Tadeusz DASZCZYŃSKI[1], Zbigniew POCHANKE[1], Marcin SZEWCZYK[1], Szymon STOCZKO[1], Przemysław KAŹMIERCZAK[2]

Warsaw University of Technology (1), Elektroteam Sp. z o.o. (2)

doi:10.15199/48.2020.11.39

Impact of the receiving transformer on the measurements of long-term load capability of the innovative LV switchgear

***Abstract**. This article presents an innovative design of low voltage switchgear and measurements of the long-term current-carrying capacity of the main lines. The functional requirements for the switchgear have been defined for the purposes of powering the equipment and production lines of the domestic pulp and paper production plants. Due to the significant leakage inductance of the installed transformer, the originally planned long-term current-carrying capacity tests failed, therefore a simulation analysis of the influence of the installed transformer on the measurement was carried out.*

***Streszczenie.** Niniejszy artykuł przedstawia innowacyjną konstrukcję rozdzielnicy niskiego napięcia oraz pomiary długotrwałej obciążalności prądowej torów głównych. Wymagania funkcjonalne dla rozdzielnicy zostały zdefiniowane na potrzeby zasilania urządzeń i linii produkcyjnych krajowych zakładów wytwórczych branży celulozowo-papierniczej. Z uwagi na znaczną indukcyjność rozproszenia zainstalowanego transformatora nie udały się pierwotnie zaplanowane próby obciążalności długotrwałej prądowej, dlatego przeprowadzono analizę symulacyjną wpływu zainstalowanego transformatora na pomiar. (**Wpływ transformatora odbiorczego na pomiar obciążalności prądowej długotrwałej innowacyjnej rozdzielnicy niskiego napięcia**).*

Keywords: LV switchgear, laboratory tests, transformer.
Słowa kluczowe: rozdzielnica nn, badania laboratoryjne, transformator.

Introduction

Each power grid product market availability is preceded by long process of computational design, verification engineering tests and final type tests of product performed by certified laboratory, in a way defined by appropriate standards. Concerning switchgears two standards are applied. PN-EN 61439 for low-voltage switchgear and controlgear assemblies and PN-EN 62271 for high-voltage switchgears. Those standards define wide range of necessary tests to pass, including voltage tests, electromagnetic compatibility tests, short time withstand current tests and temperature rise tests.

For switchgear current conducting performance, are essential current tests, including temperature rise tests. The scope of test is analysis of temperature distribution in order to locate possible excessive temperature growths, during nominal load current flow. Temperature distribution inside switchgear is result of generated and dissipated heat balance, influenced by ambient temperature, cubicle dimensions, conducted current and effectiveness of heat dissipation from current paths and installed apparatuses [1].

Therefore main concern in switchgear design is providing of optimum air flow inside cubicle. Considering reliability, maintenance and cost issues, conventional air flow is preferred, even though forced airflow is way more effective [2],[3]. In optimization process, really helpful are all computational aided design (CAD) and simulation software, that allow time and cost effective process of switchgear design optimization [4 - 7]. Using simulation software main concern is focused on accurate reflecting real-life processes in model. Despite advanced engineering software, some necessary simplification in model, will not reflect perfectly real-life object. That is why achieved virtual results should be verified during tests on physical object during temperature rise tests.

Temperature rise tests are performed in high current circuits, that are prepared and tuned accordingly to current requirements and type of tested object. One of such high current circuits is located in Laboratory of Electrical Apparatus and Switching Processes at Warsaw University of Technology. In this Laboratory there are conducted different types of research:

- Switching capacity tests
- Short-circuit and short-circuit withstand strength test
- Temperature rise test
- High-voltage tests
- Diagnostics of circuit breakers and transformers
- Vibroacoustics

The Laboratory has high-current and high-voltage sources. Test stands and specialized control and measurement equipment enable testing of real phenomena accompanying the operation of electrical devices. Main research areas:

- Study of switching processes in AC and low voltage circuits - LV and high voltage HV
- High-current tests - long-term current carrying capacity (up to 10 kA) and short-circuit tests (up to 100 kA)
- Vibroacoustics in diagnostic tests
- Electromechanical diagnostics of high-voltage circuit breakers
- Diagnosing the vacuum state of vacuum switches on a model chamber.

Innovative LV switchgear

The designed low voltage switchgear up to 130 V AC, intended to supply the systems for breaking cellulose fibers, is an innovative design. There are no solutions on the market in which primary equipment, protection automatics and a high-power low voltage transformer (242 kVA) are integrated in one housing. It should be noted that this is a product intended for a specific application. Single-line functional diagram of one feeding bay of the switchgear, which has been prepared for testing is shown on Fig. 1.

