Standardized design solutions for typical and adapted distribution substations 10(20)/0.4 kV

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Abstract – **In this paper will be shown the whole process of designing type and adapted distribution substations 10(20)0.4 kV using the standardized solutions. In addition, will be given calculations required for the dimensioning of the medium voltage and low voltage equipment, grounding, such as the calculations of the short-circuit currents on the MV and LV side, depended the current load on the MV and LV side, the generated heat at the maximum load of the transformer and the value of earth resistance. All calculations will be performed for standardized types of equipment, depending on the power of the transformer.**

Keywords – **distribution substations, designing, standardized solutions.**

I. Introduction

The subject of this paper is part of the technical solution for power supply to an appropriate facility from an adapted substation. For connection to the new substation of the power distribution network is planned new dual cable which is included input-output connection for up to two injection cells in the MV switchgear of the substation, which is not the subject of this paper.

According to the approved peak power of 656 kW, given in the Decision for the consent for connection (issued by the Distribution System Operator - ODS in the Republic of Macedonia - EVN Macedonia), a transformer with a power of 800 kVA is chosen, and the measurement of the electricity should be placed on medium voltage side.

Technical data for substation: Rated operating voltage 10 (20) kV, Maximum operating voltage 24 kV, Operating voltage (Ue) on the low side 0,4 kV, Rated frequency 50Hz, Level of insulation on the medium side 50 kV, Impulse voltage that can be maintained (U 1.2/50 μs) on medium side 125 kV, Impulse voltage that can be maintained (U 1.2/50 μs) on low side 8 kV, Rated current of circuit breaker (line feeder) 630 A, Rated current of circuit breaker (transformer feeder) 200 A, Rated current of circuit breaker between MV switchgear and LV switchboard 1250 A, Thermal current which can be maintained for a short time on LV side 25 kA, Dynamic current which can be maintained for a short time on LV side 40 kA, Power of transformer 800 kVA.

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II. Disposition of Equipment

The facility consists of two sectors: a medium voltage switchgear, a low voltage switchboard and transformer box.

The transformer box is placed in the right part of the facility and in this part an oil transformer with porcelain insulators 10.5 (21) /0.42 kV, 800 kVA will be installed. The substation in the transformer box has an oil pit to collect the oil that may expire in the event of a major accident.

The middle voltage unit will be placed in the sector for the MV and LV plants at the far left side of the building.

The LV switchboard will be placed on the barrier wall bordering the transformer box.

III. Medium - voltage switchgear

The middle voltage facility will be equipped with a type 20 kV switchgear consisting of three supply input-output terminals, one coupling, one measuring and one transformer cell.

In the metallic cabinets of the injection cells, a circuit breaker with a grounding device is installed, the measuring current transformers and measuring voltage transformers will be placed in the measuring cell, a circuit breaker is placed in the coupling cell, in the transformer cell the circuit braker is combined with fuses, and the switchgear is filled with gas SF6 under pressure.

IV. Power transformer

In the substation, a transformer will be built with the following characteristics:

TI-ERM 630 kVA: power 800 kVA, transformation ratio 3 x 10,5(21)/0,42 kV, connection Dyn5, frequency 50 Hz, transformer type oil, no conservation, cooling mode ONAN, no load losses 1400 W, load losses at 75º 8700 kW, impedance voltage at 75º 6%, dimensions 1735x830x1900 mm, oil weight 460 kg, total weight 2300 kilograms.

The connection between the low voltage connections of the transformer and the input switches of the low voltage switchboard, as a type solution, is with a 3 x (4 x NYY-0 1 x 2 40 mm^2 Cu RM) + 2 x NYY-0 1 x 240 mm^2 Cu RM.

V. Low-voltage switchboard

The low voltage installation is performed as a type switchboard on a stand-alone frame. The plant consists of a supply, a protective and an exhaust part.

The supply part is in the middle upper part of the board and the cables that are driven from the transformer's second side are connected here. It is equipped with a low-voltage three-phase circuit breaker type NS 1250N 3p 1250A, Micrologic 2.0, Schneider Electric.

The product consists of ten power supply terminals to equipped with a vertical three-phase circuit breaker with fuses 630 A.

VI. Meausuring

Measuring the electricity is an obligation for the electrical distribution system's operator, with single-pole isolated measuring voltage transformers along their transmission ratio 20000 / 1.73 (10000 / 1.73) /100/1.73/100/1.73 V / V / V and electrical voltage transformers with transformation ratio 2x25/5/5 A/A/A, 24 kV.

VII. Commands

The circuit breaker can be manually operated onsite, using manipulating handles. Moreover, turning the LV switch on and off, can be manually controlled onsite.

VIII. Blockades

In order to prevent making mistakes during usage and handling the substation's equipment, the following blockades will be provided: the separate switch can be turned on along with a special handle, it will be located in the middle voltage block, next to the entrance door and access to the MV fuses because of their replacement, it is accessible only when the separated switch is turned off, as an alternative like the only case when the door is opened and the fuses can be replaced.

IX. Lighting

ATS is illuminated with two 1 × 24 W lamps, IP65 housing, mounted in the sector of MV and LV installation and transformer box.

