Fault Behavior Calculation of High Efficient Single Phase Induction Machines using 2-D Transient FEM

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Calculation of the fault behavior of highly efficient single phase induction machines by means of the finite-element method necessarily includes a transient process. The different switching states of both windings and the capacitors must be taken into account; for this an electrical circuit is coupled. Faults (separated by time, rotor position and phase angle) are presented and calculated by finite-element models. The results of different operating strategies of single phase induction machines are compared.

***Index Terms*— Coupling circuits, circuit faults, induction motors.**

I. INTRODUCTION

According to the UNIPEDE voltage dip statistic the time interval of 5% of all voltage dips is smaller than 100 ms with a remaining voltage lower than 40%. Besides duration and the remaining voltage, the fault behavior of a single phase induction machine also depends on the phasing and on the rotor position. A breakdown at the voltage maximum differs from a breakdown at voltage zero-crossing.

Voltage dips with longer time intervals can be neglected because of the rotor time constant of single phase induction machines. The effects of such voltage dips on the transient behavior of single phase induction machines are calculated by 2-D transient finite-element models with coupled electric circuit models. By such models all relevant aspects can be taken into account.

II. EXTERNAL ELECTRIC CIRCUIT

The auxiliary winding of single phase induction machines is connected to a run capacitor. At start-up, a start-capacitor is sometimes used or the auxiliary winding is directly connected to the grid. The chosen circuit depends on the load condition of the machine during speed-up. Fig. 1 shows the possible electric circuits. C_R is the run capacitor and C_{St} is the start capacitor.

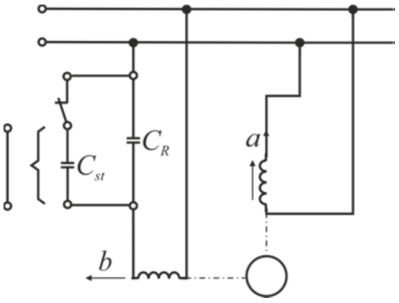

Fig. 1. Electric circuit of a single phase induction machine.

A centrifugal switch or positive temperature thermistor (PTC) disconnects the start current path from the run current path at a predefined speed. Furthermore, the impedances of the stator end windings and the rotor end rings must be taken into account by an electric circuit coupled to the 2D-FEM models. By 2-D simulation of single phase induction machines, the influence of harmonic effects must be checked. Additional asynchronous and synchronous torque development due to the high harmonics must be verified in detail because of the missing skewed rotor.

The skewed rotor can be taken into account by the methods presented in [1]. The used script calculates the effect of skewing on average torque and RMS voltage. The test machine chosen here has $N_S = 24$ stator and $N_R = 16$ rotor slots (Fig. 2). This slot combination guarantees the elimination of additional torques, forces and noise caused by higher harmonics [2] with dominant amplitudes.

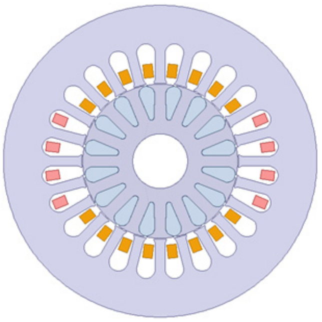

Fig. 2. Cross section of the chosen single phase induction machine.

Besides this, single phase induction machines have an additional 3rd higher harmonic. The amplitude of this higher harmonic depends on the winding distribution, especially of the auxiliary winding because of its reduced number of slots per pole and phase [3].

When a start capacitor is used, the effects of the 3rd harmonic are negligible because the (nearly) 90° phase shift between the currents in the two windings leads to a rotating field. In the case of machines without a start capacitor, a nearly rotating field can be produced by specially adapted auxiliary winding (turns per slot). Therefore, a 2-D transient FEM model with a coupled electric circuit is acceptable. Only the torque ripple caused by the slot harmonics remains. However this does not contribute to the fault behavior of the machine.

III. Transient FEM Calculation

The fault behavior of a single phase induction machine is investigated with respect to two types (loaded and unloaded). The machine speeds up from zero to no-load speed respectively rated speed. The stator voltage is V_1 = 230 V and the frequency is f_1 = 50 Hz. The time step of the simulation is Δt = 200 µs and the simulation time is t = 1 s.

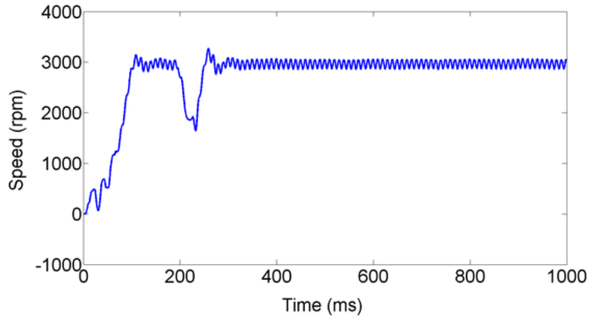

Fig. 3. Simulated speed (start-up, voltage-dip) for the best case; no-load.

