Automation of calculations of power transformers windings parameters taking into account the position of the voltage regulator

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Abstract. We consider the issues of modeling power lines using a self-adjusting mathematical model which allows analyzing the lines operating modes while tracking instantaneous values of parameters. The obtained model can be used to build high-speed protection against phase-to-phase faults in power lines with a voltage of 10-35 kV, which have a small length.

1 Introduction

For calculation of short circuits in a circuit with power transformer with a voltage regulator device [1–8], the well-known method described in [9] and [10] uses assumptions, according to which transformer resistances are calculated only for the average and limiting taps of the voltage regulator. This simplification leads to a significant error in calculation of currents during short circuits, which unjustifiably increases the unbalance of the differential protection of power transformer and reduces the sensitivity of the current relay protection and automation (RPA). The proposed software product eliminates this disadvantage.

2 Materials and methods

The high voltage side (HV) of most power transformers in neutral is equipped with on-load tap changer (LTC). The LTC purpose is to keep voltage on the low-voltage side of the transformer close to nominal, regardless of the change in voltage on the HV winding. This can be achieved by automatically changing the transformation ratio of power transformer.

Range of on-load tap changing (LTC) of most 110–220 kV power transformers is $\Delta U = \pm 16\% \times (\pm 9 \times 1.78\%)$ of the rated voltage on the HV side. The rated voltage in the passports of 110 kV power transformers corresponds to the average tap of LTC and, as a rule, is 115 kV. For the limiting taps of LTC, the effective voltage on HV windings is determined by the formulas:

$$U_{\min} = U_{\text{av}} - \Delta U = 115 - 0.16 \times 115 = 96.6\ \text{kV};$$
$$U_{\max} = U_{\text{av}} + \Delta U = 115 + 0.16 \times 115 = 133.42\ \text{kV}$$

The actual range of the operating voltage in 110–220 kV networks is significantly less. In accordance with the State Standard for Electric Power Quality, the minimum operating voltage in a 110 kV network should not decrease by more than 10% (i.e., not lower than 99 kV). The maximum voltage according to the condition of the insulation resource conservation should not exceed 126 kV. Consequently, the entire factory range of voltage regulator of a power transformer is not used in practice.

Each i –th LTC tap-off corresponds to a short-circuit voltage of transformer U_{Ki}, active R_i and inductive X_i resistances of transformer windings [9]. The catalog data of power transformers present short circuit voltages for the average $U_{K.av}$, maximum $U_{K.\max}$ and minimum $U_{K.\min}$ branches of the LTC switch.

The windings impedances of a two-winding transformer is calculated taking into account the LTC position using the following formulas [9, 10]:

$$Z_{av} = \frac{U_{K.av}}{100}\frac{U_{av}^2}{S_{rat}};$$
$$Z_{\max} = \frac{U_{K.\max}}{100}\frac{U_{\max}^2}{S_{rat}};$$
$$Z_{\min} = \frac{U_{K.\min}}{100}\frac{U_{\min}^2}{S_{rat}}$$

In these formulas, the values $U_{K.av}$ are taken for the average, and $U_{K.\max}$ and $U_{K.\min}$ for the limiting branches of the LTC device. Surprisingly, the following simplifications were adopted by the methodology: the maximum voltage at the HV side of the transformer is assumed to be 126 kV (whereas $U_{K.\max}$ corresponds to

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a voltage of 133.42 kV), and instead of the minimum permissible by GOST voltage in the network $U_{K.\min}$ = 99 kV, the adopted value is 96.6 kV [11].

Such assumptions are associated with simplified calculations, and the actual increase in the range of short circuit currents comparing with LTC range is assumed to increase the safety margin. We believe that the accepted assumptions unreasonably reduce the sensitivity of the relay protection not only of power transformers, but also of current protection of power lines. The resistances of windings of power transformers are the initial data for calculation of short-circuit currents and subsequent determination of settings of relay protection means. The accuracy of calculations and, therefore, the reliability of power supply to consumers should be a priority. We are sure that calculation of transformer resistances should be performed for the actual range of the LTC regulator, and the short-circuit voltages should correspond to the selected regulator branch. The short circuit voltage on intermediate taps should be calculated using linear interpolation.

