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A non-destructive methodology for estimating the magnetic material properties of an asynchronous motor <i>Abdallh AA, Sergeant P, Dupré L</i>	34
Experimental study of a stator inter-turn short-circuit in a double star induction machine <i>Djelloul M, Radouane HR</i>	35
A permanent magnet integrated starter generator for an onboard range extender application <i>Wang C, Jin MJ, Shen JX</i>	36
Alternative approach to FEM-based modeling and simulation of power transformers in transient behavior <i>Mandache L, Topan D, Dolan A</i>	37
Optimal shape and material design of rotor slot for induction motors <i>Lee G, Min S, Hong J</i>	38
Simulation of magnetic field of core and magnetic leakage field in magnetical controlable reactor <i>Yuan J, Zheng, Rao B, He X</i>	39
Performance simulation of Axial Flux Permanent magnet machine using MAGNET software <i>Joseph JJ</i>	40
Soft magnetic amorphous core for the stator of novel high-speed induction motors <i>Kolano R, Kolano-Burian A, Krykowski K, Polak M, Szynowski J</i>	41
Experimental characterization of the iron loss variability in stators of electrical machines <i>Ramarotafika R, Benabou A, CléNet S, Mipo J</i>	42
The Evaluation of On-line Observer System of Linear Induction Motor Using a Transient FEM \& Experiment for Sensorless Vector Control <i>Kim H, Lee J, Lee S</i>	43
Relays top gear: ferrodinamic versus electrodynamic <i>Buzduga C, Cernomazu D, Ciufudean C, Filote C</i>	44
Modeling a magnetoelastic transducer/microgenerator with amorphous core <i>Zucca M, Bottauscio O, Beatrice C, Fiorillo F</i>	45
Experimental determination of interdependencies of hysteresis and eddy-current losses in resistance spot welding transformer iron cores <i>Petrun M, Polajzer B, Klopčič B, Dolinar D</i>	46
Evaluation of iron core quality for resistance spot welding transformers using current controlled supply <i>Petrun M, Klopčič B, Polajzer B, Dolinar D</i>	47
Temperature distribution for several material grades in direct-drive PM synchronous generators for 5 MW wind turbines <i>Kowal DA, Sergeant P, Dupré L, Vandenbossche L</i>	48
Characteristic Analysis \& Optimum Design of Permanent Magnet Assisted Synchronous Reluctance Motor for Premium Efficiency Performance <i>Lee B, Song H, Lee J</i>	49
Optimum LIM Interval Selection of Vector Controlled Moving Secondary Plate Conveyor System Using FEM \& SUMT for Constant Speed Control <i>Lee B, Lee J, Kim H</i>	50
A Novel Stator Design of Synchronous Reluctance Motor by Loss \& Torque Evaluations Related to Slot Numbers using Coupled Preisach Model \& FEM <i>Song H, Kim H, Lee J</i>	51
Characteristics Analysis in a Pole Changing Memory Motor using FEM \& Preisach Modeling <i>Lee S, Lee J, Jang S</i>	52

Alternative approach to FEM-based modeling and simulation of power transformers in transient behavior

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The optimal design of power transformers requires analyzing the whole electromagnetic system, including the power supply and the load, in rated operation mode and malfunction modes. This aim requires adequate computer aided design tools capable to provide results with satisfactory accuracy. Even though cosimulation approaches involving a FEM-based simulator for the electromagnetic and thermal field analysis coupled with a time-domain circuit simulator could offer the most accurate results, they are the most costly regarding hardware/software requirements and simulation time. Moreover, the FEM-based simulators deal difficulty with the ferromagnetic phenomena, and they commonly fail in the management of the inertial behavior of ferromagnetic materials related to the static hysteresis. In this context, we propose an extremely effective modeling and simulation procedure of single-phase and multi-phase transformers in the time-domain, exploiting the known principle of equivalent diagrams with lumped circuits.

The modeling procedure leads to a mathematical model reduced to a nonlinear differential-algebraic equation system, so that it is SPICE-compatible. Our systematic study brings a significant improvement comparing to similar approaches of other authors, through the degree of generality and the ease of use due to a carefully exploited concept of modularity.

The main module of the model (conceived as a SPICE subcircuit) combines a ferromagnetic piece as magnetic field path carrying the main magnetic flux φ (assumed as uniform within the cross section), a winding of N turns and DC resistance R spooled on it and

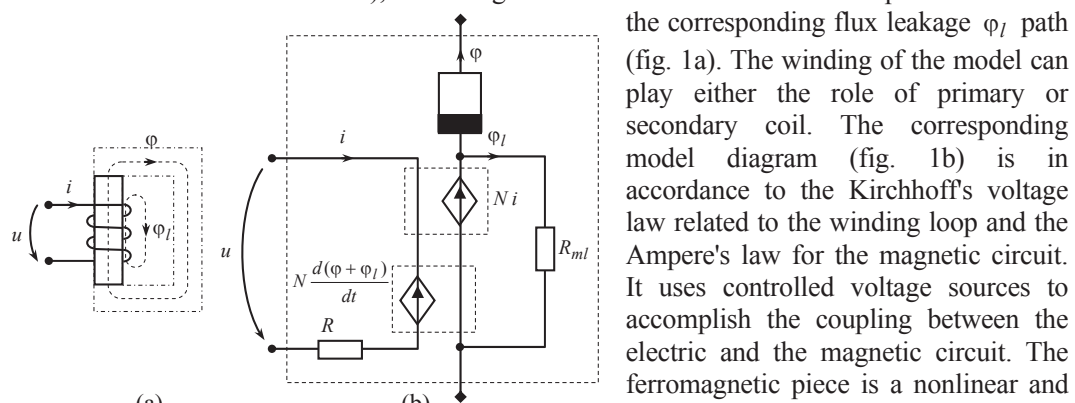


Figure 1: Transformer wired leg (a) and its time-domain model (b).

the corresponding flux leakage φ_l path (fig. 1a). The winding of the model can play either the role of primary or secondary coil. The corresponding model diagram (fig. 1b) is in accordance to the Kirchhoff's voltage law related to the winding loop and the Ampere's law for the magnetic circuit. It uses controlled voltage sources to accomplish the coupling between the electric and the magnetic circuit. The ferromagnetic piece is a nonlinear and inertial resistance treated according to the Jiles-Atherton model of the ferromagnetic hysteresis [1] with the

Langevin approximation of the anhysteretic characteristic, combined with our previously developed model of eddy currents [2]). Convenient combinations of leg-winding models allow simulating power transformers of almost any structure.

The method is remarkable through the extremely short computation time and satisfactory results, comparing to the FEM-based modeling and simulation approaches, as it will be proven in the extended form of the paper by means of the commercial simulators SPICE and FLUX 3D. It was conceived as an effective design and optimization tool.

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- [1] D.C. Jiles, D.L. Atherton, *Ferromagnetic Hysteresis*, IEEE Transactions on Magnetics, vol. MAG-19, No. 5, September 1983, pp. 2183-2185.
 [2] L. Mandache, D. Topan, *Managing eddy current losses and ferromagnetic material nonlinearities in distorting regimes*, IEEE International Electric Machines and Drives Conference, IEMDC '09, Miami, 3-6 May 2009, pp.1449-1454.

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