Testing of Electric Drive with a Serial Connection of the Same Phases of Two Induction Motors through Computer Simulation

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Abstract: Objective - check the functionality of the circuit of an electric locomotive fan drive that is not speed-controlled, containing two induction motors, the same stator phases of which are connected in series. Methods: computer simulation of electric drive at rated voltage and under-voltage at different values of shaft load and not equal parameters of motors. The simulation results are presented. Results: the simulation showed that, despite the possibility of sustainable operation at rated voltage, this scheme at under-voltage supply is unstable. Conclusion: the auxiliary electric drive circuit with a series connection of the phases of two induction motors is not recommended for use.

Key-Words: - auxiliary electric drive, electric locomotive, induction motor, computer simulation, capacitive voltage divider, fan, parameters.

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1 Introduction

This article describes an example of the implementation of one of the main objectives of the computer simulation when it is used in the synthesis of new schemes of electric drives, namely: to test the feasibility and quality of operation of the proposed scheme, taking into account the specific conditions of use, based on which a decision is made about the suitability or unsuitability of the considered option. Specifically examined the functioning of the electric locomotive auxiliary drive with a series connection of the same phases of two 3-phase induction motors.

2 Problem Formulation

To simulate the direct start of two 4-pole squirrel-cage induction motors (IM) of type NVA-55 or ANE-225 (used in the auxiliary electric drive of AC electric locomotives in Russia, [1], [2], [3], [4], [5]), the same phases of which are connected in series, author uses the mathematical model of 3-phase IM which described in, [2], (rotor parameters of IM reduced to stator, [6], [7], [8]). Modeling of the fan load (bottom in Figure 1) was performed according to, [2]. The stator windings of two motors represent a three-phase symmetrical system, connected in a wye circuit without a neutral wire. To equalize the voltage distribution of two motors between the beginning and the end of each stator phase winding, a capacitor is connected in parallel to the winding (C-voltage divider, Figure 1). The ratings of all capacitors are the same (1000 μF each in Figure 1). OrCAD is used as a tool for simulation, [9], [10], [11].

3 Problem Solution

It was revealed that at a load corresponding to the rated power of the IM, the system does not provide stable operation even in the ideal case, when the parameters in each of the motors and each of the loads are the same (Figure 2). In this case, the presence or absence of capacitive dividers, as well as the ratings of the capacitors, is not of fundamental importance.

The process develops as follows. Differences in IMs' load are gradually increasing. One of the IMs "stalls": the electromagnetic torque drops (gradually to zero) and, as a consequence, the rotation speed too. Another IM accelerates above the rated rotation speed, without reaching the synchronous speed, i.e., from the moment the speed of the first IM drops, the speed of the second increases. The second IM operates stably at an increased rotation speed. On the IM that loses torque, the voltage decreases. On the stator of the IM remaining in operation, the voltage increases. The phase currents of the corresponding IMs behave similarly.

