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Operation impact of the ICEM power testing laboratory on the Slovenian power network

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Abstract. The ICEM power testing laboratory is designed mainly for power testing the electrical power system elements and partly for voltage testing of the middle-voltage equipment. The paper deals with the theory of power testing and operation of the ICEM power testing laboratory for high currents. A brief presentation of its electrical equipment and is shown. Calculation of short circuits and voltage drops is made analytically and by using the simulation tool PSCAD/EMTDC. Operation of the ICEM power testing laboratory and its impact on the electric power system are analysed. Results of analytical calculations are compared with results of simulations and the applicable measurement. The final estimation is given also with regard to the applicable valid international standards.

Key words: high-power laboratory, power testing, test current, voltage drop, simulation, power system

Vpliv delovanja močnostnega laboratorija ICEM na elektroenergetsko omrežje

Povzetek. Članek obravnava področje močnostnih preskušanj in obratovanje močnostnega laboratorija (ICEM) za velike tokove. Takšna preskušanja zahtevajo dobro opremljene laboratorije in posebne preskusne postopke, ki jih v detajlih podajajo in opisujejo standardi. Področje dela v ICEM obsega meritve s področja močnostne elektrotehnike za nizke, srednje in visoke napetosti. Električno gledano je navedena lokacija idealna za močnostni laboratorij, saj se nahaja v neposredni bližini RTP Pekre s kratkostično močjo okrog 5000 MVA.

V ICEM je mogoče izvajati preskušanja s spremenljivimi AC in DC napetostmi. Pri AC napetostih dosegajo preskusni tokovi vrednosti do 50 kA pri faktorju moči cos $\varphi = 0{,}2$ in pri DC napetostih vrednosti do 35 kA s časovno konstanto do 15 ms. Bistveni del ICEM je močnostni preskusni transformator z močjo 2 MVA in kratkostično napetostjo 2,2 %, sinhronsko stikalo, ohmska in induktivna bremena. Napajanje ICEM je izvedeno iz 10 kV zbiralk hidroelektrarne Mariborski otok (HEMO). Takšen način povezave zagotavlja dve osnovni možnosti napajanja ICEM, iz HEMO ali iz RTP Pekre.

Izračuni in simulacije kratkostičnih tokov in padcev napetosti so izvedeni za konfiguracije omrežja, prikazane na slikah 2 in 3. Analitični izračuni so izvedeni v skladu s [3], za primer trifaznega kratkega stika na nizkonapetostni strani v točki E v ICEM. Za vsako točko so v tabelah 1 in 2 podane štiri vrednosti, in sicer začetni simetrični kratkostični tok I_k'', udarni kratkostični tok i_u, vrednost fazne napetosti U in padca napetosti ΔU. Simulacije so izvedene s simulacijskim orodjem PSCAD/EMTDC, ki se uporablja za analizo elektroenergetskih sistemov. Simulacijska modela prikazana na sliki 6 in 7 sta zgrajena na osnovi konfiguracijske sheme omrežja podane na sliki 2 in 3.

Vsi izračuni in simulacije so izvedeni za najbolj neugodne pogoje, kar predstavlja trifazni kratki stik brez bremena. Rezultati kratkostičnih tokov in padcev napetosti so prikazani v tabeli 1 in 2, in grafično na sliki 8 in 9. Kratkostični tok I_k'' v točki E v ICEM-u dosega vrednosti med 110 in 130 kA. Vrednosti tega toka dobljene z analitičnim izračunom so okrog 10 kA višje v primerjavi z rezultati simulacij. Pri napajanju ICEM-a iz HEMO so vrednosti kratkostičnih tokov okrog 9 kA večje v primerjavi z napajanjem ICEM-a iz RTP Pekre. Primerjava napetostnih padcev upoštevaje analitične izračune in simulacije podaja precej izenačene vrednosti. Upoštevaje točko priključitve so pri napajanju iz RTP Pekre padci napetosti večji za 5 do 8%.

Dejstvo je, da kratkostični tok pri preskušanjih nikoli ne bo presegel vrednosti 50 kA in da padec napetosti v točki C na 10 kV zbiralkah HEMO nikoli ne bo presegel 10 %. Na ta način razmere odgovarjajo zahtevam [5], ki dovoljujejo odstopanje napetosti za srednjenapetostno omrežje v mejah ± 10%.

