A consistent model of a three-phase mains choke for use in transient simulation environments has been developed. The measurement and model-building process based on standard 2-port scattering parameters has been described in detail. The particular mains chokes investigated here provides sufficient common-mode suppression only up to few MHz. The loss of common-mode suppression is caused by the parasitic winding capacitances. Differences between the model behavior and a rigorous impedance measurement of the DUT are most likely caused by parasitic winding capacitances and coils asymmetries.

I. INTRODUCTION

- Using scattering parameters for consistent impedance modeling
- Model used for conducted emissions simulations (9kHz – 30MHz)
- Here: simplified 6-port scattering parameter model
- Measuring all unique scattering parameters by a standard 2-port network analyzer
- Consistent modeling of common-mode and differential-mode response in a realistic transient simulation scenario

II. MEASUREMENT REQUIREMENTS

- Frequency range 10Hz to 300MHz to cover fundamental frequency (50Hz)
- Dynamic range ≥100dB to cover interesting impedance range
- Using broadband ferrites to suppress sheath waves on coaxial measurement cables
- Calibration at the connection plane of the DUT
- Connection to DUT as short as possible

III. DUT-STRUCTURE

- Three coils on one toroidal ferrite core in one multilayer structure
- Rigid magnetic coupling
- Current-compensated for fundamental frequency (50Hz)
- Unknown behavior at higher frequencies due to parasitic capacitances, stray inductances and asymmetries

DUT 1: 3x100µH, 230V, 65A  DUT 2: 3x2.3mH, 230V, 65A

- Results given as a graphical comparison between simulated 6-port and measured 2-port impedance curves separate in common-mode (simulated 6-port in blue traces and measured 2-port in brown traces) and in differential-mode (simulated 6-port in magenta traces and measured 2-port in red traces) by above setups
- Calculation of the relative error curves by subtraction of the simulation results with the measured results separate in common-mode (blue traces) and in differential-mode (col traces)

IV. METHODOLOGY

- Scattering parameter matrix simplification due to symmetrical structure of the DUT:
  1. Reciprocity: $S_{11} = S_{22} = S_{33} = S_{44} = S_{55} = S_{66}$ and $S_{12} = S_{21} = S_{34} = S_{43} = S_{56} = S_{65}$
  2. Symmetry: $S_{13} = S_{31} = S_{24} = S_{42} = S_{35} = S_{53} = S_{64} = S_{46} = S_{25} = S_{52} = S_{45} = S_{54} = S_{16} = S_{61} = S_{26} = S_{62} = S_{36} = S_{63} = S_{46} = S_{64}$
- Only four scattering parameters to be measured S11, S12, S13 and S14
- Assembling of the simplified 6-port scattering parameter matrix by a MATLAB script after the measurement

V. MEASUREMENT AND SIMULATION SETUPS

- Reflection-free termination of the free ports during measurements
- Comparison of the simulated impedances against standard 2-port measurements

VI. RESULTS AND DISCUSSION

Explanation of the high common-mode difference in the frequency range from 60kHz to 3.5MHz of DUT 2 in detail:
- Higher inductance value leads to double layer winding structure and extended equivalent circuit
- Asymmetry between the three coils on the core
- Inductance value of coil 3 3.5% lower than coil 1 and coil 2
- The common-mode capacitance in series with the inductance asymmetry acting as differential-mode inductance decreases the simulated common-mode impedance level by about 60% compared to the rigorous common-mode impedance measurement
- Effect suspends at 3.5MHz when differential-mode impedance crosses common-mode impedance

REFERENCES