3 Results and discussions

To improve the accuracy and speed of resistance calculation for each LTC branch, the authors developed a software module “Online Electric: Calculation of parameters of equivalent power transformer circuits taking into account the position of the on-load regulator”

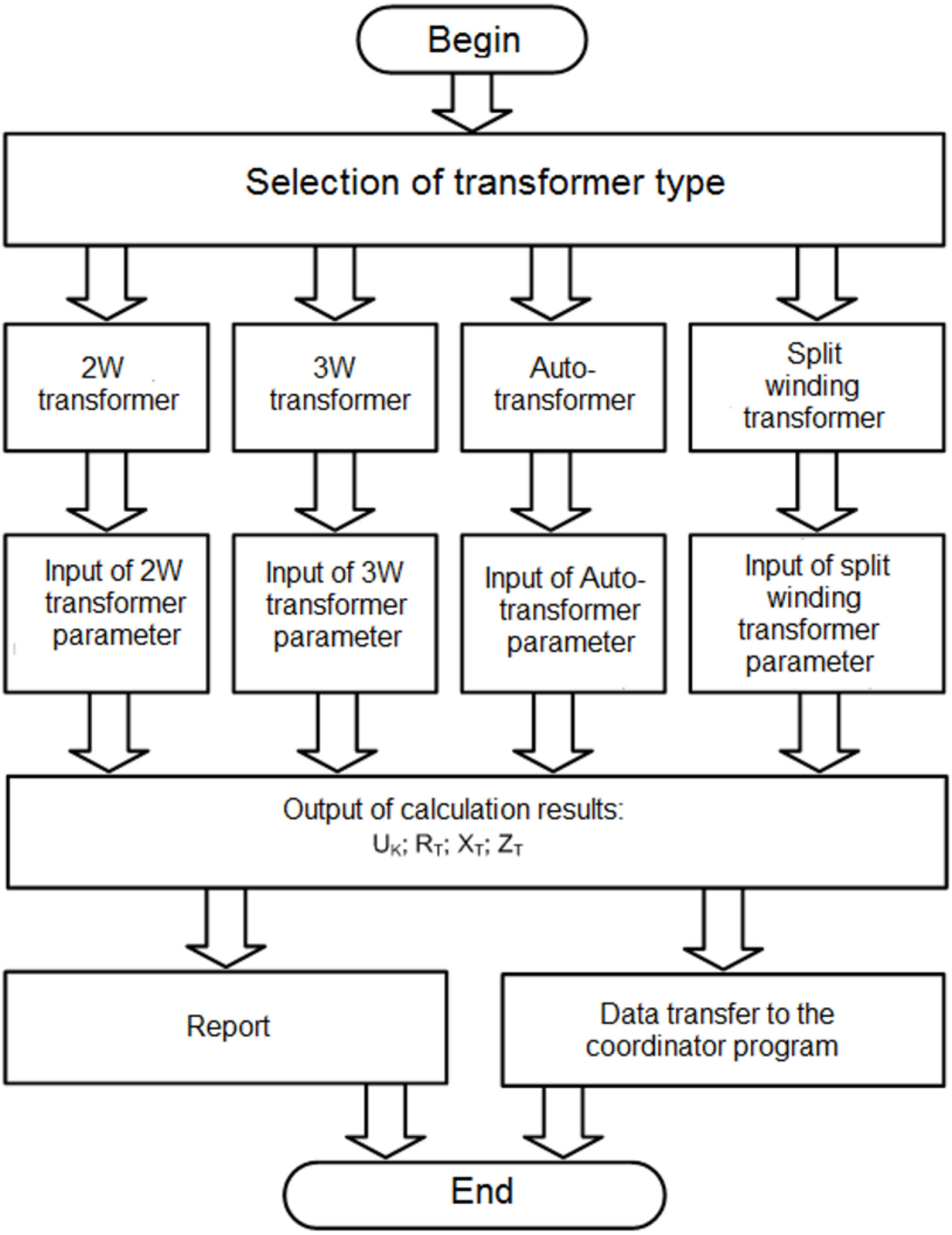

Fig.1. Block diagram of the module "Online Electric: Calculation of power transformer parameters taking into account LTC".