Na podlagi opravljene analize lahko potrdimo, da bo vpliv delovanja ICEM-a na HEMO minimalen. Razvidno je, da ima priključna točka ICEM-a na električno omrežje v HEMO zadostno kratkostično moč za predvidena močnostna preskušanja. Na enak način lahko potrdimo, da bo vpliv delovanja ICEM-a na RTP Pekre še nekoliko manjši, zaradi večje oddaljenosti in nekaj večje kratkostične moči v RTP Pekre.

Ključne besede: močnostni laboratorij, močnostna preskušanja, preskusni tokovi, padci napetosti, simulacije, elektroenergetsko omrežje

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1 Introduction

The ICEM power testing laboratory makes measurements on the low-, medium- and high-voltage levels, determines compatibility of the selected products with the requirements of domestic and foreign rules and regulations, standards and certifications, makes and elaboration of R&D projects for new products and technologies, and provides training in the form of seminars, courses and expert meetings.

The testing circuit during AC power tests is supplied either by a special generator or by the power grid. The advantage of the generator supply is in the possibility of parameter changing during the test, while its high cost is the major drawback of this solution. The grid supply is much cheaper but the parameters fully depend upon the supplying network. In the latter case, the point of supply in the network with a appropriate fault level should be found.

The location of the ICEM laboratory is from the point of view of electricity supply almost ideal; in its close vicinity there is the Pekre substation with the fault level of about 5000 MVA.

The ICEM power laboratory consists of two major parts, i.e. the part for AC and the part for DC tests.
In the AC part one-phase, two-phase and three-phase tests are made. There are the following four permanent testing voltages available: 380, 401, 507 and 549 V, as well as their combinations. The testing currents are up to 50 kA at the power factor cos $\varphi = 0,2$.

In the DC part there are the following permanent testing voltages available: 537, 567, 717 and 776 V. The testing currents reach up to 35 kA with the time constant of 15 ms.

Reaching of the above testing parameters is enabled by the 10-kV cable supplying ICEM from the busbar of the Mariborski otok hydro power plant (MO HPP). The laboratory can be independently supplied also from the Pekre substation through the 10/110 kV transformer in MO HPP and through the first circuit of the MO HPP – Pekre overhead line.

The 2 MVA testing transformer, which is the ICEM essential part, is supplied by a 10 kV cable.
The two possibilities of supplying the ICEM laboratory, are shown in Figure 1.

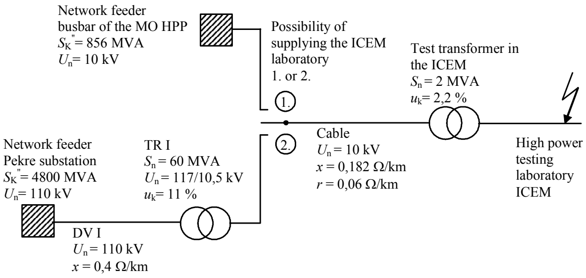

Figure 1: Possibility of supply of power laboratory
Slika 1: Možnosti napajanja močnostnega laboratorija

The first possibility is supply from the 10 kV busbar system of the MO HPP. The three generator units, as well as the two 60 MVA transformers, connected through a 2x110 kV line to the Pekre substation, are connected to this busbar system. This option is used for permanent supply of the power laboratory and for performing small-scale tests.

The second option is supply from the first 10 kV busbar system of the MO HPP. This system consists of a 60 MVA 110/10 kV transformer and the eastern circuit of the 2x110 kV overhead lines connected to the Pekre substation. At the same time, all the three generator units are connected to the second busbar system through the second 60 MVA 110/10 kV transformer and the western circuit of the overhead line connected to the Pekre substation. This option of supply is used for performing of power tests with testing currents above 10 kA, since separate operation reduces the dynamic impact of the laboratory on the operation of the generator units.

Power testing causes high currents and transient states that may negatively effect operation of the nearby MO HPP, since the power laboratory is connected to the power plant main busbar system, or even to the Pekre substation, where the MO HPP is connected to the Slovenian electric power system (EPS).

