing grids offers a great and sensible possibility to renovate the elements simultaneously. During the 2020-2030 years, the fifths part of global electric grids is expected to be updated, 16 million km of distribution lines and 1.5 million km of overhead lines approximately.

Since electrical substations are the key nodes of electrical power systems arranging the connections between primary source of power, it is clear that further improvements and best technological solutions integration will satisfy the power objects according to the 21st century standards [6].

2. MODERNIZATION ANALYSIS

The usage of technologies in electrical installations creates a significant improvement, in terms of increasing reliability, safety, operational flexibility, and finally economic efficiency. Nevertheless, when using cutting-edge equipment in the design of switching devices, instrument transformers, and conductors, the expected effect involves huge economical costs. The planning a substation to been build or modernize with non-conventional equipment creates significantly useful results. Especially, considering the less footprint of the non-conventional instrument transformers (IT) and disconnecting circuit breakers (which may be up to 90%), the price of land allocation for the substation can be decreased successfully as a major part of investments. The decreased footprint will lead the design or modernization process to more advantages. The amount of the reduction for construction and installation will reach up to 25% of total construction costs for conventional substation components.

During the designing of a new substation, the greatest costs are associated with the transporting and mounting of equipment. Moreover, for air-insulated substations with a high level of voltage like 500 kV, the construction cost will be about 63% of the total cost. For indoor substations, the percentage will be even higher, reaching 68%. Considering the switchyard of 500 kV substation only, the share of equipment cost is defined as about 72%. The resting 28% percentage of the cost comprises only the construction cost. By comparing this value with the erection percentages of the total substation and considering the first or previous construction expenses of the conventional substation as an evident loss, modernization of the switchyard only will become an affordable, sensible, and leading option. That, leading the investments to cover the equipment itself firstly, will keep the price-performance ratio of the modernization at a sensible level. Therefore, to increase the efficiency and reliability of existing substations, it is advisable to modernize the facility, besides building a new one.

On the other hand, the economic analysis findings outlined that, in some cases, the construction of a new substation may be more profitable than updating an existing one. According to various estimates, the deterioration of the equipment of Russian substations today averages 50%. Considering the total expenses, rebuilding the substation might create more reliable and sustainable results. Whereas, a partial reconstruction of the existing substation with a moderate degree of deterioration in general, is more than appropriate in the current economic conditions. Also, since the replacement of technically and physically obsolete equipment is necessary during each reconstruction, the increase in the reliability and the continuity of the power supply, make the procedure certainly preferable. In the light of the given information and findings, besides comparing rebuilding and modernizing, focusing on the modernization costing analysis might help define the details of future plans for substations.

As a primary goal of power systems, all inlets, outlets, and intermediate steps of a substation should be operated according to the limitations defined according to the policies, demand expectations, capacity characteristics, and the system's physical situation. Furthermore, as well as all common forms of industrial energy, electricity might be dangerous in case of running out of control. Even with an optimistic view, any possible failure may interrupt the system and create indirect problems. Each failure should be predicted and compensated precisely to prevent an accident or interruption. Such as all power systems, to keep the substation safe and under control, the design of secondary systems such as measuring and controlling systems requires significant attention. The industry of IT as a fundamental member of measuring and controlling systems provides the safe, reliable, and inventive solutions for modern needs. Nevertheless, considering the costings and estimating the share of IT in all substation investments will be defined as 1-3%. Surprisingly, besides the high costs of other equipment with the higher technology, new generation IT provides new technology at less cost.

In addition, the modern technology of non-conventional equipment will make the process more sensible based on reduced costs for maintenance, minimizing of utilization costs, refusing the copper cables, elimination of the analogue-digital converters, and modernized controls over the system's working factors. Taking into account aforesaid, the possibility to increase the speed of operation of protective relaying will be higher and the differential protection will operate with higher level of sensitivity.

As in all engineering fields, the cost-performance relationship should be kept at a reasonable level in the design or modernization of the substation. Fortunately, there is serious competition among manufacturers and it is possible to find better solutions in the purchasing process. Because especially for the secondary equipment such as fiber optic cables, optical sensors, and data cables, more items will be needed. For example, for a 500 kV switchyard three fiber optic cables will be required in general. These will be for protective relaying, backup protection, commercial accounting, and other measurements.

