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Transformer Inrush and Voltage Sag – P28 Studies

August 2017

Introduction

- This presentation is intended to give a simple overview of transformer inrush and energisation and why it is important to network operators (DNOs).
- When a transformer is energised it can draw many times its rated power which can cause a significant voltage dip on the distribution network causing problems for other customers.
- In the UK, the standard that covers the allowable voltage dips is ENA P28.
- Inrush studies are usually required by the DNO for generating sites protected by a G59 relay, as the G59 relay can lead to multiple trips and re-energisations a year.
- Location of the G59 relay is a key factor!

Transformer Inrush - Overview

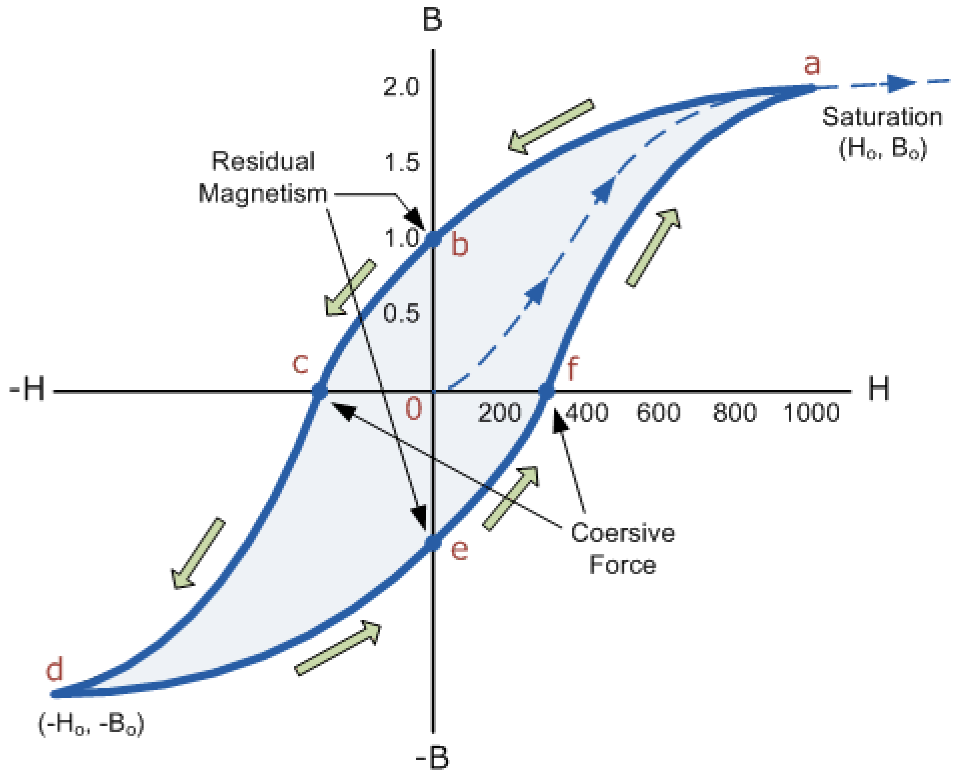
- When transformers are switched on they become magnetised, this process can draw a large amount of power.
- The transformers load does not matter – even unloaded transformers cause this effect.
- Small distribution transformers (<2.5MVA) usually have an inrush current of 8-10x their rated power, while larger power transformers tend to have an inrush current of 5-8x their rated power.
- Inrush can last from a few cycles to several seconds.
- Transformer inrush is a non-linear electromagnetic transient phenomena and difficult to analyse with standard power system analysis software.

Transformer Inrush – Overview Continued

- The magnitude of the inrush current and network voltage dip, depends on:
  - Transformer design,
  - Remnant flux in the transformer,
  - Switching angle,
  - Network short circuit level.
- It is difficult to mitigate inrush currents - if the energisation causes an excessive voltage dip then it is necessary to consider pre-magnetization systems or Pre-Insertion Resistors (PIRs).
- These can be expensive and difficult to obtain if their requirement is identified at the last minute.

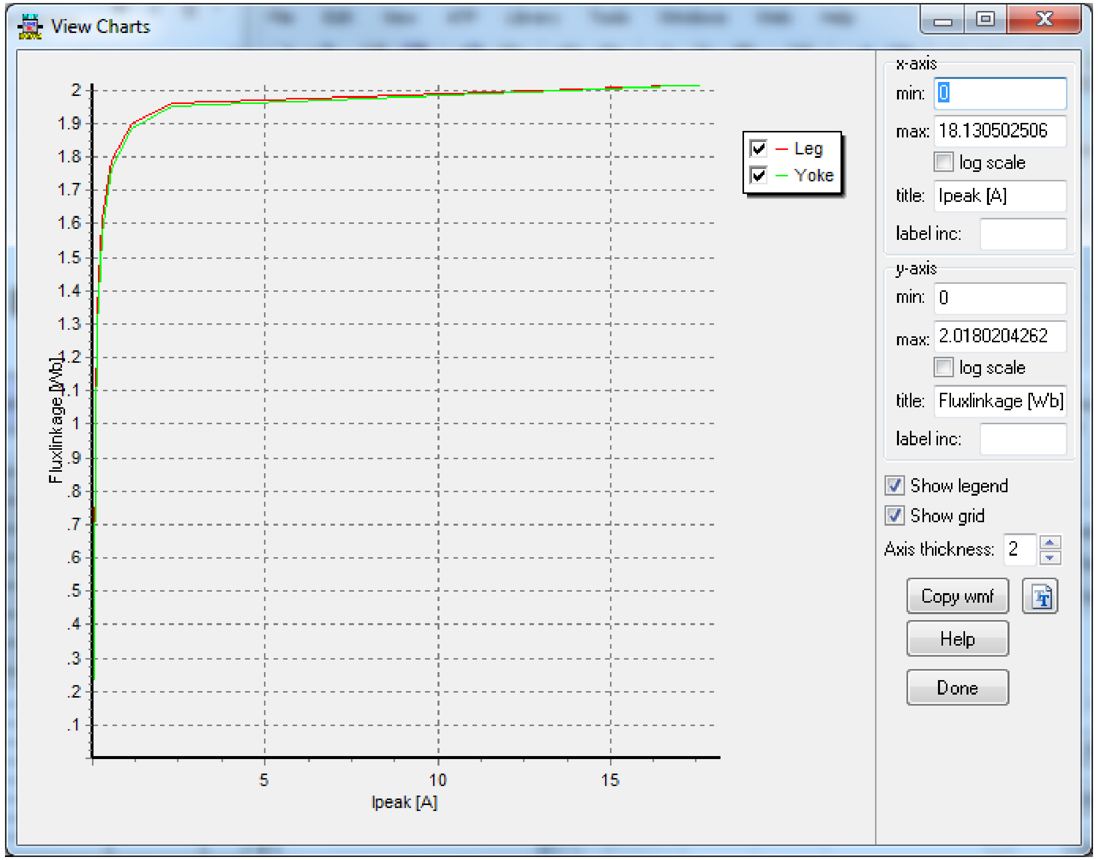
Transformer Magnetization – Simple Theory