X. Protection

For transformer's protection, from short-circuits currents on the medium voltage side and short-circuits currents from LV busbars, we will provide and highly powered fuses such as MV VM50 A, with a striking needle that automatically activates the circuit breaker deactivation inside the transformer filed. The transformer is protected from overloading by a secondary thermal replay(4-8)A, which automatically turns the switch off inside the transformer field on the high voltage side, in conditions of extremely increased temperature above the prescribed one.

XI. Earthing

In order to protect our employees from highly unaccepted voltage, we will provide working and protective grounding. Besides protecting our stuff, grounding will be used in KBTS for transformer's proper and normal work, where we predict to perform grounding on the main substation.

To accomplish our working grounding goal, we are willing to perform a set of three galvanized probes, with length of 1.5 meters and a cross section of 63 millimeters. Probes will be placed as vertices of a equilateral triangle with side's length of 15 meters. Each other, probes are connected with two rows of galvanized tape FeZn 40 x 4 millimeters square, where they will be set 25 meters from substations. Whole working grounding is connected with cable H07V-K-1 x 50 millimeters square and it is directly connected with transformer's zero. (Due to the spatial availability, the inverstor during the performance will decide the exact location of the grounding and consequently its proper way of realization).

Protective grounding will be performed as a set of two rectangular shapes, placed on galvanized tape FeZn 40 x 4 millimeters square, set on appropriate position around substations. Their interconnection must be correct, as well as connection to the potential equalization rail. First shape is placed on 1 meter distance and 0.5 meters depth of substations's shapes. On the other hand, the second one is placed on 1 meter distance from the first one and 1 meter depth. Additionally to our protective grounding will be connected a galvanized steel tape, which is parallel to the middle voltage cables.

On the equalization potential will be linked: the grounding of the low voltage board, transformer's core, surge arresters, metal shears from medium voltage cables and all metal parts of substation's equipment, which are not under voltage in normal operation.

All electrical installation work will be performed in accordance of valid norms and regulations. In the end of our work, we will execute all the necessary testing, for which will be determinated and specified suitable protocols.

XII. Compensation of reactive power of the transformer

The reactive power compensation of the transformer with a power of 800 kVA is resolved with a capacitor battery alongside the LV switchboard, with a power of 50 kVAr. The capacitor battery will be connected to a single drain line on the LV switchboard via the NAY2Y-J 4x50 mm2 cable. The lead-out cable will be protected by fuses LV 125 A. This battery will only be used to compensate for the reactive power required to magnetize the core of the transformer, while for full compensation of the engaged reactive power by consumers, it is necessary to perform appropriate analyzes of the different load modes in operation, and to select appropriate automatic compensation.

XIII. FIREFIGHTING AND PROTECTION AT WORK

In the substation, it is planned to install a rubber insulating carpet 24 kV, in the sector of the MV swichgear and LV switchboard. Also, firefighting appliances are provided in both premises. In the sector of the MV switchgear, a box with protective tools and insulation equipment should be placed. On the wall beside the MV block to place plates with a single-pole pattern, the five golden rules, a manual for indicating first aid and a warning for the danger of high voltage.

XIV. CALCULATIONS OF THE SHORT-CIRCUIT AT THE 10(20) KV BUSBAR

The choice of equipment and dimensioning of the busbar is based on the power of a three-phase short circuit of the 20 kV busbar, which equals Sk3 "= 500 MVA.

- Initial three-phase short circuit is:

$$I_{k3}'' = \frac{S_{k3}''}{\sqrt{3} \cdot U_n} = \frac{500 \cdot 10^3}{\sqrt{3} \cdot 20} = 14.43 \text{ kA}$$

Peak short curcuit current is:

$$I_u = k_u \cdot \sqrt{2} \cdot I_{k3}'' = 1.75 \cdot \sqrt{2} \cdot 14.43 = 35.71 \text{ kA}$$

Where:

k_u -peak coefficient that depends on the ratio R / X on the network and for R / X = 0,1 ku = 1,75;

Effective short-circuit current value is calculated bellow:

$$I_{ks} = I_{k3}'' \sqrt{m+n} = 14.43\sqrt{0.2+0,8} = 14.43 \text{ kA}$$

Where:

m and n are coefficients that depend on the direct and alternating short-circuit current component. Their values are obtained from the diagram in dependence of the peak coefficient, and for the minimum switch-off time of the switch = 0,25 s.

Breaking short-circuit current is given bellow:

$$I_r = I_{k3}'' = 14.43 \text{ kA}$$

XV. CALCULATIONS OF THE SHORT-CIRCUIT AT THE 0.4 KV BUSBAR

To calculate the short-circuit currents and power of the 0.4 kV side, an equivalent impedance to the 0.4 kV side should be determined.

