Dynamics analysis of 220 V DC auxiliary system in power plant using different mathematical models

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Abstract- The calculation of short-circuit currents in DC auxiliary systems of power plants and substations is essential for design and application of distribution and protective devices used in these systems. Because of differences between DC and AC auxiliary systems, DC system protection designers should be take into account that important fact in calculation and dimensioning of DC auxiliary system. There are several mathematical models that are usually used for calculation of short-circuit currents in DC auxiliary system. In this paper, the authors performed short-circuit currents calculation for one real DC auxiliary system of power plant using three different, well-known, mathematical models. The results of calculations were compared with results given by testing of selectivity of DC auxiliary system on the site. Based on comparison results of different calculations and testing on the site conclusion related to choice one of three the most often used mathematical models as the most suitable has deduced.

I. INTRODUCTION

The calculation of short-circuit currents in DC auxiliary systems of power plants and substations is essential for design and application of distribution and protective devices used in these systems. Due to the fact that DC auxiliary systems and battery power sources differ from LV AC systems, it is important that DC system protection designers are aware of needs of special consideration. There are several mathematical models that are usually used for calculation of short-circuit current in DC auxiliary system. The most often used models are:

- static mathematical model (classical model)
- mathematical model that implemented in some ANSI/IEEE guidelines
- dynamic mathematical model represented by standard IEC 61660-1, published 1997

Using above mentioned mathematical models, short-circuit currents calculation in real DC auxiliary system of thermal power plant (TPP) Rijeka was performed. Calculation results were compared with results given by testing of selectivity of circuit breakers in the DC auxiliary system on the site.

NOTE:

Since above mentioned mathematical models are well-known, in this article mathematics are presented in general form and detail references can be found in standards and articles specified in reference list.

II. CALCULATION PROCEDURES

A. Static mathematical model (Classical model)

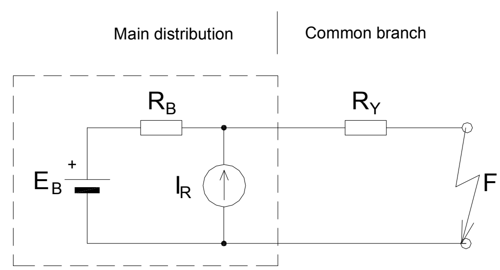

Fig. 1 – equivalent circuit diagram (Classical model)

The battery is considered as a voltage source and the rectifier as a current source. There are resistance of battery and resistance of short circuit common branch. Inductances and capacitances of batteries cells, filters, rectifier transformers and cables are not taken into account in this mathematical model. The short-circuit current calculated by equation:

$$I_{sc\,(max)} = \frac{E_B + I_R \cdot R_B}{R_B + R_Y} \qquad (1)$$

B. Mathematical model in accordance with the ANSI/IEEE guidelines

The battery, rectifier and a DC generator, as DC short-circuit sources, are considered in parallel. The inductances and resistances of DC system components has calculated and separate resistance and inductance network has constructed. These networks are reduced to single resistance and inductance. The short-circuit current is simply calculated by the voltage divided by equivalent resistance and its rate of rise by equivalent time constant, which is equal of equivalent inductance over resistance. For the needs of mentioned calculation method simplification, it has assumed that all sources have the same voltage.

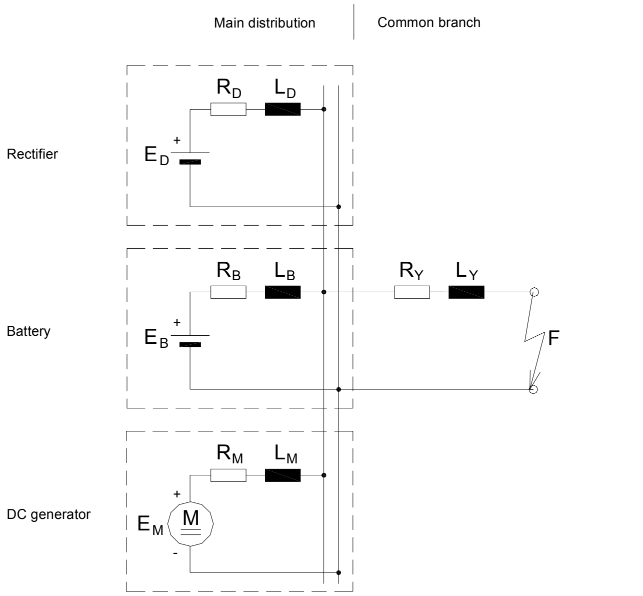

Fig. 2 – equivalent circuit diagram (ANSI/IEE model)

The instantaneous value of short-circuit current can be calculated by equation:

$$i_{sc}(t) = \frac{U}{R} \cdot (1 - e^{-\frac{t}{\tau}}) \qquad (2)$$

where:

U system rated voltage

R equivalent resistance

t time

τ time constant

For calculation of current from rectifier sources an iterative procedure is required, as the resistance to be used in Thevenin equivalent circuit at a certain level of terminal voltage during a fault needs to be calculated.