The cooking cell feeding section consists of:

- LS Susol TS 800N section compact switch (Q1),
- two power contactors (K1.1, K1.2) Metasol MC-800a by LS for switching the primary terminals of the TR1 transformer of the cooking cell,
- a transformer (TR1) type 3FR AN with a electrical power of 242 kVA by BREVE,
- Socomec three-phase network parameters analyzer (AS1) DIRIS A10 installed on the upper voltage side of TR1 transformer,
- digital overcurrent relay (SEP1) Sepam 10 B 43E by Schneider Electric for low voltage side circuits of transformer TR1,

- a single-phase converter of network parameters (PV1) P30P by Lumel installed on the lower voltage side of the TR1 transformer,
- digital transformer TR1 (ZT1.1) temperature control relay of the TR-100 type by Novatek-Electro.

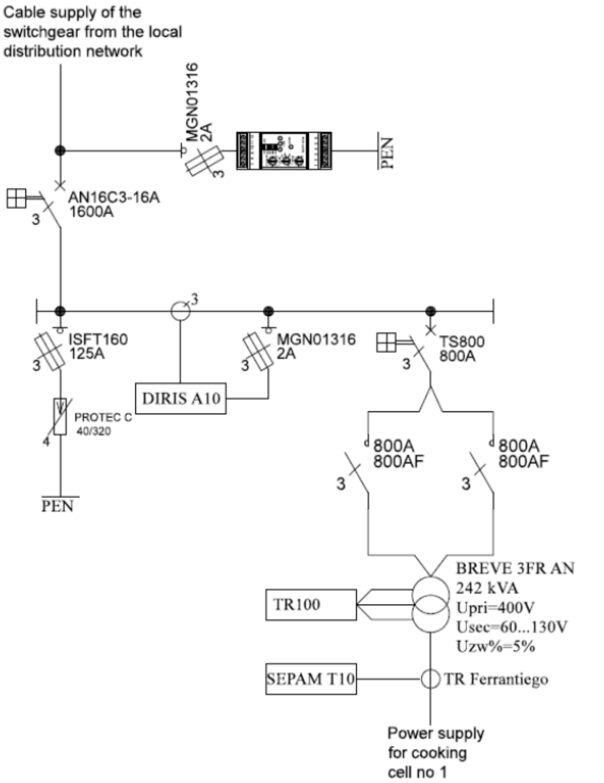


Fig. 1. Single-line functional diagram of one feeding bay of the switchgear

The LV switchgear was tested in the Laboratory of Electrical Apparatus and Switching Processes in Institute of Electrical Power Engineering, Warsaw University of Technology. The switchgear was manufactured by Elektroteam Sp. z o.o. and the tests were carried out from May till end of June 2020. Laboratory stand for long-term load capacity is shown on Fig. 2. The system was powered by the mains voltage, the short-circuit transformers were connected in a triangle on the primary side. The short-circuit transformers were star-connected on the secondary side, and the voltage on this side of the short-circuit transformers was 110 V AC. The tested LV switchgear was connected to short-circuit transformers with 2x YKY 1x150mm2 cables per phase. The currents on individual phases were measured with a CMP-2000 clamp meter.

Three different methods are now allowed for verification (the Original Manufacturer is responsible for choosing the suitable verification methods) [8]: testing with current, derivation, calculation. The calculations can be done doing FEM simulations [7]. As can be noticed, for some characteristics like resistance to corrosion or mechanical impact, only laboratory testing for verification is allowed. For other characteristics, such as short-circuit withstand strength, testing and comparison with a tested reference design are possible. Instead, for other characteristics such as temperature-rise, all three verification options are accepted indifferently: testing, comparison with a reference design or assessment. There is no more reliable verification method than hardware laboratory testing. While testing for long-term load capacity the problem with influence of the receiving transformer on the measurements rised.

