Induction Motor Impact on Effective and Thermal Short-Circuit Current

Lidija M. Korunovic[1] and Dobrivoje P. Stojanovic[2]

Abstract - **The analysis of three-phase faults in the industrial network with high and low-voltage induction motors is given in the paper. Network topology influence on effective and thermal short-circuit current is considered. In this way it is shown how motor electrical distance from the faulty place influence on mentioned variables. Also, effective and thermal current changes of an induction motor are analyzed dependent on the motor supply voltage during the fault.**

Keyword - **induction motor, short-circuit, industrial network**

I. Introduction

Calculation of short-circuit currents is fundamental for the selection and checking of equipment and apparatus in power stations, as well as for adjustment and reliable work of relays. By rule, calculation of short-circuit current is performed with load influence neglect. However, in middle and low-voltage networks load influence can be of importance. This is especially distinctive in industrial networks and self-consumption facilities of power plants where great number of low-voltage (LV) and high-voltage (HV) induction motors are installed.

In [1-3] detailed analysis of induction motor (IM) influence on maximal short-circuit current is given. In an complex industrial network all motors more or less are influenced by the fault, depending on the electrical distance from the faulty place. The measure of the electrical distance from the faulty place is the motor voltage during the short-circuit. The voltage changes at motor terminals determine the induction motor behavior during the fault. Namely, due to voltage variations, motor reacts and changes its current. Motor current value, as well as the question will it continue running or not, depend on voltage value and its mechanical load. It is also of importance what is the IM influence on effective end thermal short-circuit current. All mentioned facts intrude the need to exploit in details all phenomena connected with IM dynamic in long periods of time. In this sense, the paper is continuation of the researches from [1-3].

The analysis of IM influence on effective and thermal current during the fault is performed on the bases of simulation results of typical industrial network with two voltage levels. Mathematical model which define transients is described by the set of Park's differential equations of the motors and transformers, as well as by corresponding algebraic equations.

The aim of the paper is to direct attention to engineers on the phenomena as are decrease or increase of effective and thermal current during the fault which are caused by induction motor dynamic. Also, it is shown how motor dynamic influence on operation of neighboring motors.

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II. Simulation Scheme and Mathematical Motor Model

A typical industrial network consists of great number of motors which are usually supplied through cables of different lengths. According to the structure variety of such a kind of network, the authors are examined simplified network shown in Fig. 1 to indicate the phenomena mentioned in Introduction. Thus, three-phase short-circuits are simulated at middle and low-voltage busbars during different operation modes of the motors. The number of motors and parallelly connected transformers, as well as the moment of fault occurrence are changed.

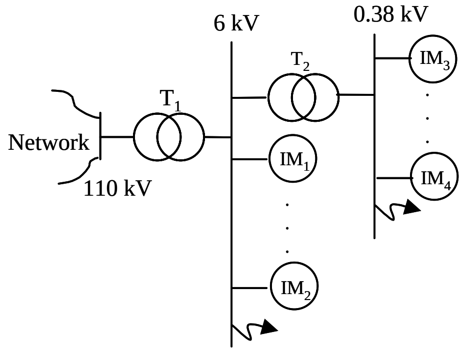

Fig. 1. Basic one-line system scheme

The network elements are described by d, q components where d and q axes are connected with rotor. Data of motors and other system elements are given in Appendix. The changes of motor parameters with slip, as well as magnetic circuit permeation, are not considered in the paper.

Three-phase induction motor dynamic is described in such a manner the electrical part is presented by fourth order model in state space, and mechanical part by second order equation system [4]:

- electrical system

$$u_{ds} = R_s i_{ds} + \frac{d\Phi_{ds}}{dt} - \omega\Phi_{qs}, \quad (1)$$

$$u_{qs} = R_s i_{qs} + \frac{d\Phi_{qs}}{dt} + \omega\Phi_{ds}, \quad (2)$$

$$0 = R_r i'_{dr} + \frac{d\Phi'_{dr}}{dt}, \quad (3)$$

$$0 = R_r i'_{qr} + \frac{d\Phi'_{qr}}{dt}, \quad (4)$$

$$T_e = 1.5p\left(\Phi_{ds} i_{qs} - \Phi_{qs} i_{ds}\right), \quad (5)$$

- mechanical system

$$\frac{d\omega}{dt} = \frac{1}{2H}\left(T_e - F\omega - T_m\right), \quad (6)$$

$$\frac{d\theta}{dt} = \omega. \quad (7)$$

In the above relations conventional symbols of individual variables are used, and all values are in per unit.

