Verification of the calculation procedures for evaluation of short-circuit currents in 220 VDC auxiliary system of TPP Rijeka

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Abstract: - DC auxiliary systems are usually relied upon as the last source of reliable electric power at an installation of power plants and substations. Because DC auxiliary systems and battery power sources differ from AC systems, it is important that DC system protection designer is aware of their special considerations. In Standard IEC 61660-1 is given mathematical model for dynamics analysis in DC auxiliary systems of power plants and substations. In this paper, the authors performed short-circuit currents calculation in real DC auxiliary system of TPP Rijeka using mathematical mode defined in standard IEC 61660-1. Calculation results were verified on site during DC circuit breakers selectivity testing.

Key-Words: - DC auxiliary systems, thermal power plant (TPP), substations, mathematical model, short-circuit, circuit-breaker, selectivity.

1 Introduction

DC auxiliary systems are usually relied upon as the last source of reliable electric power at an installation of power plants and substations. That is the reason why the transient behavior of DC auxiliary systems has recently gained great interest. The greatest effort in standardization of DC short-circuit current calculation is represented by standard IEC 61600-1, *Calculation of Short-Circuit Currents in DC auxiliary installations in power plants and substations*. Using mathematical model for dynamics analysis in DC auxiliary systems defined in this IEC Standard, short-circuit currents calculation in real DC auxiliary system of TPP Rijeka was performed. Calculation results were verified on site during 220 VDC circuit breakers selectivity testing.

2 Evaluation of short-circuit currents

2.1 Mathematical model for dynamics analysis in accordance with the IEC 61600-1

Mathematical model for short-circuit current evaluation in DC auxiliary systems considers following items that are sources of possible contribution to the fault current:

- rectifiers in three-phase AC bridge
- stationary lead-acid battery
- smoothing capacitors
- DC motors.

The equivalent circuit diagram of DC auxiliary systems under study is shown in Fig.1.

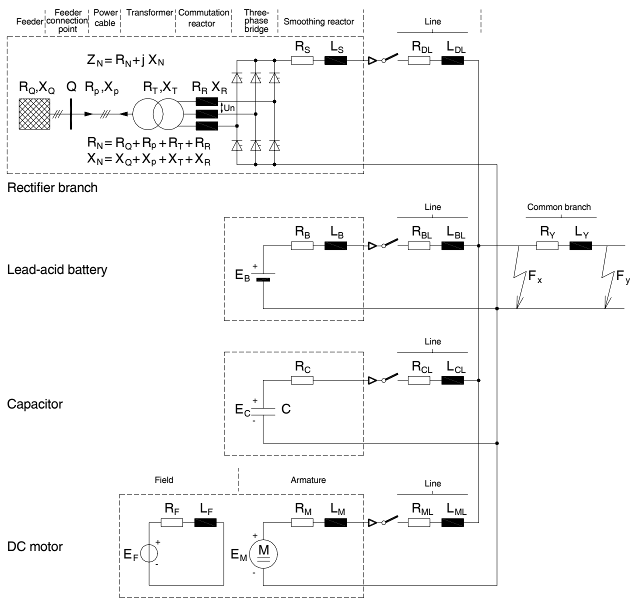

Fig. 1 – equivalent circuit diagram of the DC auxiliary system

The approximation function for each short-circuit current of the above-mentioned four sources is describe by

$$i_1(t) = i_p \frac{1-e^{-\frac{t}{\tau_1}}}{1-e^{-\frac{t_p}{\tau_1}}}, \quad 0 \le t \le t_p \tag{1}$$

$$i_2(t) = i_p \cdot [(1-p) \cdot e^{-\frac{t-t_p}{\tau_2}} + p], \quad t_p \le t \tag{2}$$

$$p = \frac{I_k}{I_p} \tag{3}$$

where

- I_k quasi-steady-state short-circuit current
- i_p peak current
- t_p time to peak
- τ_1, τ_2 rise and decay time constants

These characteristic values are defined for each different source once certain electrical parameters (i.e., resistance, reactance, etc.) and nominal voltage are known and by using some correction factors evaluated on an experimental basis. Detail references about theoretical background can be found in Standard IEC 61600-1 (1997-06).