Computation of short circuits and voltage drops are made analytically and by using the PSCAD programme package. By comparing results obtained with these two methods, the laboratory operation and its impact on the electric power network are analysed from the prospective of the applicable valid standards, rules and regulations.

2 Computations and simulations of short circuits and voltage drops

In this chapter, we show results of computations and simulations of three-phase short circuits and voltage drops. They are given in a tabular form for individual points of supply and tap positions of the testing 380 V transformer. The values of currents and voltage drops are in this case the highest.

Our computations and simulations were made for both possibilities of the laboratory supply, as described in chapter 1. The analytical calculations and the description of the simulation with the PSCAD/EMTDC programme tool are given below. Both the analytical calculation and the PSCAD/EMTDC simulation model are based on the network configuration, shown in Figures 2 and 3.
Figure 2 shows the network configuration for the first option, i.e. for the supply from the 10 kV busbar system of the MO HPP. Figure 3 shows the network configuration for the second option, i.e. for the direct

supply from the Pekre substation, separately from the MO HPP.

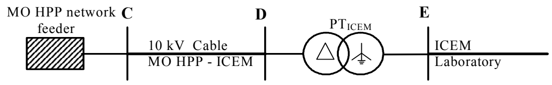

Figure 2: Network configuration – supply from the MO HPP
Slika 2: Konfiguracija omrežja – napajanje iz HEMO

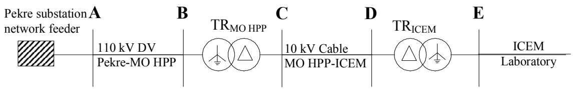

Figure 3: Network configuration – supply from the Pekre substation
Slika 3: Konfiguracija omrežja – napajanje iz RTP Pekre

2.1 Analytical calculations

The analytical calculations were made with the complex values method. Short-circuit impedances of the elements were calculated for the two network configurations shown in Figures 2 and 3. These impedances were transformed into equivalent impedances according to the voltage level at the point of short circuit in the ICEM laboratory. Thus obtained equivalent network models are given in Figures 4 and 5. On the basis of these equivalent networks, equivalent complex short-circuit impedances were calculated. These impedances were used for calculation of the complex and absolute values of the initial periodic short-circuit current. Calculations of the maximum aperiodic short-circuit current were also made.

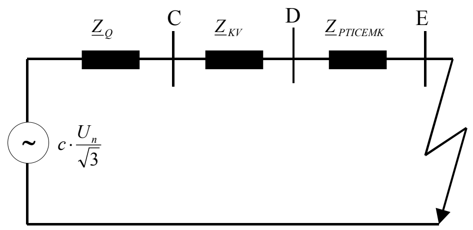

Figure 4: Equivalent network – supply from MO HPP
Slika 4: Nadomestna shema omrežja – napajanje iz HEMO

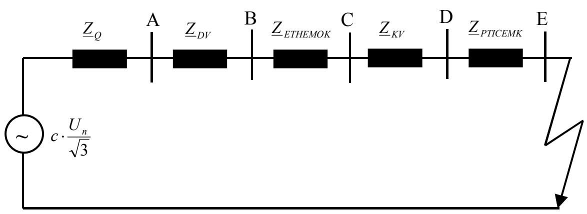

Figure 5: Equivalent network – supply from the Pekre substation
Slika 5: Nadomestna shema omrežja – napajanje iz RTP Pekre

Designations of the nodes have the following meaning: point A represents the 110 kV switchyard of the Pekre substation, point B the 110 kV busbar system of the MO HPP, point C the 10 kV busbar system of the MO HPP, point D the 10 kV side in the ICEM laboratory and point E the low-voltage side in the ICEM laboratory.