Detail references related to above described theoretical background can be found in "Ref. [2]" and "Ref. [3]".

C. Mathematical model for dynamics analysis in accordance with the IEC 61660-1

Mathematical model for short-circuit current evaluation in DC auxiliary system considers following items 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.3.

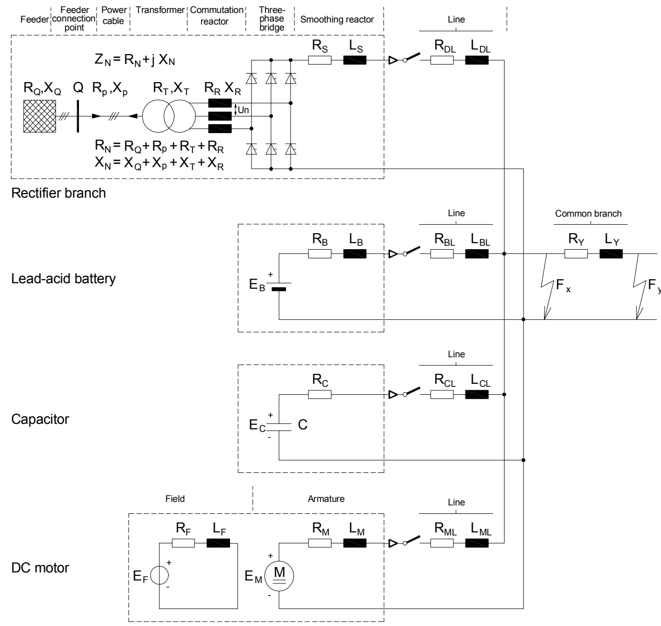

Fig. 3 – equivalent circuit diagram of the DC auxiliary system

The approximation function for short-circuit current of the above-mentioned four items is described by equations:

$$i_{sc1}(t) = i_p \frac{1 - e^{-\frac{t}{\tau_1}}}{1 - e^{-\frac{t_p}{\tau_1}}}, \quad 0 \le t \le t_p \qquad (3)$$

$$i_{sc2}(t) = i_p \cdot [(1 - p) \cdot e^{-\frac{t - t_p}{\tau_2}} + p], \quad t_p \le t \qquad (4)$$

$$p = \frac{I_k}{I_p} \qquad (5)$$

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 ″Ref. [1]″ and ″Ref. [12]″.

The total short-circuit current for the fault location Fx in Fig. 3 is obtained by adding short-circuit current of all sources without correction factor. For the fault location Fy in Fig. 3 the total short-cuircit current calculated by adding the partial short-circuit current modified by means of correction factor caused by common branch (R_Y and $L_Y \neq 0$). Formulas for calculation of partial contributions of different sources can be found in "Ref. [1]".

III. CALCULATION OF SHORT-CIRCUIT CURRENTS IN REAL POWER PLANT

Simplified block-diagram of the 220 V DC auxiliary system in respective thermal power plant is shown in Fig. 4. The calculation of maximum short-circuit currents are made on fault locations F1 and F2 by using of mathematical models described in section 2.1, 2.2 and 2.3. 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 is neglected;
- The control for limiting the rectifier current is effective only in static mathematical model but in other two mathematical models are 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 effects of circuit breakers are taken into account;
- There is no emergency lube oil pump, therefore only battery, modular rectifier and rectifier filter are valid sources of short-circuit current.

