Generator Dynamics Influence on Currents Distribution in Fault Condition

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Abstract - **Current flow calculation results along the elements of complex power system are analyzed in this work, during three-phase short-circuit taking into account relative rotor swing. Analysis is implemented on the examples when, beside infinite bus fault point is supplied by one or more generators. It is shown, that generator swing neglecting during short-circuits, essentially changing current distribution in the system, which can bring to not permissible mistakes in calculation results.**

Keywords: short-circuit, generator, oscillations

I. INTRODUCTION

Short-circuit calculation results are the base for choice and checking of the equipment in power plants and protective relay setting. Great number of papers are dedicated to short-circuit calculation problem in the world [1 - 4] and in Yugoslavia [5 - 8]. These papers developed the theory of processes during short-circuits, where the methods are different, from approximately analytical calculations to complex computer calculations. Electrical value's calculations in a moment of fault occurrence do not give answer how particular values are changing in time.

Mathematical formulation of short-circuit problem has common with dynamic stability calculation, but sometimes can be more complex. Electromagnetic and electromechanical transient process has been usually considered separately in practice, although they are essentially the same process.

At short-circuit currents calculation and their characteristic values calculation, as a rule, electromagnetic transient process is taken into account only. But as a result of fault, balance of torques at turbine-generator shaft is disturbed, so it causes electromechanical transient process which is expressed through rotor angle changing and angle changing between electromotive forces (emf) of each generator. Oscillations of these angles, caused by any rotor swing, affect to character and current distribution during short-circuit.

Entire influence of described factors produces intensive changing of electric values in transient processes caused by short-circuits, that is shown in [6, 7, 8]. This problem is especially emphasized at faults very near to power station. Relative rotor moving influence to symmetrical and nonsymmetrical short-circuit current is considered on the example of single-machine system in [6]. The same problem is analyzed in [7], when a few different generators are connected to common bus-bars.

Practical interest is to make qualitative analysis of electromechanical transient process influence to more complex power system, that was implemented in this work. Total short-circuit current and currents along system elements are analyzed, and in that way the results achieved in [6 - 8] are complemented. Result analysis is implemented for three-pole short-circuit, when this phenomenon is most expressed. Generator dynamics calculation and calculation of currents along system elements is implemented by special software for dynamic stability calculation of complex multimachine power system. All factors, which are usually neglected at traditional calculations, are fully taken into account here. As mathematical model of synchronous generator the fifth order model is used based on Park's equations. In this model, electromagnetic process in stator windings is neglected, so RMS value of alternating component of short-circuit current is attended only. Software is specially adapted for result printing and drawing of currents along system elements.

Calculation results could be practically useful for choice and checking of switching equipment and for protective relay setting.

II. MATHEMATICAL MODELING

A. The model of synchronous generator

Standard Park's model of synchronous generator [7 - 9] with one damper contour along each axis, is described by following system of equations:

Electromagnetic balance equations are:

- for stator

$$-\frac{d\psi_d}{dt} - \omega\psi_q - r i_d = u_d = -U\sin\theta \qquad (1)$$

$$\omega\psi_d - \frac{d\psi_q}{dt} - r i_q = u_q = U\cos\theta \qquad (2)$$

- for rotor

$$\frac{d\psi_f}{dt} + r_f i_f = u_f \qquad (3)$$

$$\frac{d\psi_D}{dt} + r_D i_D = 0 \qquad (4)$$

$$\frac{d\psi_Q}{dt} + r_Q i_Q = 0 \qquad (5)$$

- rotor moving equations

$$\frac{d\omega}{dt} = \frac{T_T - T_e}{J} = \frac{T_T - (\psi_d i_q - \psi_q i_d)}{J} \qquad (6)$$

$$\frac{d\theta}{dt} = \omega - 1 \qquad (7)$$

With regard to the nature of here considered problem, electromagnetic transient process is neglected in stator windings, so the values $\frac{d\psi_d}{dt}$ and $\frac{d\psi_q}{dt}$ in. (1) and (2) become zero. This simplification eliminates aperiodical components of voltage and current. So this may enable to observe periodical components of fault-current only. Also, it enables simple including stator equations into network equations.

B. Model of transmission elements

Transformers and lines are shown as serious link of resistance R and inductivity L.