Up-to-date and rather obsolete technologies may bring some risks due to practical experiments or fatigue. However, with new technology, it is much easier to define and solve possible problems. For example, at the "Tobol" 500 kV substation there are 10 SF6 circuit breakers and 25 free-standing center break disconnectors. Changing them for DCB may be sensible but the mentioned parameters about costing and performance should be considered deeply and following the certain policies in its modernization processes.

According to the Russian Power Grids Company "Rosseti" requirements, one of the largest electricity grid companies in the world, the payback period for digitalization is recommended to be limited by 10 years. At the same time, despite their higher costs, pursuing eco-friendly solutions, provides better results for nature because SF6 IT is not environmentally friendly for sure. Also, the operating costs of monitoring gas leakage, the danger of opening secondary circuits at the current transformers, maintenance, utilization costs, construction costs, the need for an analogue digital converter for compliance with the IEC61850 standard, large weight, and size make them less efficient than non-conventional IT [7].

Initially, the 500 kV switchyard was arranged according to a scheme with two circuit breakers per three connections. Six single-phase autotransformers AODCTN-167000/500/220 and six transmission lines are connected to the switchyard. Air blast circuit breakers VVBK-500-50, disconnectors RNDZ-500/3200U1, measuring transformers of current TFZM-500B-1 and voltage NKF-500-78U1 are installed in the scheme.

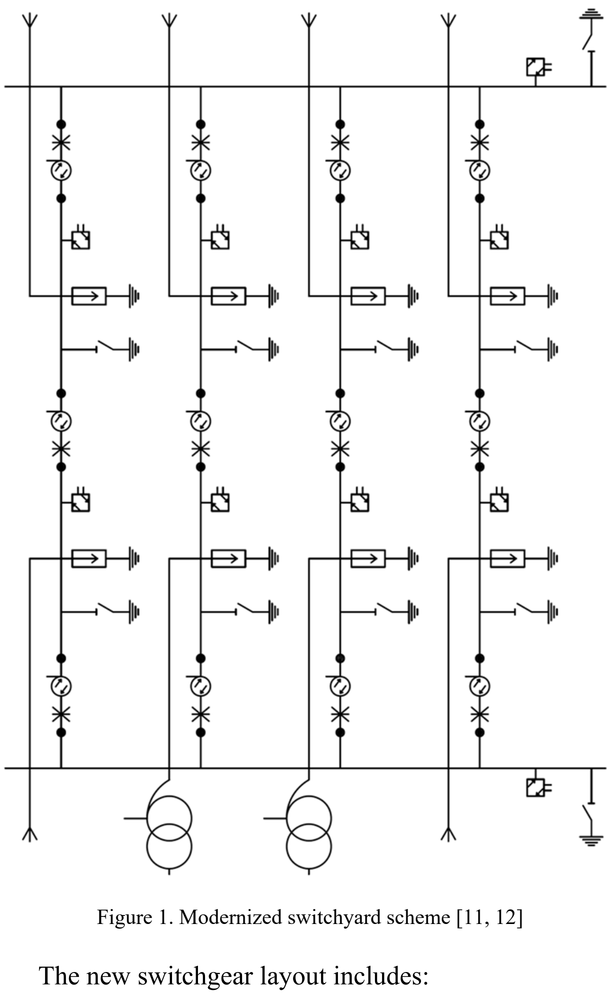

Figure 1. Modernized switchyard scheme [11, 12]

The new switchgear layout includes:
- fiber optic current sensors 500 kV electronic voltage transformers 500 kV by Profotech, Russia [8, 9],
- disconnecting circuit breakers VGT-500 type by Uralelectrotyuazmach, Russia [10].

Russian products were chosen after examining the equipment market (price, transportation time and costs.

It should be mentioned that only refusing the big amount of horizontal type disconnectors (with size about 5.4m*4.8m) from both sides of circuit breakers decreased the scheme dramatically, as well as outage time, costs, and time for service in advance [11].

Scheme layout is considered to be flexible and reliable and kept unchanged as three circuit breakers per two connections in accordance with Russian Ministry of Energy last standards. Further improvements of substation will include replacing flexible buses for rigid construction, solid-state relays and analogue-digital converters for digital protection and automation system.

Having applied the cutting-edge equipment [12, 13, 14] and solutions, the switchyard scheme was changed with enriched reliability, availability and less footprint (about 35% reduction) [15, 16].