Tap of the PT_{ICEM} testing transformer		Analytical calculations	Simulations
	Voltage phase-to-phase [kV] phase-to-neutral	(0.380) 0.220	(0.380) 0.220
Point C (10) 5.8 kV busbar of the MO HPP	I_k'' [kA]	4.9	4.8
	i_u [kA]	12.1	12.9
	U [kV]	5.2	5.2
	ΔU [%]	10.3	10.3
Point D (10) 5.8 kV in the ICEM laboratory	I_k'' [kA]	4.9	4.8
	i_u [kA]	12.1	12.9
	U [kV]	5.1	5.1
	ΔU [%]	12.1	12.1
Point E Low voltage side in the ICEM laboratory	I_k'' [kA]	129.8	121.9
	i_u [kA]	319.2	317.6
	U [kV]	0	0
	ΔU [%]	100	100

Table 1: Calculation and simulation results of the three-phase short circuit – supply from the MO HPP
Tabela 1: Rezultati izračuna in simulacije za trifazni kratki stik – napajanje iz HEMO

Tap of the PT_{ICEM} testing transforme r		Analytical calculations	Simulations
	Voltage phase-to-phase [kV] phase-to-neutral	(0.380) 0.220	(0.380) 0.220
Point A (110) 63.5 kV Pekre substation switchyard	I_k'' [kA]	0.4	0.4
	i_u [kA]	1.0	1.1
	U [kV]	62.4	62.9
	ΔU [%]	1.7	1.0
Point B (110) 63.5 kV busbar of the MO HPP	I_k'' [kA]	0.4	0.4
	i_u [kA]	1.0	1.1
	U [kV]	61.9	60.8
	ΔU [%]	2.5	4.3
Point C (10) 5.8 kV busbar of the MO HPP	I_k'' [kA]	4.6	4.2
	i_u [kA]	11.4	11.2
	U [kV]	4.9	4.7
	ΔU [%]	15.5	18.9
Point D (10) 5.8 kV in the ICEM laboratory	I_k'' [kA]	4.6	4.2
	i_u [kA]	11.4	11.2
	U [kV]	4.8	4.6
	ΔU [%]	17.2	20.7
Point E Low-voltage side in the ICEM laboratory	I_k'' [kA]	122.3	112.4
	i_u [kA]	300.1	314.3
	U [kV]	0	0
	ΔU [%]	100	100

Table 2: Calculation and simulation results of the three-phase short circuit – supply from the Pekre substation
Tabela 2: Rezultati izračuna in simulacije za trifazni kratki stik – napajanje iz RTP Pekre

The calculations were made according to [3] for the case of the three-phase short circuit on the low-voltage side at the point E in the ICEM laboratory. The results for both supply options are for individual nodes shown in the column "Analytical calculations" in Tables 1 and 2. Four values are given for each point, namely initial periodic short-circuit current I_k'', maximum aperiodic short circuit-current i_u, phase-to-neutral voltage U and voltage drop ΔU.

The "Simulations" column contains the results obtained with the PSCAD/EMTD programme tool, which is in detail described in chapter 2.2.

2.2 Simulations with the PSCAD/EMTDC programme tool

The PSCAD/EMTDC programme tool is a professional simulation tool for electric power system analysis. It consists of the PSCAD graphic interface and the EMTDC simulation driver. The graphic interface enables graphical compiling of models of electric power system components using a library of elements, running of simulations and analysing of results. The simulation driver, on the other hand, enables running of simulations of transient states and controls the course of simulations.

Simulations, as well as analytical calculations were made for both supply possibilities, so as to allow for a direct comparison. The simulation network models in PSCAD were built on the basis of the network configuration shown in Figures 2 and 3.

Figure 6 shows the simulation model in PSCAD for the first option, i.e. supply from the 10 kV busbar system of the MO HPP.

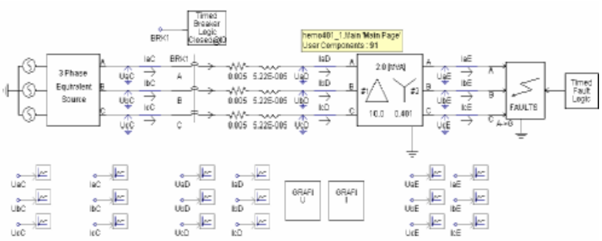

Figure 6: Simulation model in PSCAD – supply from the MO HPP
Slika 6: Simulacijski model v PSCAD-u – napajanje iz HEMO

Figure 7 shows the simulation model in PSCAD for the second option, i.e. supply from the Pekre substation, separately from the MO HPP.