Voltage balance equations on RL branch, through dq components are:

$$u_{1d} - u_{2d} = \omega L i_q + R i_d \qquad (8)$$

$$u_{1q} - u_{2q} = -\omega L i_d + R i_q \qquad (9)$$

III. NUMERICAL EXAMPLES AND RESULT ANALYSIS

Short-circuit currents calculation, taking into account generator swing, is implemented at a number of examples. Here will be shown results at a simple multimachine system shown on Fig. 1. The generators are of different rated powers and inertia time constants. Before the fault, they were loaded by rated powers.

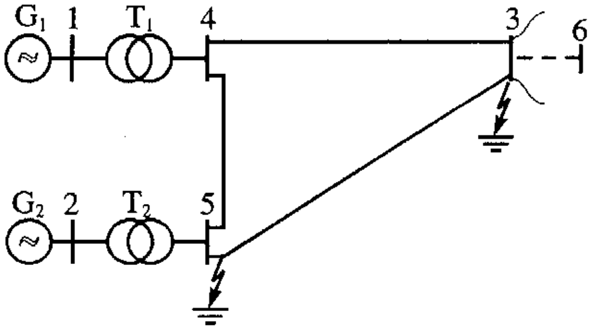

Fig. 1 Equivalent scheme of considered system

Qualitative estimation of generator swing influence on fault current is given on the base of three-pole short-circuit current calculation results for two fault location.

Let us consider, firstly, current flow in time for short-circuit in node 3. For a difference from the examples in [5 - 7], there is not radial supply of fault point here, because the line 4-5 exists. As a consequence of it, one generator current depends on another, relatively to their mutual angle. Each branch currents of the network from Fig. 1 are shown on Fig. 2. Obviously, all currents are changed intensively in fault condition, that is a consequence of rotor swing. Current I_{45} is changed so much due to angle changing between generators G1 and G2, so the questions arises could it be neglected and when. Namely, it is calculated in literature sometimes with radial supply of fault point where transversal branch currents are neglected.

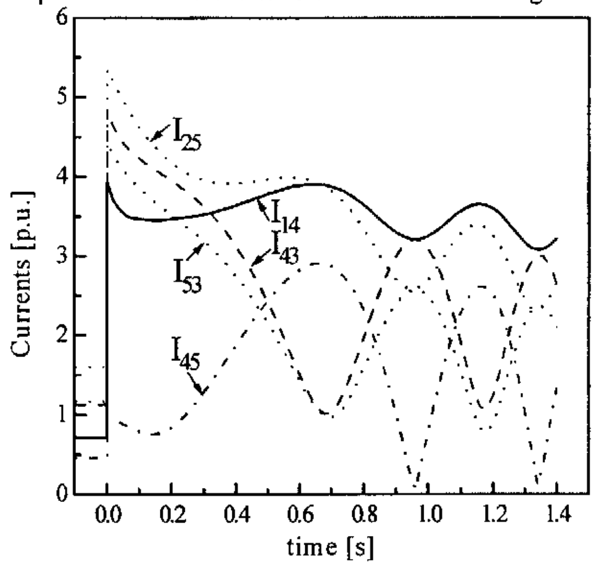

Fig. 2 Network currents during a fault in node 3.

Fig. 3 shows currents I_{43} and I_{53} coming to fault point through the lines 4-3 and 5-3 and total current coming from left (generator) side. Total current is shown as vector and arithmetic sum of currents. At vector summing, the angle between currents is taken into account, and aritmethic means the sum of RMS values of currents.

In order to compare, Fig. 4 and 5 shows the same values as on Fig. 2 and 3 but when rotor swing is neglected. This is in accordance with usual calculation of total fault current. It should be emphasized, current through the line 4-5 appears here, but significantly less. To avoid generator swing influence on branch currents, inertia constants are taken $T_{J1} = T_{J2} = 10^{10}$ in calculations.