Online-Electric > Online Calculations

Calculation of power transformer parameters taking into account LTC

Two-winding transformer | Three-winding transformer | Autotransformer | Split windings transformer

Characteristics	Designation	Meas.unit	Value	Note
Initial data				
Transformer type	-	-	TDN-10000	From catalog
Rated power of transformer	S_{rat}	kV•A	10000	From catalog
Rated higher voltage	U_{hv}	kV	115	From catalog
Rated lower voltage	U_{lv}	kV	11	From catalog
TLC parameters	N_-	pcs	-9	From catalog: Amount of stages decreasingly: 2; 4; 6; 8; 9;12.
	ΔU_-	%	-16	TLC range decreasingly: 5; 10; 10.8; 11; 11.2; 12; 16
	N_+	pcs	+9	Amount of stages increasingly: 2; 4; 6; 8; 9;12.
	ΔU_+	%	+16	TLC range increasingly: 5; 10; 10.8; 11; 11.2; 12; 16
Short-circuit voltage	$U_{K.av}$	%	10.5	From catalog: in average position
	$U_{K.min}$	%	10.49	In minimum position
	$U_{K.max}$	%	11.73	In maximum position
Short-circuit power losses	ΔP_K	kW	58	From catalog

Fig.2. Front panel of the module "Online Electric: Calculation of power transformer parameters taking into account LTC".

and sent it for the state registration to the Rospatent. The block diagram of the module is shown in Figure 1. The module allows one to determine parameters of equivalent circuits of power two-winding and three-winding transformers, autotransformers, as well as power transformers with a split low-voltage winding for all LTC taps. The module capabilities include calculation of short-circuit voltages, active, inductive and total resistances of transformer windings, as well as generating reports based on templates in a format compatible with Microsoft Word. Incorporation of the developed module into interaction with the coordinating program of the "Online Electric" web service [12] is now in progress. The coordinating program serves for the automated transfer of initial data and calculation results to other modules, including the iTKZ module for online calculation of steady-state modes and short-circuit currents in electrical networks of 0.4–1150 kV.

The proposed software product after calculating the active and inductive resistances of power transformer windings allows one to specify the values of the minimum and maximum short-circuit currents due to a more accurate calculation of the transformer short-circuit voltage on intermediate LTC tapes.

The front panel of the module is shown in Figure 2.

The calculation results are displayed (Figure 3), and can be saved in RTF format.

Calculation results

TLC position	Uhv.i, kV	Uk.i, %	Rt.hv.i, Ohm	Xt.hv.i, Ohm	Zt.hv.i, Ohm	Rt.lv.i, Ohm	Xt.lv.i, Ohm	Zt.lv.i, Ohm
-9	96.6	10.49	5.41	97.74	97.89	0.0702	1.2673	1.2693
-8	98.6	10.49	5.64	101.93	102.09	0.0702	1.2675	1.2694
-7	100.7	10.49	5.88	106.21	106.37	0.0702	1.2676	1.2696
-6	102.7	10.49	6.12	110.58	110.75	0.0702	1.2678	1.2697
-5	104.8	10.49	6.37	115.04	115.21	0.0702	1.2679	1.2698
-4	106.8	10.5	6.62	119.58	119.76	0.0702	1.268	1.27
-3	108.9	10.5	6.87	124.22	124.41	0.0702	1.2682	1.2701
-2	110.9	10.5	7.13	128.94	129.14	0.0702	1.2683	1.2702
-1	113	10.5	7.4	133.75	133.95	0.0702	1.2684	1.2704
0	115	10.5	7.67	138.65	138.86	0.0702	1.2686	1.2705
+1	117	10.64	7.95	145.5	145.72	0.0702	1.2851	1.287
+2	119.1	10.77	8.23	152.57	152.79	0.0702	1.3017	1.3036
+3	121.1	10.91	8.51	159.86	160.09	0.0702	1.3182	1.3201
+4	123.2	11.05	8.8	167.38	167.61	0.0702	1.3348	1.3366
+5	125.2	11.18	9.09	175.13	175.36	0.0702	1.3514	1.3532
+6	127.3	11.32	9.39	183.11	183.35	0.0702	1.3679	1.3697
+7	129.3	11.46	9.7	191.33	191.57	0.0702	1.3845	1.3863
+8	131.4	11.59	10.01	199.78	200.03	0.0702	1.401	1.4028
+9	133.4	11.73	10.32	208.49	208.74	0.0702	1.4176	1.4193
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
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-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-

Fig.3. Form of software output of calculation results.

4 Conclusions

Summarizing, we would like to note that the software module improves the accuracy and speed of calculating the parameters of power transformers on all LTC taps and allows one to increase the sensitivity of relay protection and controls of transformers and power lines by approximately 10%.

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