The total short-circuit current for the location F_X in Fig. 1 is obtained by adding short-circuit current of all sources without correction factor and for location F_Y in Fig. 1 by adding the partial short-circuit current modified by means of correction factor σ_j that is needed because in that case there is a common branch (R_Y and $L_Y \neq 0$). Formulas for calculation of partial contributions of different sources can be found in Standard IEC 61600-1 (1997-06), too.

The total short-circuit current is found by superimposing the partial short-circuit currents from different sources at the short-circuit location. The approximation function for total short-circuit current is described by

$$i_{tot}(t)=\sum_{j=1}^{m}\sigma_j i_{pj}\frac{1-e^{-\frac{t}{\tau_{ij}}}}{1-e^{-\frac{t_{pj}}{\tau_{1j}}}}, \qquad 0 \le t \le t_{pj} \qquad (4)$$

$$i_{tot}(t)=\sum_{j=1}^{m}\sigma_j i_{pj}\left[\left(1-p_j\right)e^{-\frac{(t-t_{pj})}{\tau_{2j}}}+p_j\right] \qquad t_{pj} \le t \le T_K \qquad (5)$$

$$p = \frac{I_{kj}}{I_{pj}} \qquad (6)$$

where

- $i(t)$ is the total short-circuit current
- j is the numeral of voltage source
- m is the number of source
- T_K is the short-circuit duration
- σ_j is correction factor of j-voltage source

2.2 Calculation of short-circuit currents in the 220 VDC auxiliary system of TPP Rijeka

Block diagram of the 220 VDC auxiliary system in TPP Rijeka is shown in Fig.2. Calculation of maximum short-circuit currents are made on fault locations F1, F2, F3, and F4 by using mathematical model described in section 2.1. Thereby following switching and operating conditions are taken into account:

- The conductor resistances are referred to a temperature of 20 °C;
- The joint resistance of busbars are neglected;
- The control for limiting the rectifier current is not effective;
- All sources are connected to busbars but initial load is neglected;
- Any diodes for decoupling parts of system are neglected;
- The battery is charged to full capacity;
- The current limiting effect of circuit breakers are taken into account;
- Parallel operation of rectifier and emergency lube oil pump is impossible.

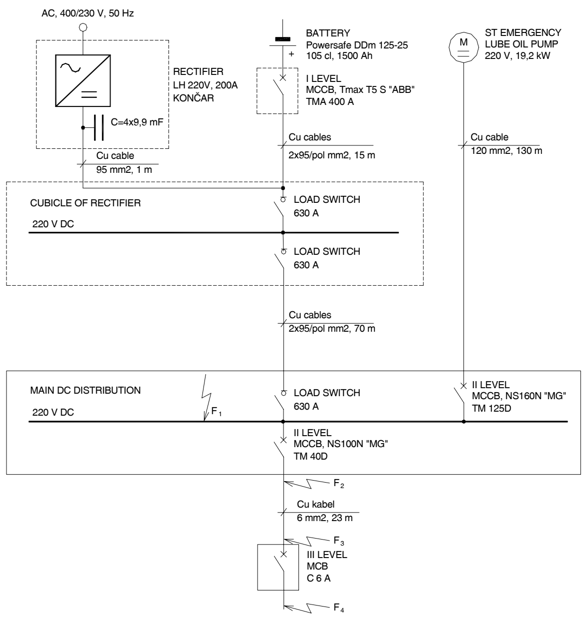

Fig. 2 – block diagram of the 220 VDC auxiliary system in TPP Rijeka

Calculation results which describe time variation of the short circuit current in the first 10 ms after short-circuit was occurred are given in table 1 for fault location F1, in table 2 for fault location F2, in table 3 for fault location F3 and in table 4 for fault location F4. Since in this case the contribution of rectifier in total short-circuit current was higher than the contribution of emergency lube oil pump, in tables 1-4 are shown calculation results only for short-circuit currents with parallel operation of three sources; battery, rectifier and capacitors.