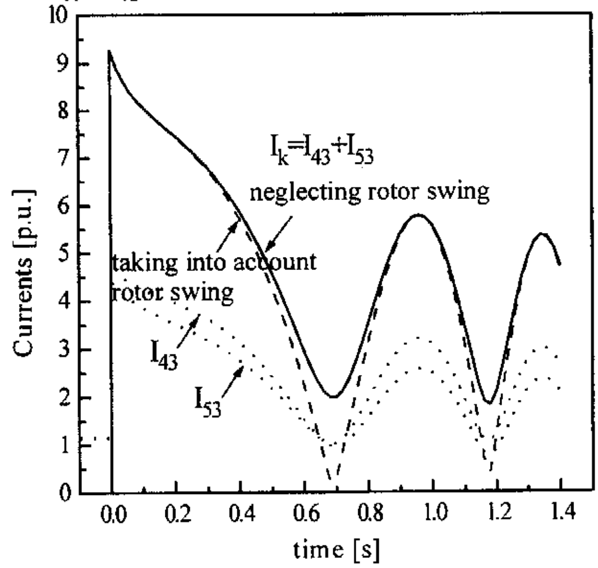

Fig. 3 Currents coming to fault point 3. from left sid

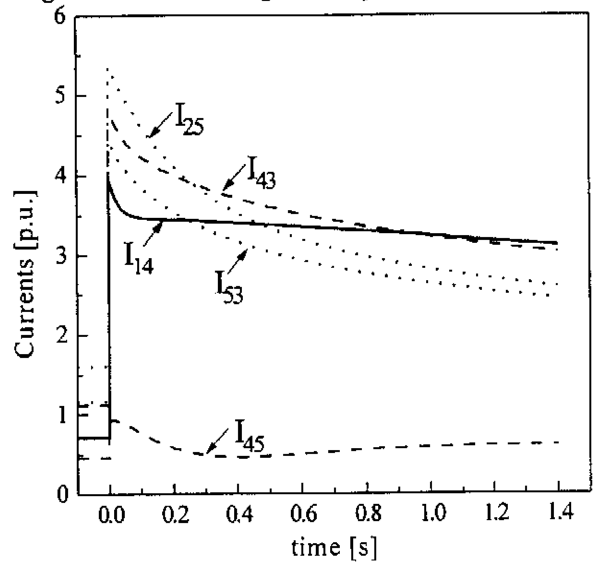

Fig. 4 Network currents during the fault in node 3 when rotor swing is neglected

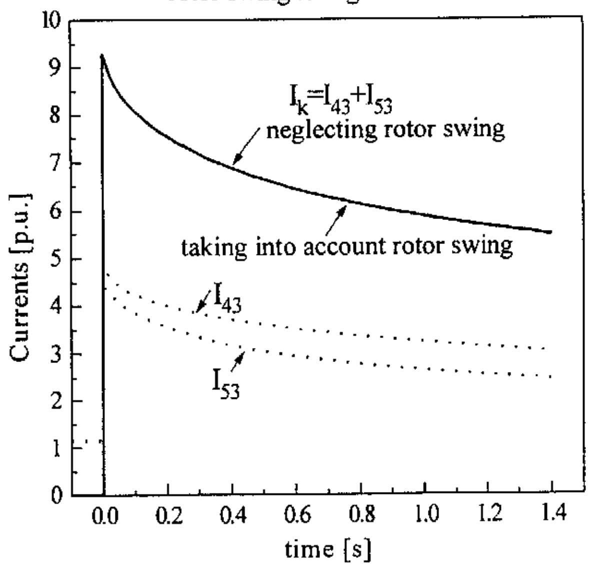

Fig. 5 Currents coming to fault point (3) from left side when rotor swing is neglected

Generator swing influence on some currents one can see on Fig. 6. to 11. which show parallel values of fault current in the case with (—) and without (---) taking into account relative rotor moving.