3. ONLINE SUBSTATION DESIGN INTERFACE

According to the details described above, it is possible to say that substation design and modernization is of great importance. Especially, the future potential of digital substation applications supports the predictions in this regard. According to the report published by Global Market Insights in 2020, Digital Substation commercial volume, which was 96 billion USD in 2020, is expected to exceed 130 billion USD in 7 years. This 7-year increase expectation paves the way for digitalization in the substation market. The CAGR (compound annual growth rate) is over 6% to such an extent. Additionally, government regulatory policies and updates to conventional power system components for energy companies and customers will contribute the positive economic prospects. The energy research and development sector are expected to experience a significant increase due to the increasing demand for efficient transmission and distribution control systems. In the absence of efficient power grids in developing countries, efforts to expand existing infrastructure are increasing at a level that meets expectations.

The positive trend of today's consumers towards substation installation to provide reliable source of power and the increase in power grid operation time, availability, efficiency will force the energy industry and influence to the new breakthrough technologies design. In addition to the report, when the worldwide pandemic in 2019 is taken into account, it can be understood that the expected increases in the use of renewable energy resources and in the substation, market are in a mutualistic relationship and web design of many technological processes are crucial [17].

Based on this potential, a world-wide web-based interface was created which leads the users to enter the initial data of the electrical power system, to see the basic principles of substation design or modernization, to define the required values for each element, to choose the elements according to the required values, to define the approximate cost, lifetime, efficiency, reliability and scheme layout, to compare and analyze the different effects of the combinations of the elements, and to generate the report that includes all useful information regarding the design or modernization procedure [18].

The interface welcomes the user to the form in Table 1 with checkboxes showing that it is possible to choose one to three sources and one or two loads while entering the initial data of the system.

Table 1. Example of entering the initials to the interface [18]

Voltage Value (UHV)			500	kV
Sources				
● S1 ● S2 ○ S3	Source1		Source2	
Apparent Power	8000		9500	MVA
Reactance	0.8		0.9	Per Unit
OHL Length	240		80	km
Please define the power demand qualifications				
Loads				
● L1 ● L2	Load1		Load2	
Voltage	220		10	kV
Active Power Demand	360		56	MW
r_sim	0.87		0.8	-
Power Factor	0.92		0.9	-
Operating Hours	7500		5000	Hours
Please define the ratio of transformer load by consumer category				
Consumer Categories	Range		Value	3-ph PT
● 1st Category	0.65 - 0.70		0.70	≥ 2
○ 2nd Category	0.70 - 0.80		0.80	2
○ 3rd Category	0.90 - 0.95		0.95	1 or 2
○ Design Preference	Enter here…			
Please define the network qualifications				
S Basis			1000	MVA
Number of Transformers			2	-
Please define the voltage value for the periodical current at zero time				
Voltage Value (USC)			500	kV

Especially in this part, the backend development of the interface was created with several arrangements to let the interface answer different options such as:

- single source - single load,
- single source - two loads,
- two sources - two loads.

If all the required values are entered into the system according to the definitions, the submission button leads the user to the following part as Table 2, which gives a chance to the user to check and verify the entered values.

In Tables 3 and 4 it is possible to generate the primary or detailed report with one click and achieve all the useful information as results of the calculations and algorithms. The web design part consists of different layers such as frontend (visible) and backend (hidden) development and completely satisfies the requirements for ergonomic usage. HTML frameworks were used to accelerate the backend of the interface and to create a clean, sensible, and efficient look at the frontend of the interface.

In this regard, it was one of the challenging parts to show the possibilities of the interface to the user. At this point, JavaScript was used to animate some parts of the interface providing ergonomic usage with collapsible elements, alerts and warnings. At the same time PHP coding was effective and sensible while creating the calculations and tables during backend development.

Table 2. Checking the initial parameters [18]

Voltage Value (UHV)		500	kV
Sources	Source1	Source2	
Apparent Power	8000	9500	MVA
Reactance	0.8	0.9	Per Unit
OHL Length	240	80	km
Loads	Load1	Load2	
Voltage	220	10	kV
Active Power Demand	360	56	MW
r_sim	0.87	0.8	-
Power Factor	0.92	0.9	-
Operating Hours	7500	5000	Hours
Network Initials			
Transformer Load Ratio		0.7	-
S Basis		1000	MVA
U Mid-rated		515	kV
Number of Transformers		2	-
Specific Resistance		0.30	ohm/km
Edit Initial Data			

Table 3. Primary results of the interface [18]