In Fig. 3 is shown calculated variation of total short-circuit currents during the first 10 ms for fault location F1-F4.

Table 1 – Short-circuit current in F1

	Contrib. of rectifier	Contrib. of battery	Contrib. of capacitor	**i_{tot} (A)**
i_k (A) t=1 ms	73	3245	2194	**5513**
i_k (A) t=2 ms	138	4975	1320	**6433**
i_k (A) t=3 ms	196	5897	794	**6886**
i_k (A) t=4 ms	246	6388	477	**7112**
i_k (A) t=5 ms	291	6650	287	**7228**
i_k (A) t=6 ms	331	6790	173	**7293**
i_k (A) t=7 ms	365	6864	104	**7333**
i_k (A) t=8 ms	396	6902	62	**7361**
i_k (A) t=9 ms	423	6898	38	**7359**
i_k (A) t=10 ms	447	6895	23	**7365**

Table 2 – Short-circuit current in F2

	Contrib. of rectifier	Contrib. of battery	Contrib. of capacitor	**i_{tot} (A)**
i_k (A) t=1 ms	33	2318	1010	**3361**
i_k (A) t=2 ms	62	2940	750	**3751**
i_k (A) t=3 ms	87	3107	556	**3750**
i_k (A) t=4 ms	110	3146	413	**3669**
i_k (A) t=5 ms	130	3144	306	**3580**
i_k (A) t=6 ms	147	3142	227	**3516**
i_k (A) t=7 ms	163	3140	169	**3471**
i_k (A) t=8 ms	177	3137	125	**3439**
i_k (A) t=9 ms	189	3135	93	**3417**
i_k (A) t=10 ms	199	3133	69	**3402**

Table 3 – Short-circuit current in F3

	Contrib. of rectifier	Contrib. of battery	Contrib. of capacitor	**i_{tot} (A)**
i_k (A) t=1 ms	15	993	354	**1362**
i_k (A) t=2 ms	29	1017	316	**1361**
i_k (A) t=3 ms	40	1017	281	**1338**
i_k (A) t=4 ms	51	1016	251	**1318**
i_k (A) t=5 ms	60	1016	223	**1299**
i_k (A) t=6 ms	68	1015	199	**1282**
i_k (A) t=7 ms	75	1015	177	**1267**
i_k (A) t=8 ms	82	1014	158	**1254**
i_k (A) t=9 ms	87	1014	141	**1242**
i_k (A) t=10 ms	92	1013	126	**1231**

Table 4 – Short-circuit current in F4

	Contrib. of rectifier	Contrib. of battery	Contrib. of capacitor	**i_{tot} (A)**
i_k (A) t=1 ms	6	655	233	**894**
i_k (A) t=2 ms	11	654	216	**882**
i_k (A) t=3 ms	16	654	200	**870**
i_k (A) t=4 ms	20	654	185	**859**
i_k (A) t=5 ms	24	653	172	**849**
i_k (A) t=6 ms	27	653	159	**839**
i_k (A) t=7 ms	30	653	147	**830**
i_k (A) t=8 ms	32	652	136	**821**
i_k (A) t=9 ms	35	652	126	**813**
i_k (A) t=10 ms	36	652	117	**805**

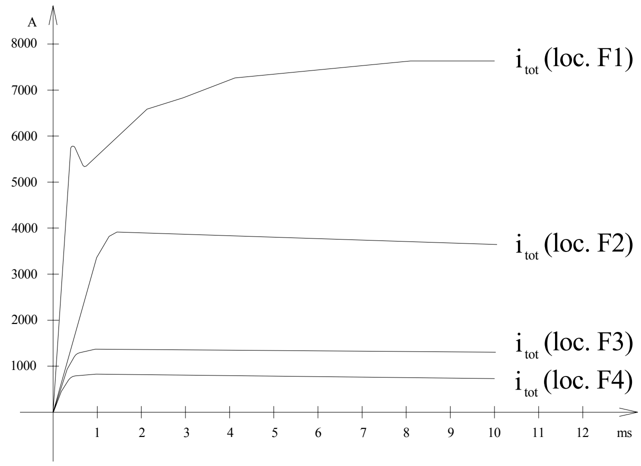

Fig. 3 – Time variation of total short-circuit current in locations F1-F4 during first 10 ms