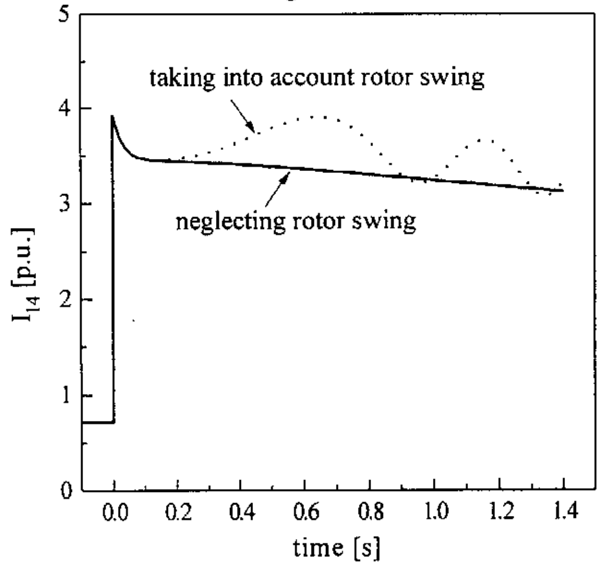

Fig. 6 Current of branch 1-4

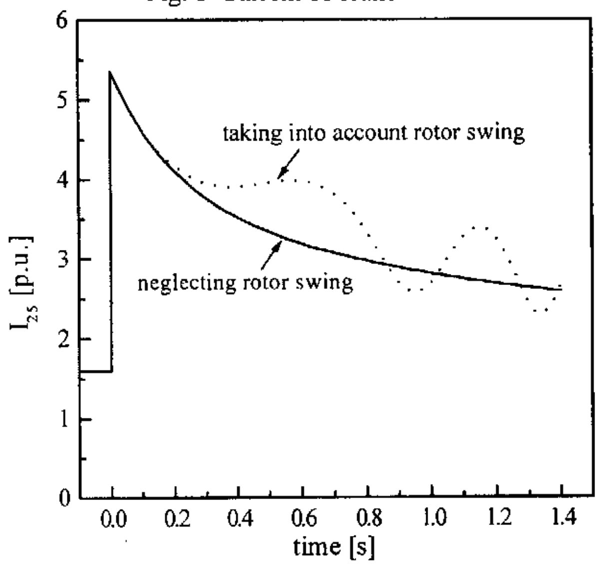

Fig. 7 Current of branch 2-5

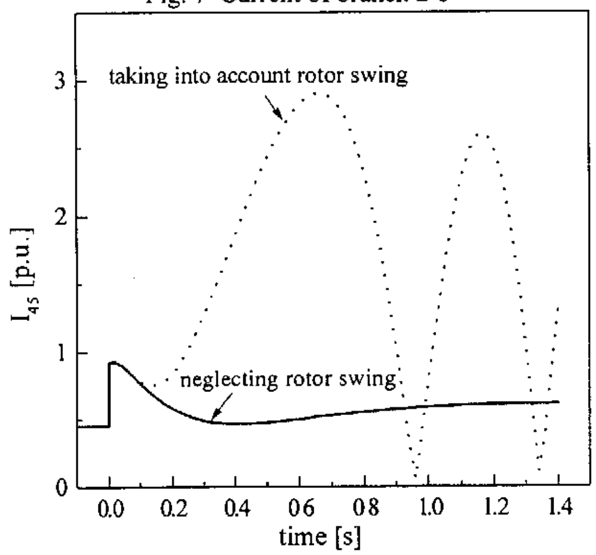

Fig. 8 Current of branch 4-5

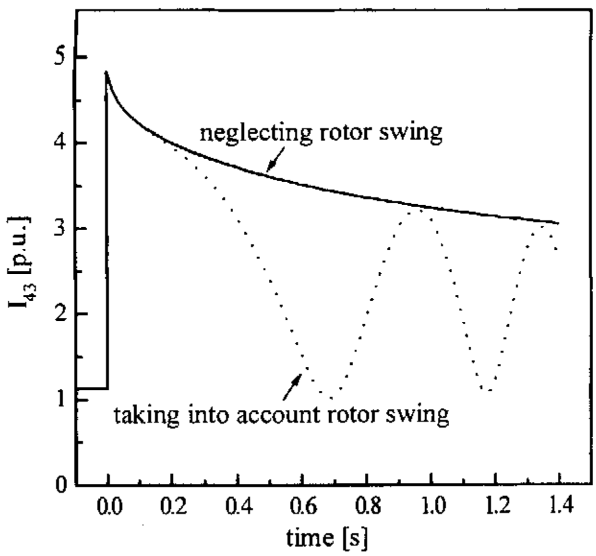

Fig. 9 Current of branch 4-3

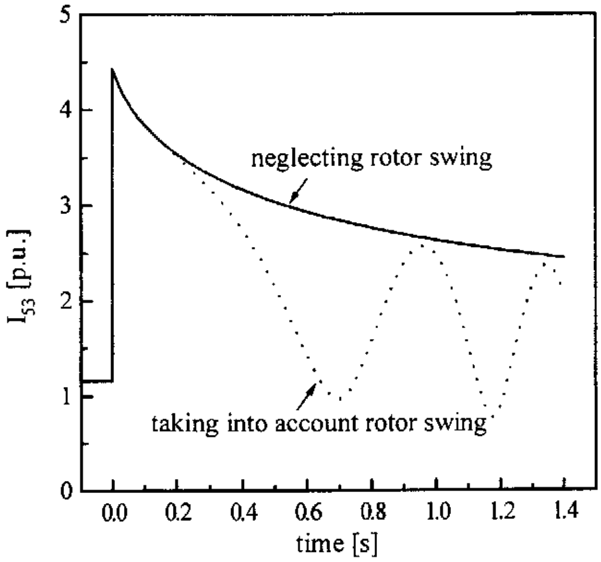

Fig. 10 Current of branch 5-3

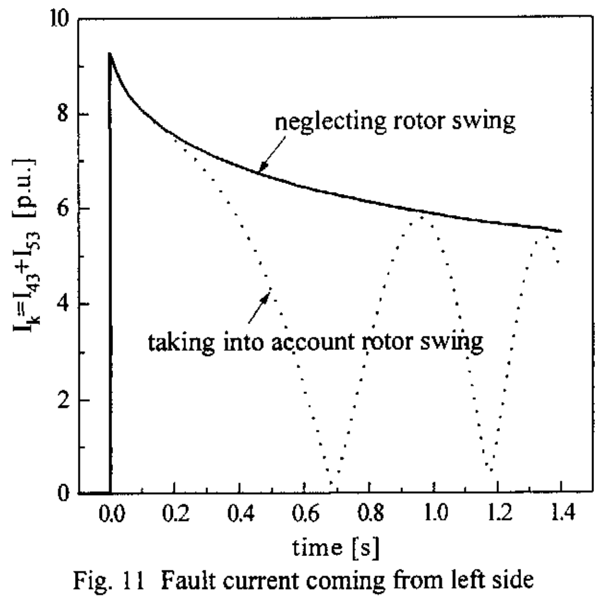

Fig. 11 Fault current coming from left side

It is interesting that generator currents I_{14} and I_{25} and current I_{45} also have oscilatorilly character; after beginning fall, their values are increasing again due to rotor swing, after certain time they accept the values near to beginning ones (Fig. 6 and 7) or even grater, that is the case with I_{45} (Fig. 8). In concrete example, current I_{14} gets it's repeated maximum in t=0.64s, which accounts I_{14} = 3.905pu, that is very near to beginning subtransient value I_{14}'' = 3.9324pu. In the same instant, this current is 16.6% grater than corresponding one when rotor swing is neglected. Current increasing is more expressed at linking line 4-5, where maximal value, achieving in t=0.66s, is even 3.14 times greater than beginning one. All these can be interesting from protective relaying standpoint. Certainly, a question arises is the fault lasting so long in real conditions. Otherwise, in conditions when rotor swing is neglected, generators currents are damping continually. For a difference of generator currents, currents I_{43} and I_{53} have smaller values in conditions of rotor swing neglecting. Also, their sum current $I_k = I_{43} + I_{53}$ is rapidly decreasing, so in t=0.68s it is only 3.58% of the value obtained when rotor swing is neglected (Fig. 11).

There are similar dependencies for fault in any other node. Fig. 12 shows network branch currents for three-phase fault in node 5, and Fig. 13 shows total fault current. Total fault current has oscilstorilly character here and their values are always less than current sum of each branches. As it was told before, oscilatorilly character of fault current is a consequence of generator swing, relatively to angle changing between generator G1 and G2, and angles between each generator and system. Total fault current is rapidly decreasing, and already in t=0.56 s has fallen to the value I_k = 18.204pu, that is 68.92% of current value obtained when rotor swing is neglected. Generally speaking, total fault current is always less than the sum of currents coming to fault point, because it is evaluated as vector sum of these currents. This is convenient circumstance from equipment standpoint, because the real thermal and dynamic strains are less than ones obtained by usual calculation.