III. RESULTS

Some of simulation results for various operation modes of the network from Fig. 1 are given in this paragraph. These results relate to influence of induction motor electrical distance on effective and thermal short-circuit current. For a complex network the measure of a motor electrical distance from the faulty place is its voltage during the short-circuit.

Besides the electrical distance, characteristic values of induction motor currents depend on the moment of the fault occurrence. This is shown on the example of induction motor IM_1, in the case of voltage drop at its terminals from value 1 to 0.6 p.u. due to near by fault. Then peak value of the motor current for the most unsuitable fault moment will be 2.046 times greater than peak current value for the most suitable fault moment when only periodical fault current component exists (Fig. 2). Under the most unsuitable conditions (maximal aperiodic component of short-circuit current), the increase of maximal effective and thermal fault currents of this motor are 178.96 and 141.22 %, respectively. Therefore, the results for the fault which occurs at the most unsuitable moment will be presented in next paragraphs.

Dependence of effective IM_1 current on time for different voltage values after near by fault is shown in Fig. 3. At the beginning, 0.05-0.11 s after fault occurrence, motor takes part in short-circuit current increase. In the period from 0.06 to 0.16 s, it practically does not influence on fault current, while after 0.16 s it decreases short-circuit current if the voltage is higher than critical one. For distant faults, when the voltage is higher than 0.8 p.u., motor practically does not impact on fault current. However, it should be noticed that under real circumstances, current changes will be different from those shown in Fig. 3, due to voltage changes during short-circuit.

As mentioned, analysis results of induction motor impact on effective and thermal short-circuit current for near by faults will be presented. For this reason the structure of Fig. 1 is changed. Different electrical distance of HV motors from the faulty place - LV busbar, is simulated by changing the number of parallelly connected transformers T_2. The voltage at 6 kV busbar during the fault is determined not only by the number of these transformers, but also by dynamic of the motors connected to the same busbar. If the voltage is higher than critical value, induction motor transient can be divided into two phases: the first one when HV motors operate as generators and increase fault current, and the second when operate as motors, so download the faulty place.

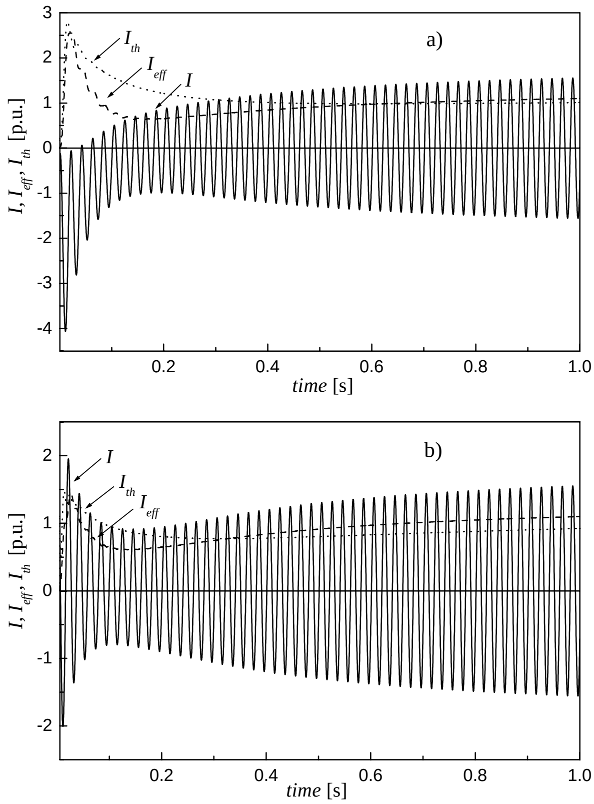

Fig. 2. Instantaneous (I), effective (I_{eff}) and thermal (I_{th}) current of motor IM_1 due to voltage drop to 0.6 p.u. a) at the most unsuitable moment, b) at the most suitable moment