3 Testing of circuit-breakers selectivity and recording of short-circuit currents on site

Circuit breaker selectivity testing was performed on site at the end of reconstruction of 220 VDC auxiliary system in TPP Rijeka. Short circuit was generated in all fault locations where short circuit currents were calculated (Fig.2, fault locations from F1 to F4). Time variations of short circuit currents were recorded by oscilloscope.

Circuit breaker selectivity was checked for characteristic disposition of circuit-breakers in 220 VDC installation.

- 1. level; Tmax T5 S, TMA 400, I_1=0,7xI_n, I_2=7,5 xI_n, “ABB”
- 2. level; NS100N, TM40D, I_1=0,8xI_n, I_2=12,5xI_n, “Merlin Gerin”
- 3. level; C32HDC, C-6 A

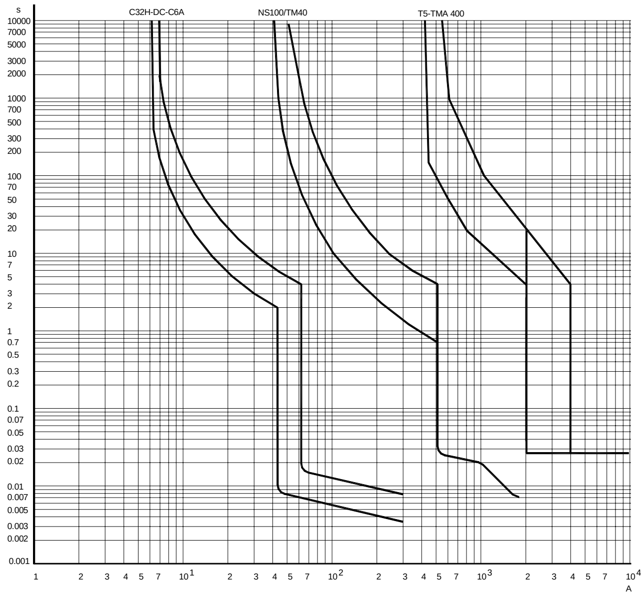

Fig. 4 – Breaking I-t curves for circuit breakers situated in three protection level

I-t curves of three circuit-breakers situated in different protection levels of 220 VDC auxiliary installation are shown in fig. 4. We can see that time selectivity is ensured for "low" short-circuit currents. For verifying selectivity at "high" short-circuit currents we performed selectivity testing on site.

Circuit breaker selectivity testing in TPP Rijeka verified selected circuit breakers disposition up to maximum short-circuit current 3300 A for circuit breakers situated in the first and the second level and up to maximum short-circuit current 680 A for circuit breakers situated in the second and the third level.

In Fig. 5-8 are shown testing results for variation of total short-circuit currents during the breaking of fault in all observed fault locations. In case recorded in fig. 5, short-circuit current was broken by circuit-breaker situated in protection level 1 (Tmax, ABB), in fig. 6 and 7 by circuit-breaker situated in protection level 2 (NS100N, MG), and in fig. 8 by circuit-breaker situated in level 3 (miniature CB).