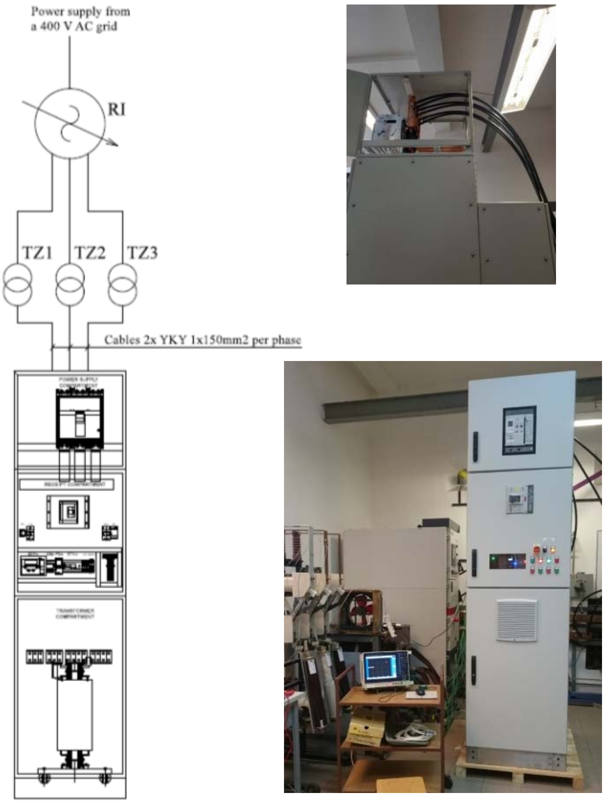


Fig. 2. Laboratory stand for long-term load capacity

Simulation of LV transformer

The conducted analysis is aimed at explaining why - despite the significant power of the high-current source - 3x500 kVA - it was not possible to force a short circuit in the installed 3FR AN transformer. The explanation is based on the revealed dependencies between voltages and currents in transformer windings depending on its load resistance.

The relationships between the voltages and currents were simulated using Matlab-Simulink simulation software. The simulation was performed on the model shown in Fig. 3. The parameters of the transformer model are shown in Tab. 1.

Table 1. Parameters of 3FR AN transformer simulation model

Parameter	Value
Nominal power [kVA]	250
Nominal frequency [Hz]	50
Nominal voltage winding 1 / 2 [V]	400 / 75
Inductance winding 1 / 2	0.001 / 0.001
Resistance winding 1 / 2	0.04 / 0.04
Magnetization inductance [p.u.]	1e6
Magnetization resistance [p.u.]	1e6

The nominal load of the 3FR AN transformer was set to R_0 = 0.0699 Ω. The source voltage absolute value was set to 400/sqrt(3). The TSx1-500 power transformers, rated at 500 kVA with 15/0.88 kV/kV connections each, have the short circuit reactance X_{TW} equals to 0.055Ω. The voltages at the primary windings of the 3FR AN transformer are described according to equations (1)-(7):

(1) $$E_{11} = U_a - U_b$$
(2) $$E_{12} = U_b - U_c$$
(3) $$\Delta E_{11} = jX_{TW}(I_a - I_b)$$
(4) $$\Delta E_{12} = jX_{TW}(I_b - I_c)$$
(5) $$v_{11} = E_{11} - \Delta E_{11}$$
(6) $$v_{12} = E_{12} - \Delta E_{12}$$
(7) $$V_1 = v_{11} - v_{12}$$

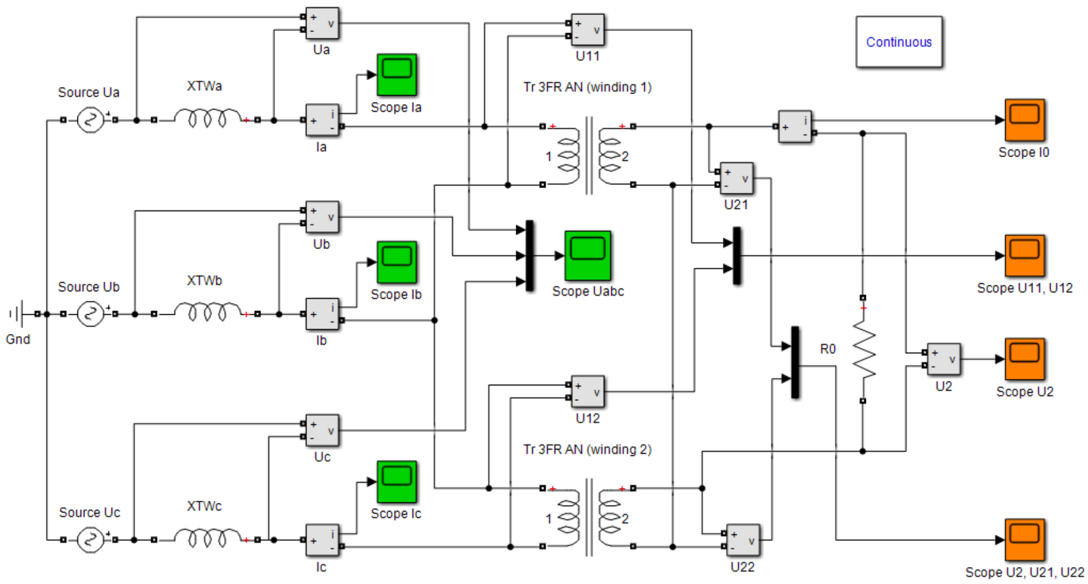
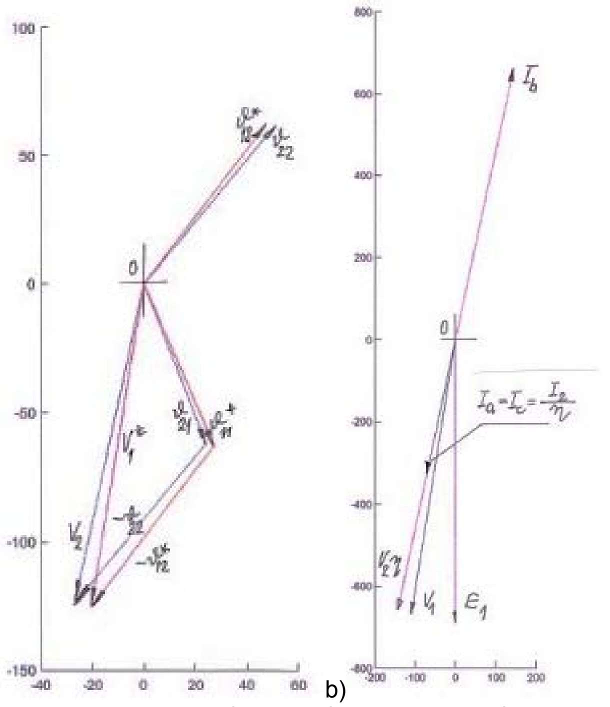