Fig. 3 shows the simulated speed of the test machine. This high efficiency single phase induction machine has only one common capacitor for start-up and run. The motor accelerates within 100 ms up to its no-load speed of n_0 = 2970 rpm. At 195 ms a voltage dip for occurs. The theoretical background for the transient behavior of three phase induction machines is given in [4]. This theory must be adapted to single phase machines because they contain both a forward and backward rotating field. First, it is assumed that the rotor flux does not noticeably damp during the voltage dip and the rotor speed is constant during the time of the voltage dip. Second, the torque pulses by the forward rotating field can be neglected compared with those given by the backward rotating field.

(1) shows the torque pulses of the backward rotating field, when damping is neglected,

$$T(t) = 2T_B\left[\cos(\omega t - \alpha) + (1-\sigma)\sin \omega t - \cos(2\omega t - \alpha)\right]. \quad (1)$$

The torque T (T_B is the breakdown torque of the machine) depends on the phase angle of the supply voltage α at the end of the voltage dip, and the rotor position. σ is the leakage coefficient of the machine, ω the angular frequency and t the time. When the voltage dip is much shorter than the no-load rotor time constant, the rotor position influences the transient behavior.

At n = 3000 rpm the best position of the rotor to turn-on again is 20 ms and the worst case is 10 ms. For a longer breakdown the rotor position does not contribute because the rotor flux is reduced down to zero. Furthermore, transient currents in both windings must be avoided. Fig. 4 shows the currents of the main winding (green line), auxiliary winding (red line) and the sum of both currents (blue line). Fig. 4 demonstrates that all currents are zero at nearly the same time. This point is when the supply voltage is at its maximum. Fig. 3 shows a minimum speed of these best conditions at n = 1500 rpm. Friction losses and inertia torque affect this speed change. It can be minimized by an increased inertia.

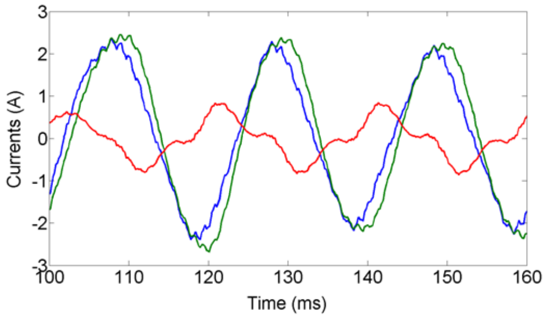

Fig. 4. Stator winding currents of the machine at no-load.

Fig. 5 shows the worst case. The break down time is 10 ms and the voltage is turned on when the voltage is zero.

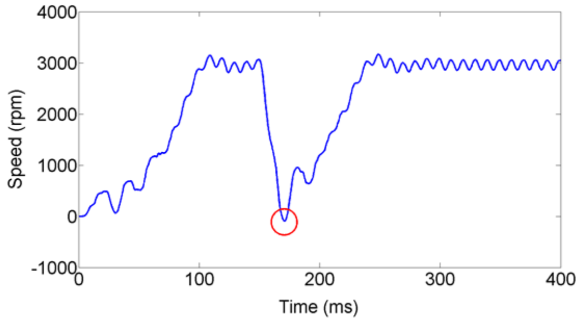

Fig. 5. Simulated speed (start-up, voltage-dip) for the worst case; no-load.

Fig. 5 shows that in the case of an electrical circuit with a PTC, the machine will stop and a restart is not possible before the PTC has cooled down.

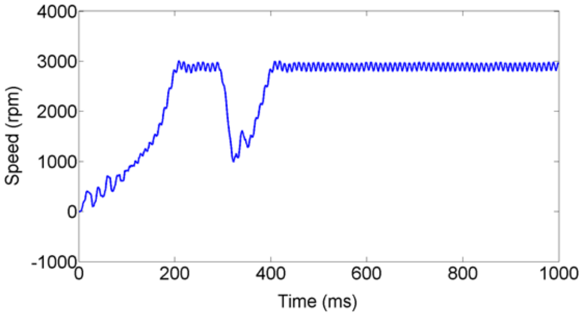

Fig. 6. Simulated speed (start-up, voltage-dip) for the best case and loaded.

Fig. 6 illustrates the best case when the machine is loaded with the nominal torque. During the speed-up the machine is unloaded and then the machine is loaded with a constant torque.

References

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