The simulation results are for the two supply variants given in Tables 1 and 2 in the "Simulations" column, separately for individual nodes and for the 380 V voltage tap. Designations of nodes are the same as in the case of analytical calculations: point A represents the 110 kV switchyard of the Pekre substation, point B the 110 kV busbar system of the MO HPP, point C the 10 kV busbar system of the MO HPP, point D the 10 kV side in the ICEM laboratory and point E the low-voltage side in the ICEM laboratory.

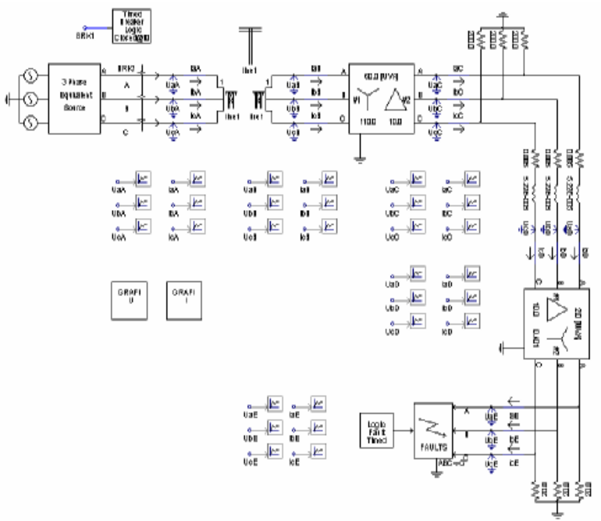

Figure 7: Simulation model in PSCAD – supply from the Pekre substation
Slika 7: Simulacijski model v PSCAD-u – napajanje iz RTP Pekre

The simulations were performed for the case of the three-phase short circuit at point E on the low-voltage side in the ICEM laboratory. Four values are given for each point, namely initial periodic short-circuit current I_k'', maximum aperiodic short-circuit current i_u, phase-to-neutral voltage U and voltage drop ΔU.

3 Analysis of results

A comparison was made between results of analytical calculations and for the computer simulations. They were made for two investigated variants of supply and are given in a tabular and graphical form for individual nodes and the voltage tap of the 380 V testing transformer for which the highest values of currents and voltage drops were obtained.

It should be noted that all the calculations were made for off-load short circuit states and for the time most inconvenient for fault occurrence. Such examples are of course possible only in the case of failure. The purpose of these calculations was mainly to detect the worst possible situation in which the ICEM power laboratory would affect the electric power network with respect to voltage drops in various nodes of the supply network.

Figure 8 shows a comparison between results of analytically calculated short-circuit currents and of PSCAD/EMTDC simulations. It can be seen that the absolute values of short-circuit currents I_k'' are in the case of analytical calculations slightly higher than in the case of simulations. This difference is very small and is mainly the result of accounting for the 10 % voltage reserve in the analytical calculations.

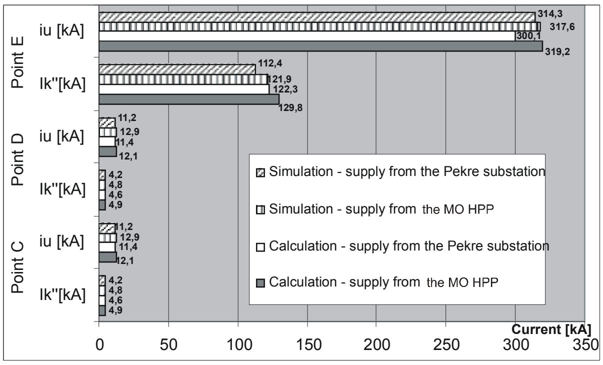

Figure 8: Comparison of the three-phase short-circuit current as an example of analytical calculations and simulations with PSCAD/EMTDC

Slika 8: Primerjava trifaznih kratkostičnih tokov za primer analitičnega izračuna in simulacije s PSCAD/EMTDC

Figure 8 brings also allows for a comparison between short-circuit currents for both options of the laboratory supply. It is evident that the values of short-circuit currents I_k'' for the case of supply from the MO HPP are by some 6 % higher than in the case of the supply from the Pekre substation. The reasons for this are isolation of the laboratory from the generators and prevalence of the impact of impedance of the 110/10 kV transformer in the MO HPP.