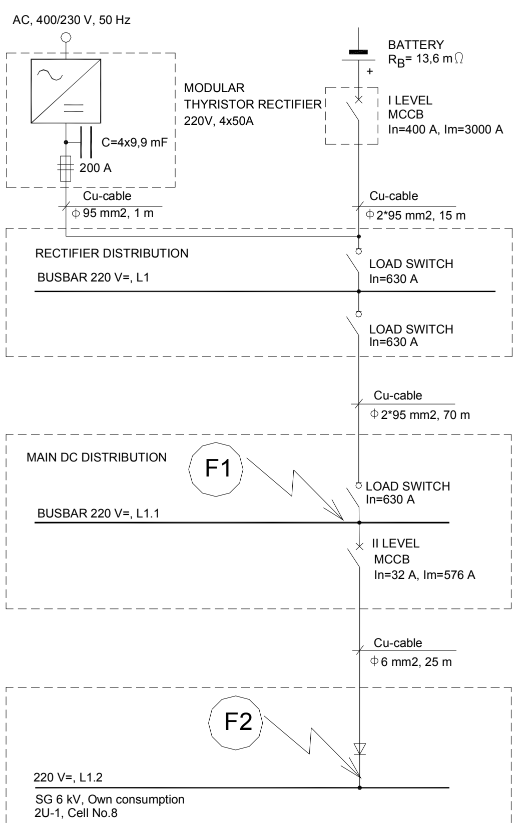

Fig. 4 – Simplified block-diagram of the 220 V DC auxiliary system in TPP

A. *Calculation according to static mathematical model*

By using of static mathematical model described in section 2.1. short-circuit current reaches maximal value immediately. All system inductances and capacitances are neglected, and there is no evaluation of transient short-circuit currents. Using equation (1) for the fault location F1 in the 220 V DC auxiliary system in TPP Rijeka the short-circuit current is:

$$I_{sc}\,(F1) = 6697 \text{ A}$$

and for fault location F2 value of short-circuit current is:

$$I_{sc}\,(F2) = 1155 \text{ A}$$

B. *Calculation according to the ANSI/IEEE guidelines*

In this mathematical model for short-circuit calculation, system inductances are taken into account but system capacitances are neglected.. Transient phenomena can be partly calculated. Calculation results which describe time variation of the short circuit current in the first 10 ms after short-circuit occurred are given in table I, for fault location F1 and in table II for fault location F2.

TABLE I
SHORT-CIRCUIT CURRENT IN FAULT LOCATION F1

	i_{sc} (A)
t= 1ms	3623
t= 2ms	5629
t= 3ms	6739
t= 4ms	7353
t= 5ms	7693
t= 6ms	7881
t= 7ms	7985
t= 8ms	8042
t= 9ms	8074
t= 10ms	8092

TABLE II
SHORT-CIRCUIT CURRENT IN FAULT LOCATION F2

	i_{sc} (A)
t= 1ms	554
t= 2ms	862
t= 3ms	1031
t= 4ms	1125
t= 5ms	1177
t= 6ms	1206
t= 7ms	1222
t= 8ms	1230
t= 9ms	1235
t= 10ms	1238

C. *Calculation according with the IEC 61660-1*

In this mathematical model for short-circuit calculation, system inductances and capacitances are taken into account. This model is the most suitable to implementation of dynamics analysis of DC auxiliary system because the model represents real situation in the DC auxiliary system. Calculation results which describe time variation of the short circuit current in the first 10 ms after short-circuit occured are shown in table III, for fault location F1 and in table IV for fault location F2.

TABLE III
SHORT-CIRCUIT CURRENT IN FAULT LOCATION F1

	i_{sc} (A)
t= 1ms	3457
t= 2ms	4910
t= 3ms	5839
t= 4ms	6442
t= 5ms	6833
t= 6ms	7086
t= 7ms	7249
t= 8ms	7355
t= 9ms	7424
t= 10ms	7470

TABLE IV
SHORT-CIRCUIT CURRENT IN FAULT LOCATION F2

	i_{sc} (A)
t= 1ms	1114
t= 2ms	1266
t= 3ms	1275
t= 4ms	1273
t= 5ms	1271
t= 6ms	1269
t= 7ms	1267
t= 8ms	1264
t= 9ms	1262
t= 10ms	1260

D. *Calculation result comparison*

In Fig. 5 and Fig. 6 are shown comparison of calculation results given by implementation of mentioned mathematical models. The curves show calculated variation of short-circuit current during the first 10 ms for fault locations F1 and F2.

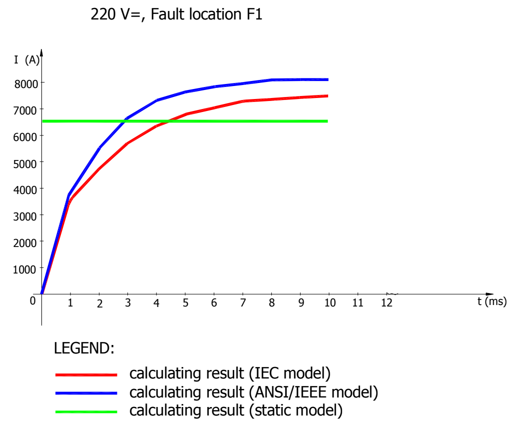

Fig. 5 – Time variation of short-circuit current in location F1 during first 10 ms