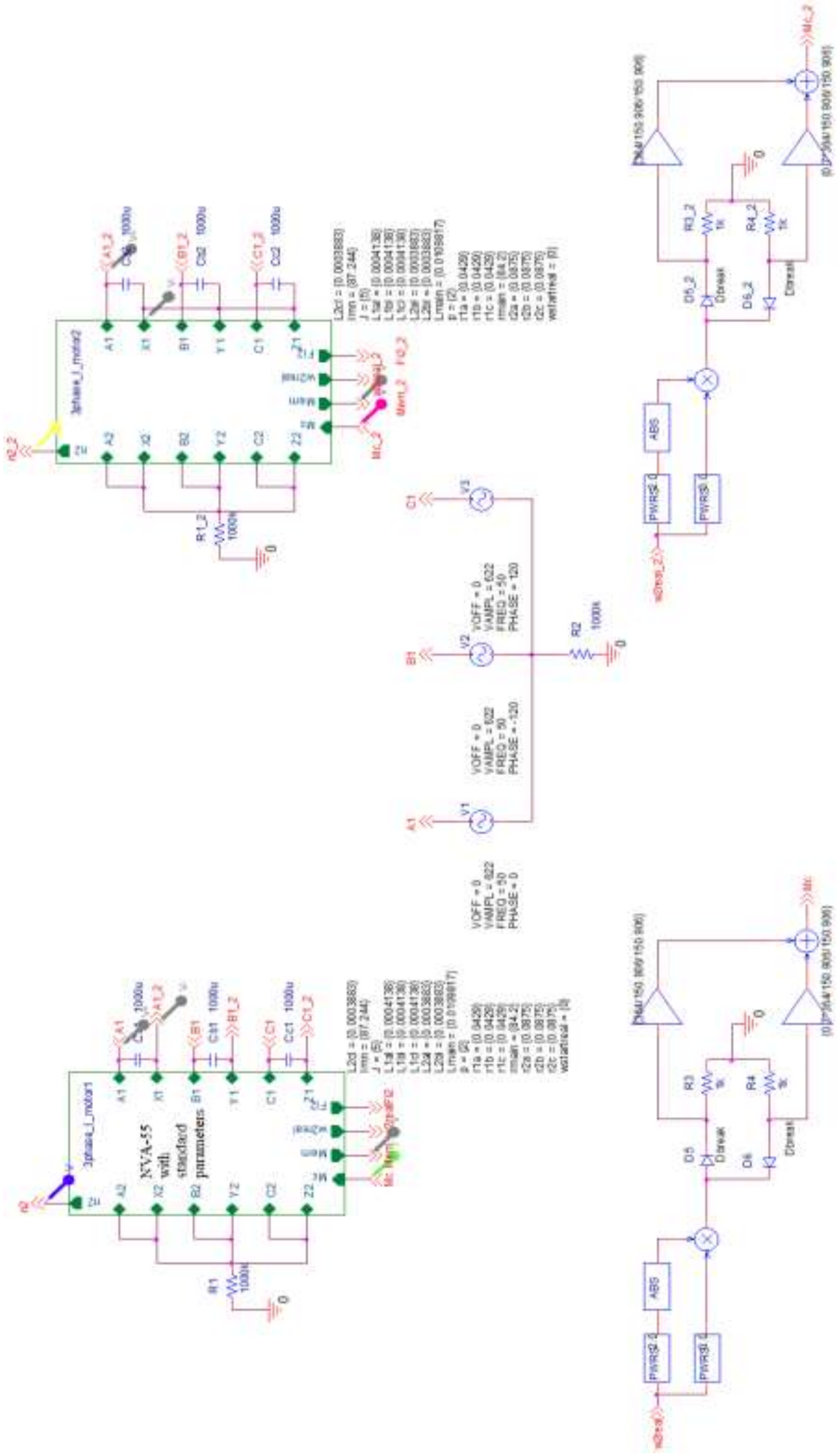

Fig. 1: View of the OrCAD-based, [9], [10], [11] computer model of an electric drive of two motor-fans with a series connection of the phases of stators of the IM of type NVA-55 . Between the beginning and end of each phase winding of the stator, a capacitor is connected parallel to the winding

With unequal parameters, the IM tends to "stall": with a larger moment of inertia, a larger load torque on the shaft, less inductance, and a larger resistance.

Stable operation of two series-connected IM motor fans can be achieved if three conditions are met:

1) in capacitive voltage dividers, resistances must be connected in series with the capacitors (RC voltage divider, Figure 3);