Fig. 3. Simulation model of 3FR AN transformer: $u_{a\text{-}c}$ – source phase voltages, $X_{TWa\text{-}c}$ – reactances of single-phase short-circuit transformers

Fig. 4a shows a vector diagram of the transformation of the primary 3 phase voltage $V_1{}^* = \frac{V_1}{\eta}$ to the single phase secondary voltage. The ratio of the transformer is $\eta = \frac{400}{75}$. Fig. 4b shows a vector diagram of the relation between currents and voltages at the 3FR AN transformer windings.



a) b)

Fig. 4. Vector diagrams of: a) transformation ration of primary 3-phase voltages to secondary single phase voltage, b) relation between currents and voltages at transformer windings

The above vector diagrams show that the short-circuit impedances of high-current transformers and of the transformer analyzed at the rated load, clearly change the phase relationships between the voltages, however do not significantly affect the voltage value at the load resistance.

For the purpose of the simulations reported in this paper, the following load was assumed: 0 – $R_o = \infty$, 1 – $R_o = 0.0699\Omega$, 2 – $R_o = \frac{0.0699}{2}\Omega$, 3 – $R_o = \frac{0.0699}{4}\Omega$, 4 – $R_o = \frac{0.0699}{8}\Omega$.

Fig. 5 shows the effect of reducing the load resistance on the secondary voltage of the transformer. It can be seen that the secondary voltage is reduced significantly, which is caused by a radical reduction of the voltage at the upper transformer with a little variation of the voltage at the lower transformer. This asymmetry is a result of different phase shifts of the voltage drop at the phase b reactance of the high-current transformer.

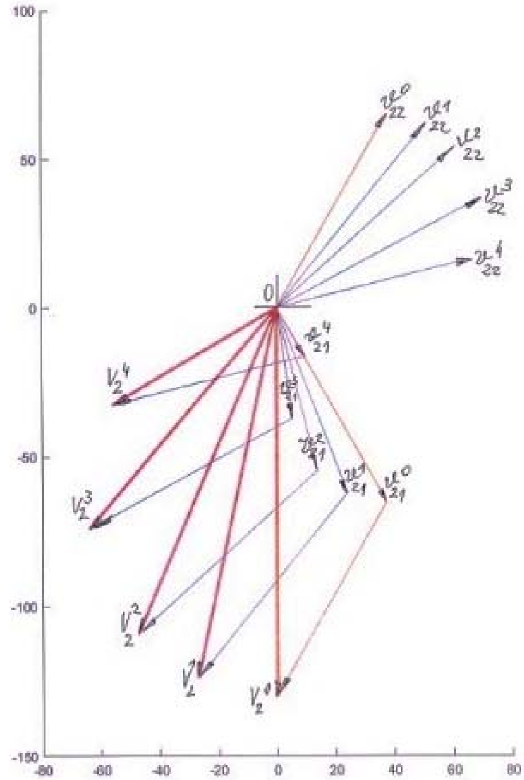


Fig. 5. Vector diagram of the effect of load resistance reduction on the transformer secondary voltage

It follows from these considerations that the reason for the failure to apply a typical high-current system to the attempt to the long-term load capability test of the switchgear, were disproportionately large voltage drops at the impedances of high-current transformers. The long-term load capability of the switchgear with the transformer according to the arrangemend analyzed, should be carried out when supplied from a rigid three-phase voltage source with a value corresponding to the transformer short circuit voltage.