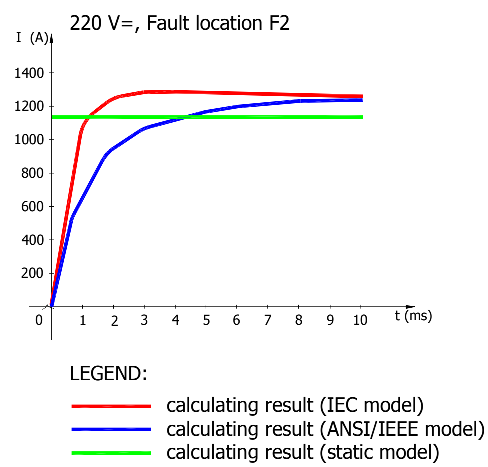

Fig. 6– Time variation of short-circuit current in location F2 during first 10 ms

IV. RECORDING SHORT-CIRCUIT CURRENTS ON SITE DURING THE TESTING OF CIRCUIT-BREAKER SELECTIVITY

Circuit breaker selectivity testing was performed on the site at the end of reconstruction of 220 V DC auxiliary system in real thermal power plant. Short circuit was generated at many fault locations. Time variations of short circuit currents were recorded by oscilloscope.

In Fig. 7 and Fig. 8 are shown results of testing for variation of total short-circuit currents during the fault breaking at fault locations F1 and F2. The results of testing compared with results calculated by three observed mathematical models. In the case recorded in Fig. 7, short-circuit current was broken by battery protection (Molded case Circuit-breaker Tmax T5, ABB). In the case recorded in Fig. 8 short-circuit current was broken by circuit-breaker situated in main distribution (Molded case Circuit-breaker NS100N, "Merlin Gerin").

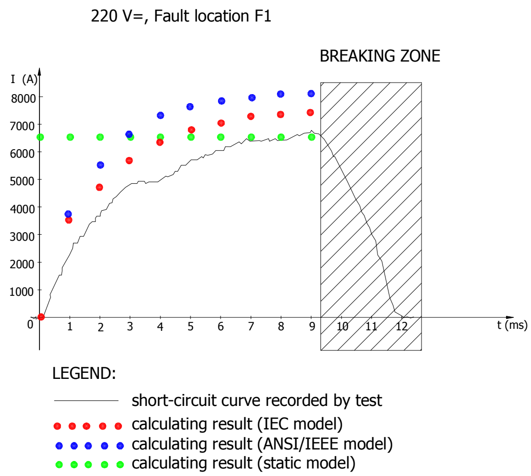

fig. 7 – time variations of short-circuit current in location F1

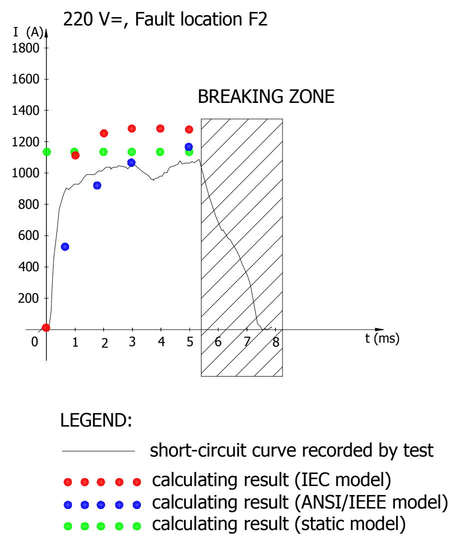

fig. 8 – time variations of short-circuit current in location F2

Comparison of calculation results given by implementing of different mathematical models and results recorded by testing on the site confirmed some practical experience in DC auxiliary system designing. Compared with ANSI/IEEE model, the mathematical model in accordance with IEC 61660-1 can better describes the real transient behavior of short-circuit current in DC auxiliary system. Thereby, classical mathematical model is suitable only for calculation of steady-state short-circuit current and it is not suitable for dynamics analysis of DC auxiliary system.

Time-current curves recorded during the mentioned testing shown in Fig. 7 and Fig. 8 well correspond with results calculated in accordance to IEC 61660-1 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 reached about 5-10 % lower amount than results given by calculation.

V. CONCLUSION

This paper has described the evaluation of short-circuit currents calculations in 220 V DC auxiliary system by implementation of different mathematical models and comparison the results from calculations with results given by testing performed in real thermal power plant. The results calculated based on mathematical model for dynamics analysis in accordance to IEC 61660-1 corresponded with short-circuit currents recorded by testing, with a generally accepted overestimation of about 5-10% on the safety side in relation with results of performed testing. The differences between simulated and experimental results supported on the assumptions done at modeling the system.

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