For a comparison of voltage drop values shown in figure 9 it can be seen that there is no great difference between those obtained with analytical calculations and those with simulations with the PSCAD/EMTDC programme tool. In the first supply option, a 10 % voltage drop at point C, i.e. at the 10 kV busbar system of the MO HPP is obtained with both calculation methods. In the second supply option, a 15.5 % voltage drop is obtained with analytical calculations and 18.9 % with simulations made at the same point.

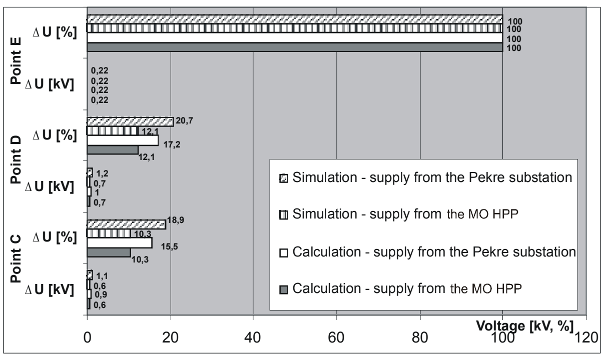

Figure 9: Comparison of voltage decreases at a three-phase short-circuit as an example of analytical calculations with PSCAD/EMTDC

Slika 9: Primerjava padcev napetosti pri trifaznem kratkem stiku za primer analitičnega izračuna in simulacije s PSCAD/EMTDC

A comparison of voltage drops for the two supply variants can also be made on the basis of Figure 9. It can be seen that voltage drops in the case of supply from the Pekre substation are slightly higher than in the case of supply from the MO HPP. In the former case, the ICEM laboratory is isolated from the MO HPP and the impact of impedance of the 110/10 kV transformer in the MO HPP prevails thus giving rise to an increased voltage drop.

Further measurements made in the ICEM laboratory enabled us to draw a parallel with the above calculations and simulations. They involved much lower short-circuit currents of up to 25 kA. The supply configuration was almost the same as shown in Figure 3.

Figure 10 shows the voltage time at point C of the 10 kV busbar system of the MO HPP for the short-circuit occurrence at point E in the ICEM laboratory. The short-circuit pre-set time was 100 ms at the short-circuit current I_k'' amounting to 25 kA. This was equivalent to 254 A short-circuit current at the 10 kV side. The voltage drop at point C during the short circuit was 4.8 %.

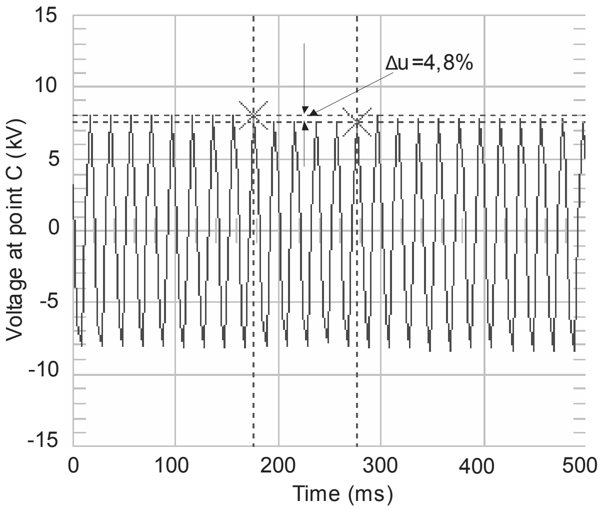

Figure 10: Voltage time at point C at short-circuit occurrence at point E

Slika 10: Časovni potek napetosti v točki C pri kratkem stiku v točki E

Based on the previous calculations and simulations, the measured voltage drop value was quite expected. The fact is that the supply of the laboratory was very similar to the ones of the analysed examples, i.e. supply from the Pekre substation, where voltage drops are the highest. It can be easily to seen that the obtained results are really credible and comparable. The short-circuit current value obtained with measurements was approximately four times lower than the one obtained with calculations and simulations. Consequently, the voltage drop was also approximately four times lower.