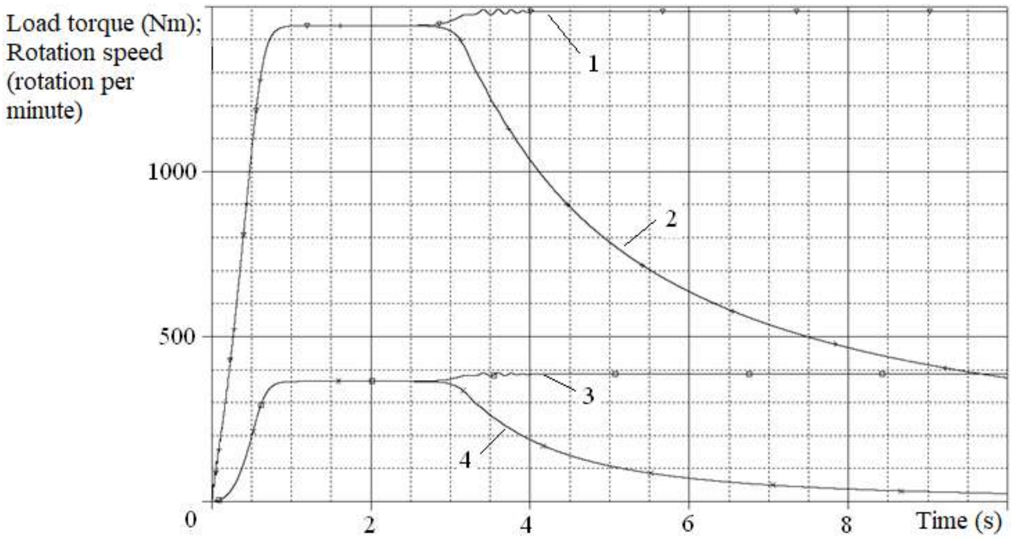

Fig. 2: Instability of joint operation of a pair of series connected IMs with completely identical parameters. Results of simulation of rotation speeds (graphs 1 and 2) and load torques (graphs 3 and 4) of two NVA-55 IMs. Graphs 1 and 3 refer to one IM, 2 and 4 to another IM

2) the loads on the motors' shafts at the rated supply voltage should be significantly lower than the rated one (for stable operation of two series connected motors at similar conditions, the load of each should not exceed 50% of the rated one);
3) the loads on the motors' shafts must be the same.

You can calculate the load torque on the shaft of one IM of type NVA-55 during long-term operation in traction mode of an electric locomotive using data from, [12], which says: "On the EP1 mainline passenger AC electric locomotive, the power consumed by the fans and oil-pump at rated mode and operation in traction is equal to 110 kW". This refers to four motor fans with NVA-55 and one oil pump. Assuming the power of the IM driving oil pump is significantly less than that of the NVA-55, we will approximately calculate the shaft power of one NVA-55: 110/4 = 27.5 kW. The torque on the shaft will be 27500/(1440·6.28/60) ≈ 180 N·m. This is 49.8% of the rated value (364 N·m). It is known, [2], [13], that in the long-term operation of the VL85 mainline freight AC electric locomotive, the power of the IM of type ANE-225 with a TsVV 89-15 centrifugal fan on the shaft is 32.5 kW, the torque is 32500/(1440·6.28/60) ≈ 216 N·.m. This is 59.3% of the rated torque value for NVA-55. According to data, [1], [13], the IM of auxiliary drives of an electric locomotive must be capable of operating without voltage stabilization in the range of catenary voltage variations ±25% of the rated one.

Assuming that one NVA-55 has standard parameters (the moment of inertia reduced to the motor shaft, J = 5 kg·m2, is taken for each motor), and the other has a 10% lower main inductance, and also that the fan is used as a load on the shaft provides 10% less load than that of the first IM (on the shaft of the IM with standard parameters at a rotation speed of 150.906 rad/s the load torque is 180 N·m, and for the second IM is 162 N·m only), we will simulate the turn-on of the circuit at the supply voltage, at 25% less than rated. The results (with the value of each capacitance of 1000 μF) are shown in Figure 4: the rotation speed of the IM with standard parameters at the end of the transition process is set at a normal level, slightly lower than 1500 rpm, and the rotation speed of the IM with a less main inductance is significantly lower. The phase voltage value for IM with standard parameters is higher than normal. The phase voltage at stator terminals of "non-standard" IM is significantly lower than normal.

