APPLICATION NOTES

Wind Farm Transformer Inrush Studies

In a typical UK wind farm, a series of radial 33kV collector circuits run from the main switchboard and link together individual wind turbine generator transformers (WTG). At the design stage, it is necessary to determine the maximum number of WTG transformers that can be energized simultaneously from the 33kV system. One of the factors to be considered is the voltage dip experienced at the point of common coupling (PCC) or interface between the electrical system of the wind farm and the utility company. The UK standard applied is the Electricity Council's Engineering Recommendation P28, which allows a 3% voltage dip. This article describes wind farm transformer inrush analysis studies the Glasgow based power systems consultants Mott MacDonald have undertaken using PSCAD™ to demonstrate compliance with P28.

Transformer Inrush When a transformer is energized, it may draw a high magnitude transient current from the supply causing a temporary voltage dip. This current, characterized as being almost entirely unidirectional, rises abruptly to its maximum value in the first half-cycle and then decays until the normal steady-state magnetizing conditions are reached. The magnitude and duration of the inrush current depends upon the following, all of which can be represented using a PSCAD™ model as follows:

- The point on the voltage wave at the instant the transformer is energized (i.e. switching angle).
- The impedance of the supply circuit.
- The value and sign of the residual flux linkage in the core.
- The non-linear magnetic saturation characteristic of the core.

Transformer Modelling The transformer model adopted for these studies is the 'classical' transient model in which each phase of the transformer is represented by a separate single-phase transformer model with no coupling between phases and magnetic core saturation is represented by a current source. Saturation is modelled on the LV winding closest to the transformer core, and flux linkage is calculated as the integral of the winding voltage. The magnetizing current represented by the current source, is related to the flux linkage by a non-linear characteristic that can be partially derived from measurements taken during a no-load (open circuit) test. Above the saturation flux density of the core material, the slope of the flux linkage/magnetizing current curve tends towards the saturated air cored inductance of the winding. This can be calculated from the winding geometry.

Figure 1a shows the variation in peak inrush current with different switching angles predicted for a 1.5MVA, 33/0.69kV, 6.0% impedance transformer when energized from a very strong 33kV

MANITOBA·HVDC RESEARCH CENTRE

Manitoba HVDC Research Centre Inc.
244 Cree Crescent
Winnipeg, Manitoba, Canada R3J 3W1
T +1 204 989 1240 F +1 204 989 1277
info@pscad.com

www.pscad.com

Figure 1a-c Study results for 1.5MVA, 33/0.690kV, 6.0% Dy11 WTG transformer.

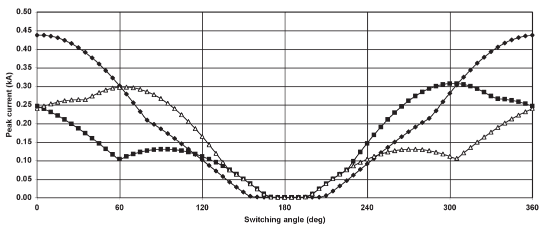

Figure 1a Variation of peak current with switching angle.

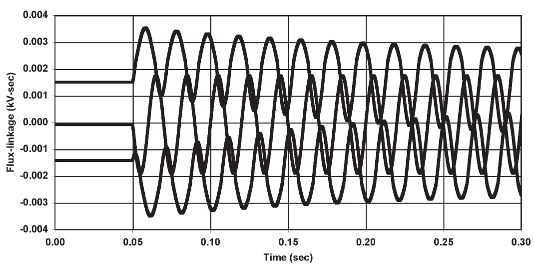

Figure 1b Instantaneous winding flux linkage switching at zero degrees.

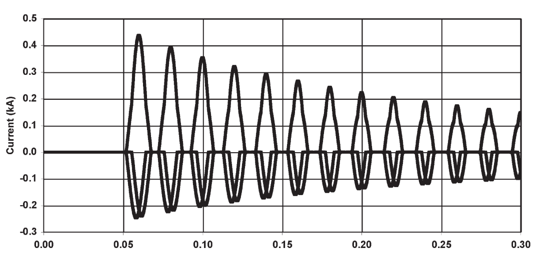

Figure 1c Instantaneous currents switching at zero degrees.

source. This study includes core residual flux and as shown in (1b) and (1c), the least favourable switching angle of zero degrees causes the phases with maximum residual flux linkage to be pushed further in saturation and generates the highest inrush current of 440A.

Case Study: 33kV Grid Connection The wind farm is comprised of 15 wind turbines connected via a 33kV collector network to the main wind farm 33kV switchboard. The individual WTG transformers are 33/0.69kV, 1.5MVA units, as described above. The PCC with the utility system is at the end of a 10km overhead line. The fault levels (rms break) at the PCC are: three-phase 6.81kA and line-ground 2.22kA.

Studies indicate that when a single 1.5MVA transformer is energized, the peak current is 407A. This is less than the 440A predicted for this rating of transformer when energized against the strong source discussed above due to the higher impedance of the lower fault level source. For this wind farm configuration, no more than three WTG transformers should be energized simultaneously to ensure that the maximum voltage drop of 3% imposed at the PCC by P28 is never exceeded. If four units are energized simultaneously, an analysis with different switching angles shows that there is a 44% probability of the voltage dip at the PCC exceeding the 3% limit.

Conclusions Mott MacDonald routinely use PSCAD™ models to determine the transient inrush current and system voltage drop caused when energizing WTG transformers. Examples presented demonstrate that the impact of point on wave switching, core residual flux linkage and transformer core saturation can be included in the PSCAD™ model. Study results for a small wind farm with a rural 33kV grid connection voltage are presented which indicate that for this installation, no more than three WTG transformers should be energized simultaneously to ensure compliance with P28. This has a direct impact on the number and placement of sectionalizing switches required on the 33kV collector network which link the 15 turbines to the main wind farm switchboard. Similar studies have been successfully completed for numerous other wind farm installations.

For further information please contact: Dr. Kenneth Smith or Mr. Roddy Wilson of Mott MacDonald Transmission and Distribution, Glasgow, UK at Kenneth.Smith@mottmac.com or Roddy.Wilson@mottmac.com