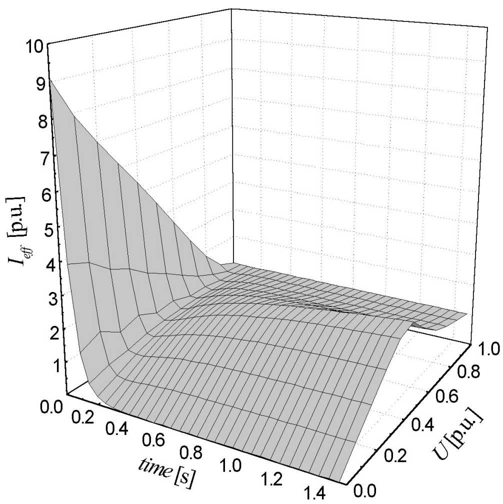

Fig. 3. Effective value variation of IM_1 current after short-circuit for different motor voltages

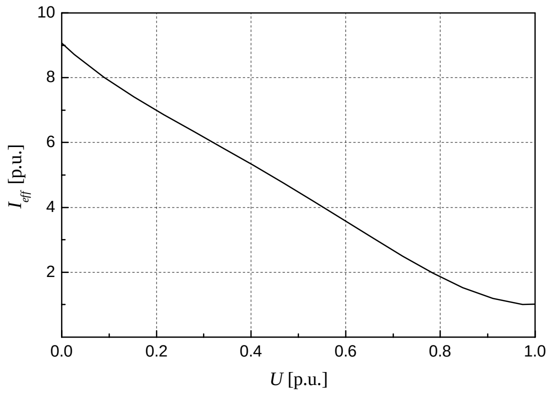

Fig. 4. Maximal effective values of IM_1 current for different motor voltages

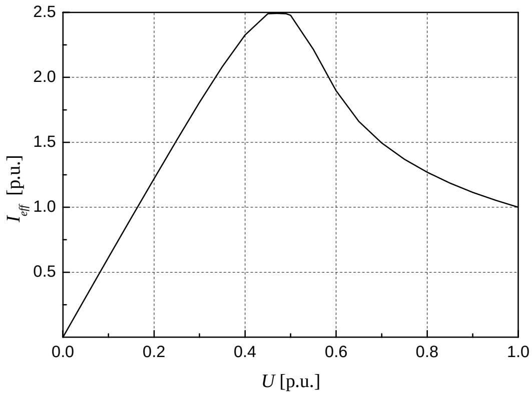

Fig. 5. Effective current of IM_1 for different motor voltages 1.5 s after short-circuit

Effective and thermal short-circuit currents for the cases of both HV motors from Fig. 1 running and without them are presented in Figs. 6 and 7. Also, the number of parallelly connected transformers T_2 is changed. From these figures is evident increase of effective and thermal short-circuit currents in comparison with the same variables when HV motors do not operate. This is consequence of the first phase of these motor transient. Maximal increase of effective short-circuit current is: 1.702, 4.552 and 4.613 % for one, two and three transformers T_2, respectively. Similar results are obtained for thermal current.

During second part of transient which starts 0.055-0.18 s after the fault moment occurrence, motors IM_1 and IM_2 continue motor operation mode if the voltage is higher than critical value. It results with effective and thermal short-circuit current decrease in this period. In the case of one transformer T_2, after 0.1 s HV motors start to download the faulty place and at 0.3 s, under voltage 0.804 p.u., restore the new steady state operation modes. Then effective short-circuit current value is 1.234 % less than that for the scheme without IM_1 and IM_2. Thermal fault current constantly decrease in time and it will be, 1 s after fault occurrence, 1.161 % less than that in the case when HV motors do not operate.

With the increase of parallelly connected transformer number, the voltage at middle-voltage busbar during the fault is lower. If the motor loads are of constant power, HV motors will have larger currents to continue running. These download the faulty place more significantly. If two transformers T_2 are connected parallelly, after 0.3 s the new operation modes of IM_1 and IM_2 are not restored because the voltage is 0.677 p.u. After 0.8 s, new operation modes will be restored under U=0.673 p.u. Then effective short-circuit current value is 2.558 % lower in comparison with that in the case without IM_1 and IM_2. If three parallelly connected transformers T_2 operate, the voltage at middle-voltage busbar is lower: 0.597 and 0.576 p.u. after 0.3 and 0.8 s, respectively. HV motors in considered period of time do not manage to restore the new operation modes. Theoretically, in the case of the long lasting fault (if the protection does not act) those will manage to restore new operation modes after enough long periods of time.