Computer simulation for the case of loading with a fan of type TsVV 89-15 at reduced voltage gave similar results. The stable operation of a pair of IMs is noted, but with very different characteristics. The currents of the same phases in two IMs are the same.

At the rated supply voltage, in the case of the same load of two IMs with TsVV 89-15 fans, the graphs of changes in voltages and rotation speeds of the IM are similar to those shown in Figure 4.

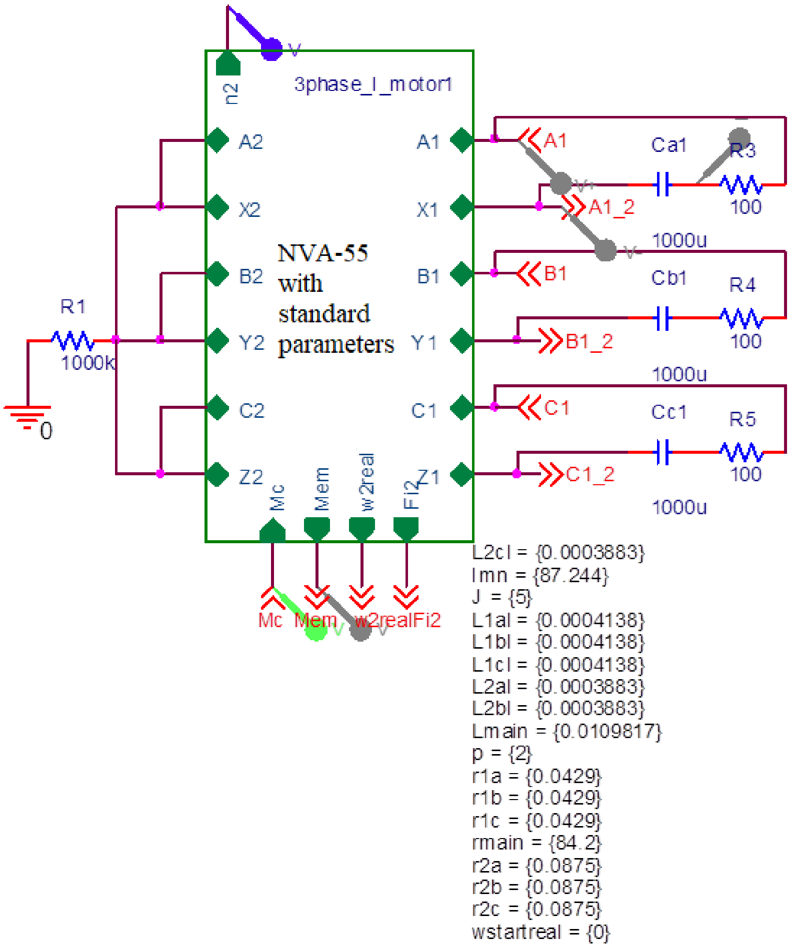

Fig. 3: OrCAD hierarchical block symbolizing the computer model of the IM of type NVA-55. In capacitive dividers, 100 Ohm resistances are connected in series with 1000 µF capacitors