Conclusions

The switchgear provided for testing is innovative due to the specificity of its application (pulp and paper industry) and the placement of a special transformer with windings connected in the V system in its cell.

Electrical switchgear is designed in accordance with manufacturing standards which define the maximum temperatures not to exceed to ensure safety of people: temperature of case and of switching devices, maximum temperature deviation for terminals.

Measurements were made for the heating test in a short-circuit system powered by three 15kV / 110V short-circuit transformers. Temperature measurements were made using thermocouples located at 10 measuring points. Temperature increases were measured for each measuring point and the heating time constants were determined.

The highest temperature was recorded on the thermocouple, which was located at the contactor's terminal block to the busbars. The lowest temperature was recorded on the thermocouple, which was located in the upper wall of the rail compartment.

An analysis of the influence of the installed 3 FR AN transformer on the measurement conditions during the heating test was carried out. Based on the conducted measurements and analyzes, a preliminary proposal of research tasks was formulated:

- carrying out a 3FR AN transformer heating test to precisely determine the transformer protection settings;
- determination and analysis of heat flows in the receiving compartment of the switchgear for the optimization of switchgear design.

***Authors**: dr inż. Tadeusz Daszczyński, Warsaw University of Technology, Electrical Power Engineering Institute, ul. Koszykowa 75, 00-662 Warsaw, Poland, E-mail: tadeusz.daszczynski@ien.pw.edu.pl; dr hab. inż. Zbigniew Pochanke, Warsaw University of Technology, Electrical Power Engineering Institute, ul. Koszykowa 75, 00-662 Warsaw, Poland, E-mail: zbigniew.pochanke@ien.pw.edu.pl; dr hab. inż. Marcin Szewczyk, Warsaw University of Technology, Electrical Power Engineering Institute, ul. Koszykowa 75, 00-662 Warsaw, Poland, E-mail: marcin.szewczyk@ien.pw.edu.pl; mgr inż. Szymon Stoczko, Warsaw University of Technology, Electrical Power Engineering Institute, ul. Koszykowa 75, 00-662 Warsaw, Poland, E-mail: szymon.stoczko@ien.pw.edu.pl; Przemysław Kaźmierczak, Elektroteam Sp. z o.o., ul. Brzozowa 8A, 97-400 Bełchatów, E-mail: p.kazmierczak@elektroteam.com.pl;*

REFERENCES

[1] Kilindjian C. and Schneider Electric, Cahier technique no. 145: Thermal study of LV electric switchboards, 1997
[2] Ryfa A., Buliński Z., Smolka J., Bedkowski M., Burzyński R., Determination of busbar system heat losses in naturally ventilated and hermetic switchgear, IET Gener. Transm. Distrib., 2017, Vol. 11 Iss. 7, pp. 1652-1660, doi: 10.1049/iet-gtd.2016.0760
[3] Xia H., Guan Y., Yu Z., Cai S., Wang X., Peng Z., Gao S., Huang A., Temperature rise test and analysis oh high current switchgear in distribution system, J. Eng., 2019, Vol. 2019 Iss. 16, pp. 754-757, doi: 10.1049/joe.2018.8371
[4] Wang L., Li X., Lin J., Jia S., Studies of Modeling and Simulation Method of Temperature Rise in Medium-Voltage Switchgear and Its Optimum Design, IEEE Trans. On Comp, Pack,and Manufa. Tech., vol. 8, no. 3., 2018
[5] Wang L., Wang R., Li X., Yan C., Temparature Rise Simulation of Medium Voltage Cubic Type Gas Insulated Switch-Gear Based on Coupling of Multi-Phisical Field, IEEE Access, vol. 7, 2019, doi: 10.1109/ACCESS.2019.2908993
[6] T. Kądziołka, M. Kryś, A. Wiertek, Analysis of power loss and temperature distribution in low voltage switchgear – coupled analysis EM + CFD in ANSYS software, Przegląd Elektrotechniczny, 94 (2018), No 1
[7] Będkowski M., Smołka J., Nowak A., Analiza numeryczna procesu wymiany ciepła wewnątrz rozdzielnicy elektrycznej, Przegląd Elektrotechniczny, vol. 2, 2013
[8] PN-EN 61439-1:2011 Low-voltage switchgear and controlgear assemblies - Part 1: General rules