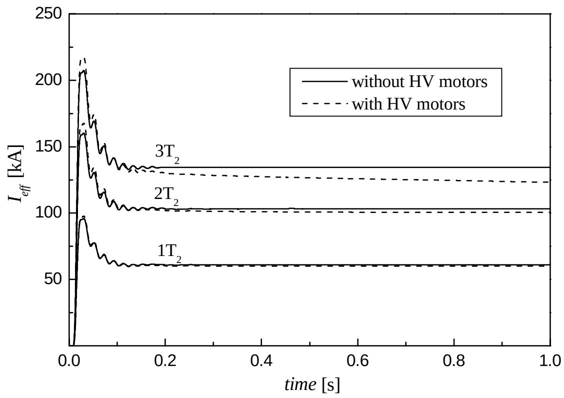

Fig. 6. Effective short-circuit current for the scheme: with one ($1T_2$), with two ($2T_2$) and with three ($3T_2$) - without (———) and with HV motors (------)

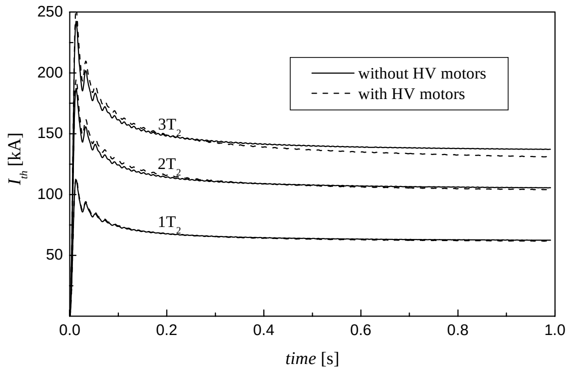

Fig. 7. Thermal short-circuit current for the scheme: with one ($1T_2$), with two ($2T_2$) and with three ($3T_2$) - without (———) and with HV motors (------)

If the voltage at the busbar is lower than critical one, motors will stop running, and during transients can decrease busbar voltage under critical value for neighboring motors. In this way neighboring motors will be indirectly stopped. This situation is in the case of two T_2, three IM_1, two IM_2 and four IM_3 and IM_4. Then the voltage at middle-voltage busbar is 0.745 p.u. after the fault, and this value is enough for the operation of both HV motor types. However, these motors increase their currents and decrease HV busbar voltage. Motors IM_2 stop running first and decrease the voltage to 0.544 p.u. Since this value is lower than critical voltage for motors IM_1, these will also stop running.

IV. Conclusion

Consideration of simulation scheme variants is confirmed the fact that during near by fault, when the voltage is higher than critical one, motor currents will start to download the faulty place 0.055-0.18 s after short-circuit. This is more significant when the voltage at motor terminals is lower. For the voltages which are lower than critical values, induction motors will stop running, increase their currents and decrease busbar voltage, so this voltage can be less than critical value for neighboring motors. From these facts, one can conclude that induction motors significantly take part in maximal and subtransient short-circuit currents, and also, their dynamic can importantly change operation conditions of neighboring consumers.

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Appendix

- Induction motors

IM$_1$: P_n=1.9 MW, U_n=6 kV, S_n=2.17199 MVA, R_s=0.00929 p.u., L_s=0.07742 p.u., R_r'=0.01031 p.u., L_r'=0.08058 p.u., L_m=5.3783 p.u., H=0.77631 s, p=3, s_n=0.01

IM$_2$: P_n=7 MW, U_n=6 kV, S_n=7.37854 MVA, R_s=0.01168 p.u., L_s=0.09488 p.u., R_r'=0.01012 p.u., L_r'=0.09772 p.u., L_m=5.7785 p.u., H=1.03175 s, p=2, s_n=0.01

IM$_3$: P_n=110 kW, U_n=0.38 kV, S_n=135.58494 kVA, R_s=0.027 p.u., L_s=0.12609 p.u., $\mathrm{R_r}$'=0.01123 p.u., L_r'=0.12609 p.u., L_m=5.3783 p.u., H=0.39604 s, p=1, s_n=0.01

IM$_4$: P_n=315 kW, U_n=0.38 kV, S_n=371.87131 kVA, R_s=0.03 p.u., L_s=0.13967 p.u., R_r'=0.01046 p.u., L_r'=0.13967 p.u., L_m=4.0855 p.u., H=0.42758 s, p=1, s_n=0.01

- Transformers

T$_1$: S_n=31.5 MVA, u_k=10.5 %, P_k=135 kW, 110/6 kV

T$_2$: S_n=2×1600 kVA, u_k=6.5 %, P_k=16 kW, 6/0.38 kV

- Network

S_{net}=1000 MVA, U_n=110 kV, R_{net}=0.1X_{net}