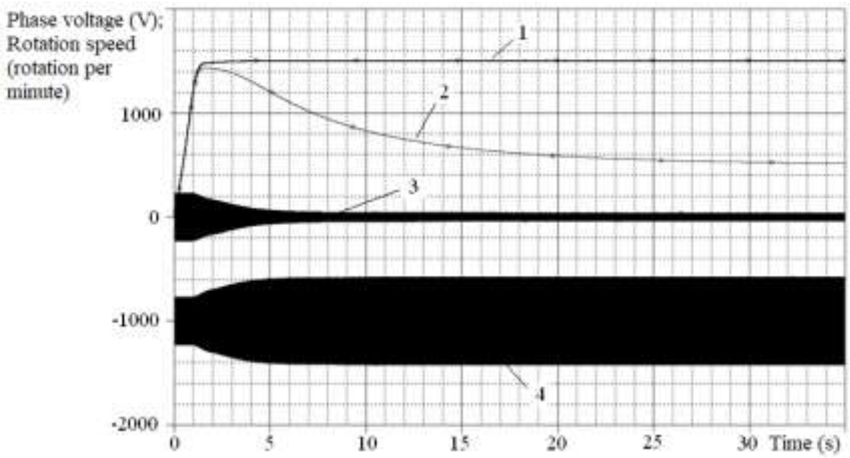

Fig. 4: Results of computer simulation the operation of two series-connected IMs at a supply voltage 25% less than the rated (graphs of phase voltages and IM rotation speeds). 1 – rotation speed of the IM with standard parameters; 2 – rotation speed of the IM with a less main inductance; 3 – graph of the voltage of the IM with a less main inductance. The graph 4 of the IM voltage with standard parameters is shifted down 1000 V for greater clarity

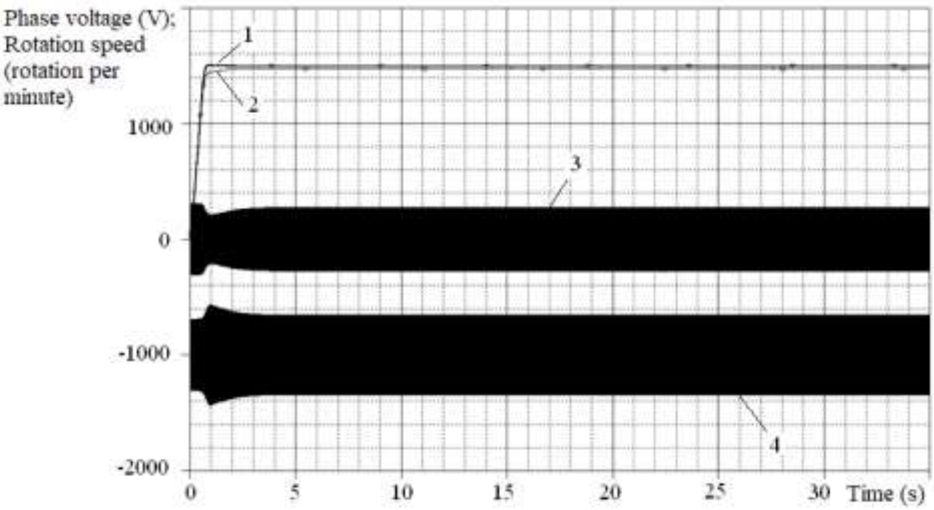

Fig. 5: Results of computer simulation the operation of two NVA-55 with different parameters at the rated supply voltage with the same fan loads on the shafts (graphs of phase voltages and motor rotation speeds). All designations similar to Figure 4

Simulation of the operation of two NVA-55 with different (see above) parameters at rated voltage with the same fan loads on the shafts of 180 N·m (torque value at a rotation speed of 150.906 rad/s) gave significantly better results (Figure 5). Both IMs operate stably in similar modes, both in terms of rotation speed and phase voltage.

Graphs similar to those presented in Figure 5 are obtained in the complete absence of RC dividers on two series-connected IMs, all other things being equal. Stable operation of a pair of IMs is not ensured when installing only C-dividers.

Stable operation in similar modes with an IM load of 50% is ensured by placing RC dividers in two phases out of three of each IM (in the same phases of the IMs). The result is similar to that shown in Figure 5.

4 Conclusion

Thus, the auxiliary electric drive circuit with a series connection of the phases of two IMs is not recommended for use, since it does not provide sufficient stability of the motor when the supply voltage decreases, despite the possibility of sustainable operation at rated voltage. Besides this for stable operation, it demands significantly less (50 %) loads on the shafts than rated.

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Conflict of Interest

The author has no conflicts of interest to declare.