The calculations will use the selected transformer data. The impedance of the network, reduced to a voltage of 0.4 kV, is calculated as follows:

$$Z_Q = \frac{c \cdot U_Q}{\sqrt{3} \cdot I_{kQ}''} \left(\frac{U_{rTLV}}{U_{rMLV}} \right)^2 = \frac{1,1 \cdot 20}{\sqrt{3} \cdot 14,43} \left(\frac{0.42}{21} \right)^2 = 0.352 m\Omega$$

where:

c - a voltage factor that depends on the voltage of the system;

U_Q - nominal voltage on the MV network;

U_{rTLV} - nominal voltage on the LV side of the transformer;

U_{rHLV} - nominal voltage on the MV side of the transformer;

I''_{kQ} - initial short-circuit current of MV network.

It follows that the inductive and ohmic resistance will be:

$$X_Q = 0,995 \cdot Z_Q = 0.35 \text{ m}\Omega; \; R_Q = 0,1 \cdot X_Q = 0.035 \text{ m}\Omega$$

The direct short-circuit impedance of the two-way transformer, as well as the ohmic resistance, are calculated according to the transformer data:

$$Z_{TLV} = \frac{u_{krT(\%)}}{100} \cdot \frac{U_{rTLV}^2}{S_{rT}} = \frac{6}{100} \cdot \frac{0.42^2}{0.8} = 0.0132 \, \Omega$$

$$R_{TLV} = \frac{P_{krT}}{3 \cdot I_{rTLV}^2} = \frac{8700}{3 \cdot 1156^2} = 0.0022 \, \Omega$$

$u_{krT(\%)}$ - short-circuit voltage of the transformer;

S_{rT} - nominal power of the transformer;

P_{krT} - losses in the windings of the transformer at a nominal current;

I_{rTLV} - nominal current on the LV side of the transformer.

As it follows, the inductive resistance of the transformer will be:

$$X_{TLV} = \sqrt{Z_{TLV}^2 - R_{TLV}^2} = 0.013 \Omega$$

Equivalent impedance of 0.4 kV busbar:

$$R_e = R_Q + R_{TLV} = 2.235 \text{ m}\Omega;$$

$$X_e = X_Q + X_{TLV} = 13.35 \text{ m}\Omega;$$

$$Z_e = \sqrt{R_e^2 + Z_e^2} = 13.53 \text{ m}\Omega$$

The calculated value of the maximum current of a symmetrical three-phase short-circuit is:

$$I_{k3}'' = \frac{cU_n}{\sqrt{3} Z_e} = \frac{1,1 \cdot 0,4 \cdot 10^3}{\sqrt{3} \cdot 13.53 \cdot 10^{-3}} = 18.84 \text{ kA}$$

For ratio R / X = 0.17 it is read ku = 1.7 and calculated the value of the peak current of a three-phase short circuit, the Breaking and durable short-circuit current is adopted to be:

$$I_r = I_t = I_{k3}'' = 5.928 \text{ kA}.$$

XVI. 20 KV CABLE DIMENSIONING

Nominal current of 20 kV busbar is:

$I_n = \frac{S_n}{\sqrt{3}\cdot U_n} = \frac{800\cdot 10^3}{\sqrt{3}\cdot 10\cdot 10^3} = 46.24$ A - when working at 10 kV level;

For the 20 kV connection power transformer-20 kV switchgear the selected cable type NA2XS (F) 2Y 1 × 50 mm2, with crosslinked polyethylene insulation, can be charged with a current of 200 A.

Thermal control of the cable (short circuit control)

The minimum allowable section of the conductors will be:

$$A_{min} = C\cdot I''_{k3}\cdot\sqrt{t} = 10.9\cdot 14,43\cdot\sqrt{0.004} = 9.95 < 50\ \text{mm}^2$$

The conclusion is that the cable is thermically satisfactory.

XVII. 0.4 kV Cable Dimensioning

$$I_n = \frac{S_n}{\sqrt{3}\cdot U_n} = \frac{800\cdot 10^3}{\sqrt{3}\cdot 0.4\cdot 10^3} = 1156\ \text{A}$$

For 0,4 kV connection energy transformer - 0,4 kV switchgear, the selected cable type NYY 4 × (1 × 240) mm2, with PVC insulation, can be charged with a current of 4 x 520 A = 2040 A, to accept the coefficient of load reduction due to poor heat dissipation in parallel cable guidance, which in the case of a bundle of four cables in the air is 0,65:

$$I_n = 1156 < 0.65\cdot 2040 = 1326A$$

Thermal control of the cable (short circuit control) Accordingly, the minimum allowable section of the conductors will be:

$$A_{min} = C\cdot I''_{k3}\cdot\sqrt{t} = 8.9\cdot 18.84\cdot\sqrt{1} = 167mm^2 < 4\times 240 = 960\ \text{mm}^2$$

The conclusion is that the cable is thermically satisfactory.

VI. Conclusion

This paper presents the use of standardized solutions currently used in the Republic of Macedonia in the design of typical and adapted substations, respecting all positive norms, laws, technical recommendations, as well as the recommendations of EVN Macedonia. Here is shown how one adapted substation with an installed power of 800 kVA is designed, how the elements are dispositioned, calculations of short circuits and at the same time the dimensioning of the equipment.

References

[1] EVN Macedonia Handbook - Transformer Tech

[2] EVN Macedonia Handbook - Cable Tech

[3] Mile Spirovski, Igor Sterjovski, Projects from Mehanotehnika DOOEL, Bitola