The above measurement method involves about 50 % of the maximum loading of the ICEM laboratory equipment. In case of the maximum testing current I_k'', this would be some 50 kA.

4 Conclusions

As already explained in the beginning of the paper, the main role of the ICEM power laboratory is power testing of electric power system elements and its secondary role is high-voltage testing.

The basic intention of the paper was to determine the level of impact of the ICEM power laboratory operation on the electric power network. All the calculations and simulations were made for the most inconvenient states for the short-circuit occurrence. One of the worst cases is a three-phase short circuit at the 380 V transformer tap in the ICEM laboratory. The current values in the case of one- or two-phase short circuit are lower or in the worst case of the same magnitude as in the case of three-phase short circuit.

By comparing analytical results of the short-circuit calculations with those obtained with simulations, it can be seen that the latter results are by approximately 7 % lower. The discrepancy is mainly the result of taking into account the 10 % voltage reserve in analytical calculations. A comparison of short-circuit currents for the laboratory supply variants shows that the short-circuit currents are in the case of supply from the MO HPP by about 6 % higher than in the case of supply from the Pekre substation. The reason is the laboratory isolation from the MO HPP generators in the case of supply from the Pekre substation isolated, which causes prevalence of the impact of impedance of the 110/10 kV transformer of the MO HPP.

A comparison of voltage drops with regard to the calculation method shows minimum differences between the results of analytical calculations and those of simulations. A comparison with regard to the supply variant shows that the voltage drop values are always slightly higher for the supply from the Pekre substation than for the supply from the MO HPP. Reason for the difference on the level of 5 % to 8 % is given above.

A good overlapping can be seen between results obtained with measurements and those of theoretical analyses. They also confirm the theoretical results. In general, it was noted that short-circuit currents are in the case of supply from the Pekre substation by some 6 % lower, while voltage drops are by some 6 % higher than in the case of supply from the MO HPP.

Nevertheless, will the current in practical cases always be limited by resistance and inductance, meaning that it will never exceed 50 kA.

With regard to the results obtained under normal laboratory operation at the current values below 50 kA, it is estimated that maximum voltage drops at point A, i.e. at the 110 kV busbar system of the Pekre substation, would amount to some 0.7 %, while at point C, i.e. at the 10 kV busbar system of the MO HPP, they would be to:

- some 7.5 % in the case of supply from the Pekre substation, and
- some 4.1 %. in the case of supply from the MO HPP.

On the basis of the obtained results and analyses a conclusion can be drawn that the impact of the ICEM laboratory operation on the MO HPP will be minimal and within limits specified by applicable rules, regulations and standards. For the medium-voltage distribution networks, the IEC 60038 standard allows voltage variations of ± 10 %, but in our case the laboratory is connected to the power plant network. Voltage dips are in this case so low that there is no danger of activation of the protection system or even of a power plant outage, which undoubtedly confirms that the fault level of this part of the network is very high.

Due to a larger distance of the ICEM laboratory from the Pekre substation, where the network fault level is higher and voltage drops lower, we can conclude that the impact of the laboratory operation on the Pekre substation and consequently on the Slovenian EPS will be even lower (0.7 %).

5 References

[1] Marjan Stegne, Obratovanje močnostnega laboratorija ICEM in njegov vpliv na EEO, diplomsko delo, Maribor, december 2002

[2] J. Pihler, Stikalne naprave elektroenergetskega sistema, FERI Maribor, Maribor 2003

[3] IEC 60909 ,″International standard, Short-circuit currents in three-phase a.c. systems - Part 0: Calculation of currents″, International Electrotechnical Commission, pp.1-137, Geneve – Suisse 2001

[4] IEC 60694 ,″International standard, Ed. 2.2 Consolidated Edition, Common specifications for high-voltage switchgear and controlgear standards″, International Electrotechnical Commission, pp.1-225, Geneve – Suisse 2002

[5] IEC 60038 ,″International standard, Ed. 6.2 Consolidated Edition, IEC standard voltages″, International Electrotechnical Commission, pp.1-21, Geneve – Suisse 2002

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