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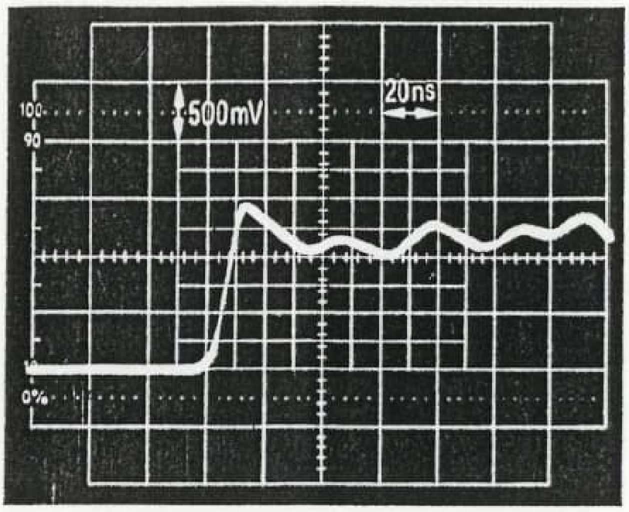
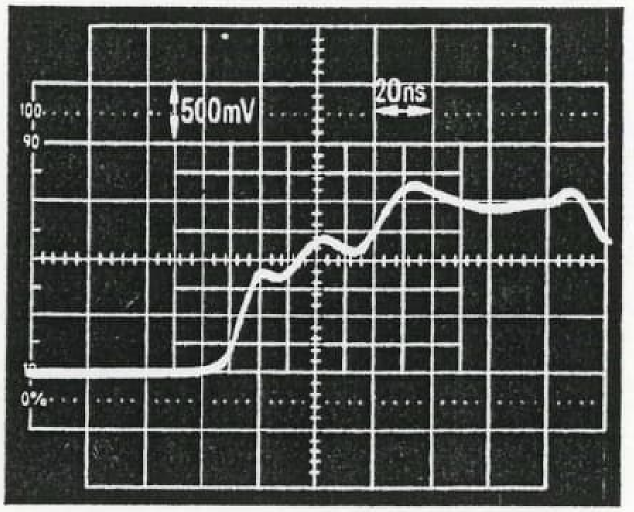
Are white-box models being accurate enough to properly estimate transformer dielectric stresses caused by network topology changes due to the proliferation of distributed renewable energy sources?

White box models are used by the manufacturer to calculate all necessary voltages for the dielectric insulation coordination. The required frequency range defines the length of the individual branches of the model. Therefore white box models may become pretty large – due to the short length of the branches many of them are required for the total winding. White box models can be generated up to single turn models of all winding types. With respect to a very high frequency range, especially the influence of bushings needs to be considered also. A simple representation with a concentrated element might not be sufficient when it comes to the evaluation of voltages in the MHz range appearing at the transformer terminals [1].
Generating simulation models of bushings for frequencies in the MHz range are a challenge for transformer manufacturer – since a detailed internal setup of the bushings is needed. In the past measurements were performed; analysing voltages at both ends of the bushing (at the transformer terminal as well as on the winding entrance). It was shown in [2] that the steep front of wave shapes (10ns) is reduced to moderate soft rise times (~50ns) turned out. Assuming the duration of the rise time at the winding entrance as one quarter of a sinus oscillation, we get 50 ns x 4 = 220 ns and a frequency of f = 1 / T = ~ 5Mhz.





Considering this an upper frequency resolution of at least 5 Mhz is required. Looking at the winding diameter in large power transformers – which determines the length of a single turn – a frequency range of up to at least 10 Mhz can be reached.
The dielectric stresses caused by network topology changes due to the proliferation of distributed renewable energy sources are not known to transformer manufacturers during design stage – as long thy are not specified or delivered by the customer Anyway as soon as the customer provides these voltages – looking at the frequency resolution the required frequency range for the white box model is derived. Simulations using these voltages can be done – considering the calculated dielectric stresses within/between windings for the insulation coordination.
It should be mentioned, that in the past numerous investigations in many research facilities were done to get information about the withstand capability under so called Very Fast Transient Voltages. However it was found that the application of all of these results is not possible to use them 1:1 in transformer design. An Extra Margin Safety Margin needs to be considered. With respect to very high frequencies (MHz range) test series on relevant transformer winding models would be helpful in the future.

Are there some cases where black box models are prefer ?

Black Box models can be generated from out form white box models – with different model size. When asking for the type of model – the purpose of need defines the answer. While white box models are the essential basis for the transformer manufacturer – providing the possibility to evaluate any dielectric stress for a proper insulation coordination, black box models seem to be quite enough – as long as a terminal equivalent representation of the transformer is needed. This is a typical situation in customer simulation – done by the customer. However nearly any used white box model can be transferred into EMTP/ATP format and delivered to the customer. It is important to specify the frequency resolution. One must be aware that any black box model

has a behaviour of Z(f) = ω*L for low frequencies going to Z(f) = 1 / (ω*C) for high frequencies. Dependent on the used frequency resolution in the white box model the number of poles of the transfer function increases. When deriving black box models from measurements one must be aware the measurements in the MHz range are very sensitive. Some errors – possible due to the influence of measuring leads, and other equipment – will be found in the so generated black box model. In CIGRE_A2C4.52 the reliability of SFRA measurements in the very high frequency range is seen critical.
Consequently Black Box models may be preferable for customer simulations – as long as a terminal equivalent behaviour of the transformer is sufficient. As soon as evaluations of the voltage inside the transformer are of relevance – this shall be done by the manufacturer suing proper white box models, in cooperation with the customer,

[1]: Verification of Withstand Capability for Very Fast Transients of a 200 MVA, 500 kV GSU-Transformer by Modelling and Testing. Alexander Rabel (Siemens AG Austria, Transformers Research) , Jian-Jason Zhou (Siemens China, Transformers Research)
attachment: 0345-A2-PS2-IA-AT.pdf, Pr-A2-208.pdf
[2]: Verhalten von Hochspannungswicklungen für Transformatoren bei Steilwellen mit Fronten im Nanosekundenbereich. Walter Müller, Werner Stein, Siemens-Energietechnik 5 (1982)
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Müller_1983_Verhalten_von_HSWicklungen_bei_Steilwellen_im_Nanosekundenbereich_Mueller&Stein.pdf