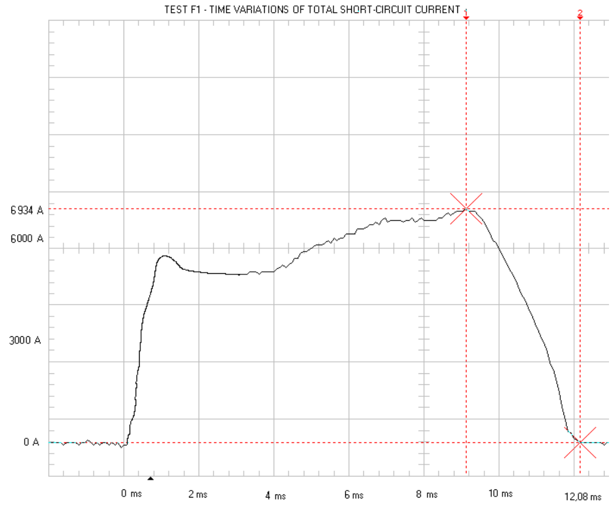

fig. 5 – time variations of short-circuit current in location F1

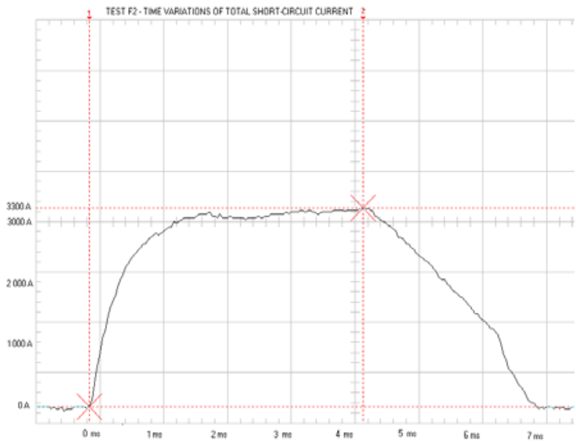

fig. 6 – time variations of short-circuit current in location F2

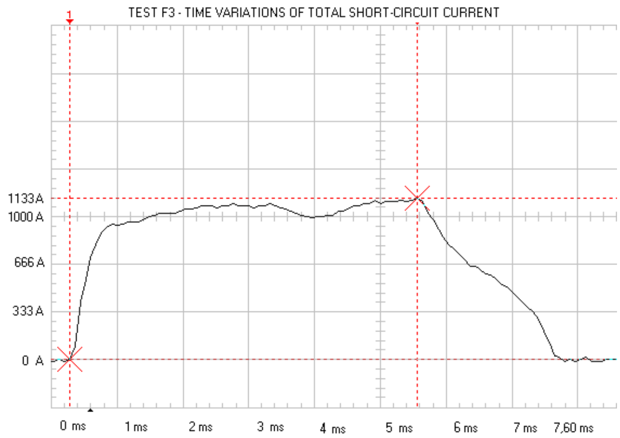

fig. 7 – time variations of short-circuit current in location F3

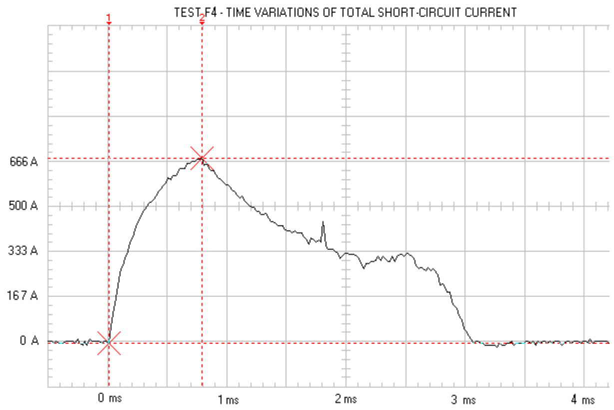

fig. 8 – time variations of short-circuit current in location F4

We can compare time-current curves recorded during the testing, shown in fig. 5-8, with calculated time-current curves, shown in fig. 3. They are corresponding in the first segment of curves before arching voltage on CB breaking contacts appears. However, the magnitude of short-circuit currents measured during the test is about 5-10 % lower than we expected according to calculation results.

4 Conclusion

This paper has described calculation procedures for evaluation of short-circuit currents in 220 VDC auxiliary system of TPP Rijeka. Mathematical model for dynamics analysis was based on IEC 61600-1. Calculation results are compared with real short-circuit currents on site during 220 VDC circuit breakers selectivity testing. The comparison has shown an overall agreement between the two sets of results, with a general overestimation about 5-10% on the safety side by calculation results.

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