Medium Voltage Power Demand (MV PD)			
MV_P	313.2	MW	Active PD at MV
MV_S	340.43478260	MVA	Apparent PD at MV
MV_Q	133.42264129	Mvar	Reactive PD at MV
Low Voltage Power Demand			
LV_P	44.8	MW	Active PD at LV
LV_S	49.777777777	MVA	Apparent PD at LV
LV_Q	21.697630296	Mvar	Reactive PD at LV
Total Active Power Demand			
MV_P	313.2	MW	Active PD at MV
LV_P	44.8	MW	Active PD at LV
HV_P	358	MW	Active PD at HV
Total Reactive Power Demand			
MV_Q	133.42264129	Mvar	Reactive PD at MV
LV_Q	21.697630296	Mvar	Reactive PD at LV
HV_Q	155.12027159	Mvar	Reactive PD at HV
Total Power Demand at HV			
HV_P	358	MW	Total Active PD at HV
HV_Q	155.12027159	Mvar	Total Reactive PD at HV
HV_S	390.16188775	MVA	Total Apparent PD at HV

Table 4. Detailed results of the interface [18]

Transformer Selection Parameters			
I Installed	0.2252600709	kA	Installed Current
Minimum Rated Apparent Power of Power Transformer at HV			
S_Rated	273.11332143	MVA	1 Power Transformer (Three phase)
S_R. (3p)	91.037773810	MVA	3 Power Transformers (single-phase)
Network Calculations			
S BASIS	1000	MVA	Accepted Basis Apparent Power
U Midrated	515	kV	Basis Voltage Level at s/c Point
I BASIS	1.1210684838	kA	Basis Current at s/c Point
Per Unit Specific Reactance			
XSP	0.30	Per Unit	Midrange Specific Reactance of Transmission Line
Source1 Reactance Values			
XS1 PU	0.1	Per Unit	Reactance of Source 1
XL1 PU	0.1357338109	Per Unit	Reactance of OHL 1
X1	0.2357338109	Per Unit	Equivalent Reactance 1
Source2 Reactance Values			
XS2 PU	0.0947368421	Per Unit	Reactance of Source 2
XL2 PU	0.0452446036	Per Unit	Reactance of OHL 2
X2	0.1399814457	Per Unit	Equivalent Reactance 2
Total Reactance			
XK1 PU	0.0878281067	Per Unit	Equivalent scheme reactance for s/c point 1

Periodical Current at Zero Time			
USC	500	kV	Voltage at s/c Point
UPU	1	Per Unit	Voltage Per Unit at s/c Point
IK1P0	12.764347605	kA	Periodical Current at Zero Time
Calculated Values for Switchyard Equipment Selection			
Parameter	Value	Unit	Explanation
U Ins	500	kV	Installed - Rated Voltage
I Ins	0.2252600709	kA	Installed - Rated Current
I B0	12.764347605	kA	Breaking Current
I Peak	33.395299972	kA	Making Current
Circuit Breaker Timing Options According to circuit breaker timing preferences and catalogue data it is possible to calculate the thermal withstanding below.			
t_CB / CB Opening Time (from the catalogue)		0.02	sec.
t_PR_min / Minimal Time of Protective Relaying		0.01	sec.
t_AR / Auto-reclosure time		0.21	sec.
	Calculate S/c Thermal Withstanding	48.878570938	kA^2 * s

4. CONCLUSIONS

Currently, the issue of modernization of electric power facilities is of great importance, because the deterioration of equipment at some electrical installations in Russia is 50% or even more. In addition, the digitalization of the industry that was announced to be achieved within ten years and compliance with the IEC 61850 standard are the exclusions of leaving the situation in its current position.

The modernization of 500 kV switchyard was firstly analyzed, calculated and eventually fulfilled by the online substation design. The interface that was created is flexible and meets user expectations by providing friendly interface with easiness of application. In this regard, the results of the Excel calculations which form the basis of the coded web-based interface, manual calculations, and the calculations of the web-based interface, were compared and the accuracy rates are extremely high.

Developed web design is expected to be in the nearest future as the tool to:

- Create a connection between manufacturers of electrical installation elements and the substation builders such as research institutes, manufacturing companies, and engineers,
- Clarify the calculation methods of the substation design procedures by writing the special manual for some engineers, students, etc.
- Minimize the possible errors and defining better results by calculating all the values according to the algorithm based on scientific formulations and accurate database parameters,
- Generate the primary and detailed results reports with numerical values of required scheme parameters, scientific graphs, costings and analytics.

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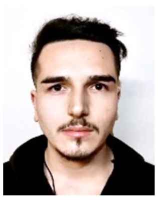
BIOGRAPHIES



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