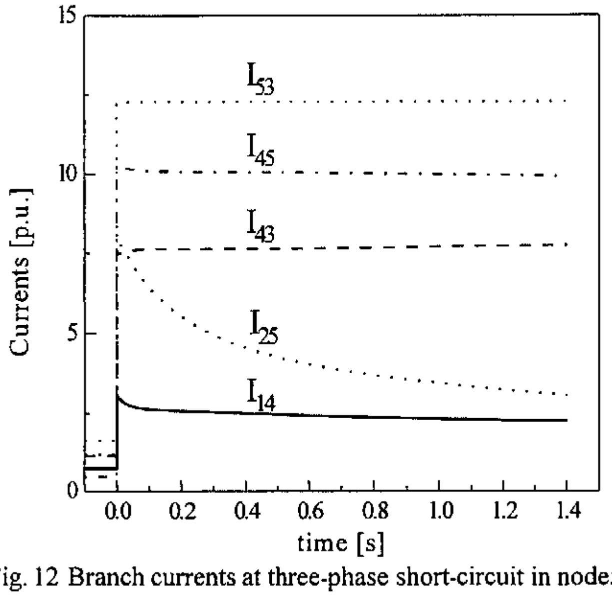

Fig. 12 Branch currents at three-phase short-circuit in node5

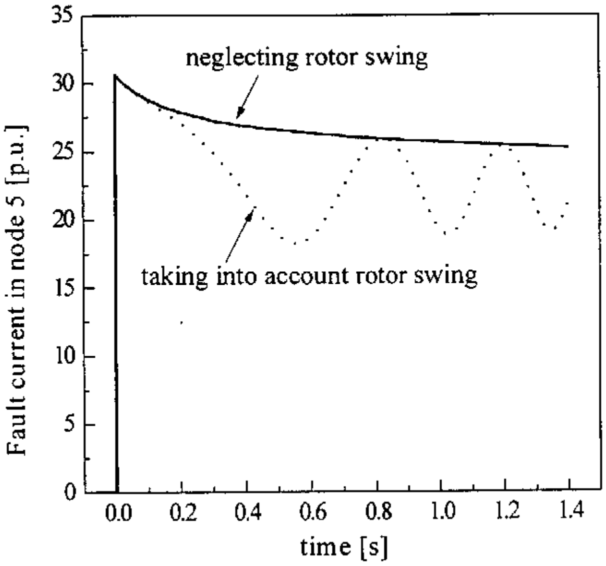

Fig. 13 Fault current at three-phase short-circuit in node 5

Long-lasting faults cause electromechanical transient process in real multimachine system where all machines participate more or less. The process is versatile, determinated by all mutual rotor angle changing. The same is process of angle changing between vectors of generator's emf, and as a consequence of it, angles changing between short-circuit current vectors. With fault occurrence, generators is downloaded and accelerate independently, so their mutual angle is changing and as a consequence of it, currents coming from generator side are changing also. Intensity of electromechanical process and it's influence on fault current is depends on fault location, the type of fault and on initial conditions. So it is necessary create the method for simple modeling of generator dynamics.

IV. CONCLUSION

This work shows calculation results of current flow along system elements and of total fault current. Qualitative analysis of rotor swing influence to aforementioned currents changing in time is given.

It is established that at longer faults (t_i >0.15s), rotor swing neglecting can bring to significant mistake in fault current evaluation. Fault current value, with taking into account rotor swing, is always less than one obtained by standard calculations, that is convenient from equipment standpoint. In same cases, currents along system elements get the values grater than expected. RMS values of current has oscilatorilly character, that can cause malfunction of protective relays.

Calculation results can be practically useful not only for equipment checking but for choice and setting of protective relays.

V. REFERENCES

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VI. APPENDIX

- generator G_1:

$P_n = 200\,MW$, $U_n = 15.75\,kV$, $cos\varphi_n = 0.85$, $n = 3000\,min^{-1}$, $x_d'' = 0.19$, $x_d' = 0.295$, $x_d = 1.84$, $T_{d0} = 6.8s$, $T_d' = 1.1s$, $T_d'' = 0.135s$, $T_a = 0.546s$, $GD^2 = 25\,tm$

- transformer T_1:

$S_n = 240\,MVA$, $u_k = 11.3\%$, $231/15.75\,kV$, $P_{Cun} = 650\,kW$

- generator G_2:

$P_n = 171\,MW$, $U_n = 15.75\,kV$, $cos\varphi_n = 0.85$, $n = 1000 min^{-1}$, $x_d'' = 0..205$, $x_d' = 0.345$, $x_d = 0.915$, $x_q'' = 0.20$, $x_q = 0.65$, $T_{d0} = 8s$, $T_d' = 0.95s$, $T_d'' = 0.035s$, $T_a = 0.20s$, $GD^2 = 68\,tm$

- transformer T_2:

$S_n = 200\,MVA$, $u_k = 10.3\%$, $231/15.75\,kV$, $P_{Cun} = 580\,kW$

- lines:

$l_{45} = 60\,km$, $l_{43} = 80\,km$, $l_{53} = 100\,km$, $r = 0.08\Omega/km$, $x = 0.41\Omega/km$