- A transformer behaviour is non-linear and is characterised by a B-H Curve
- When a transformer is first energised the transformer acts like a simple inductor and the core must be magnetized.
- This magnetization current depends on the properties of the transformer and the point on the cycle at which the transformer is energised.
- The full B-H hysteresis curve is not necessary for most inrush studies and only the top quadrant is used.



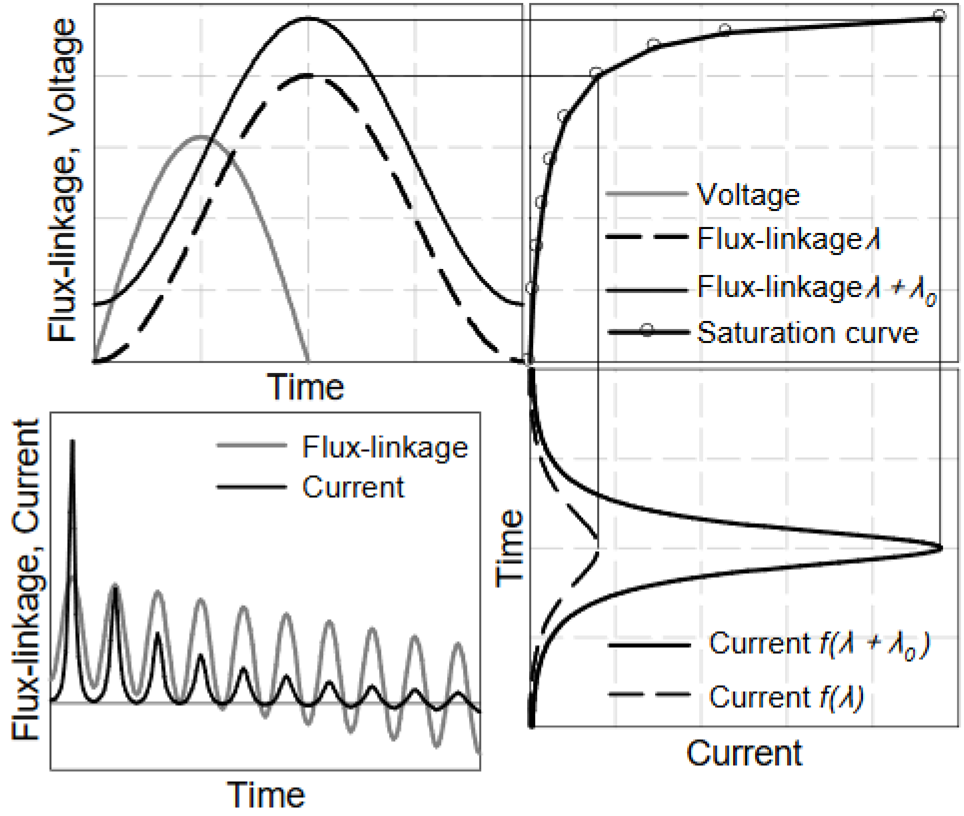
Transformer Magnetization – Simple Theory

- The B-H curve can be defined as an equivalent Flux-Current curve.
- An equivalent curve is created using the transformer open circuit test data and the ‘air core reactance’.
- The initial slope is defined by the transformer materials and construction.
- Air core reactance is the final slope of the Flux-current curve and represents the transformer in saturation (i.e. inrush)
- Air core reactance is normally not known and has to be estimated based on typical parameters or the core/yoke topography.



Transformer Inrush – Simple Theory

- When a transformer is first energised it enters the saturated region. This causes the large amount of current to flow.
- The deeper into the saturation region, the greater the current drawn.
- Energisation at a zero voltage crossing produces the most current, as the flux lags the voltage by ¼ cycle (π/2) i.e. peak flux occurs at a zero voltage.
- If the transformer contains remnant flux this can push the flux higher into the saturation region.



Network Voltage Depression

- When a large inrush current flows this results in a voltage depression.
- This is of concern to a DNO, who must maintain acceptable power quality on the network. The voltage dip limits are defined in ENA P28, and the distribution code:
  - 1% for frequent energisations
  - 3% for energisations more than 10 minutes apart
  - 10% for transient events once per year (distribution code)
- A renewable site with a G59 relay typically can experience 1 trip / quarter.
- The magnitude of the voltage depression depends on a combination of the transformer inrush current (see earlier slides) and the network strength.

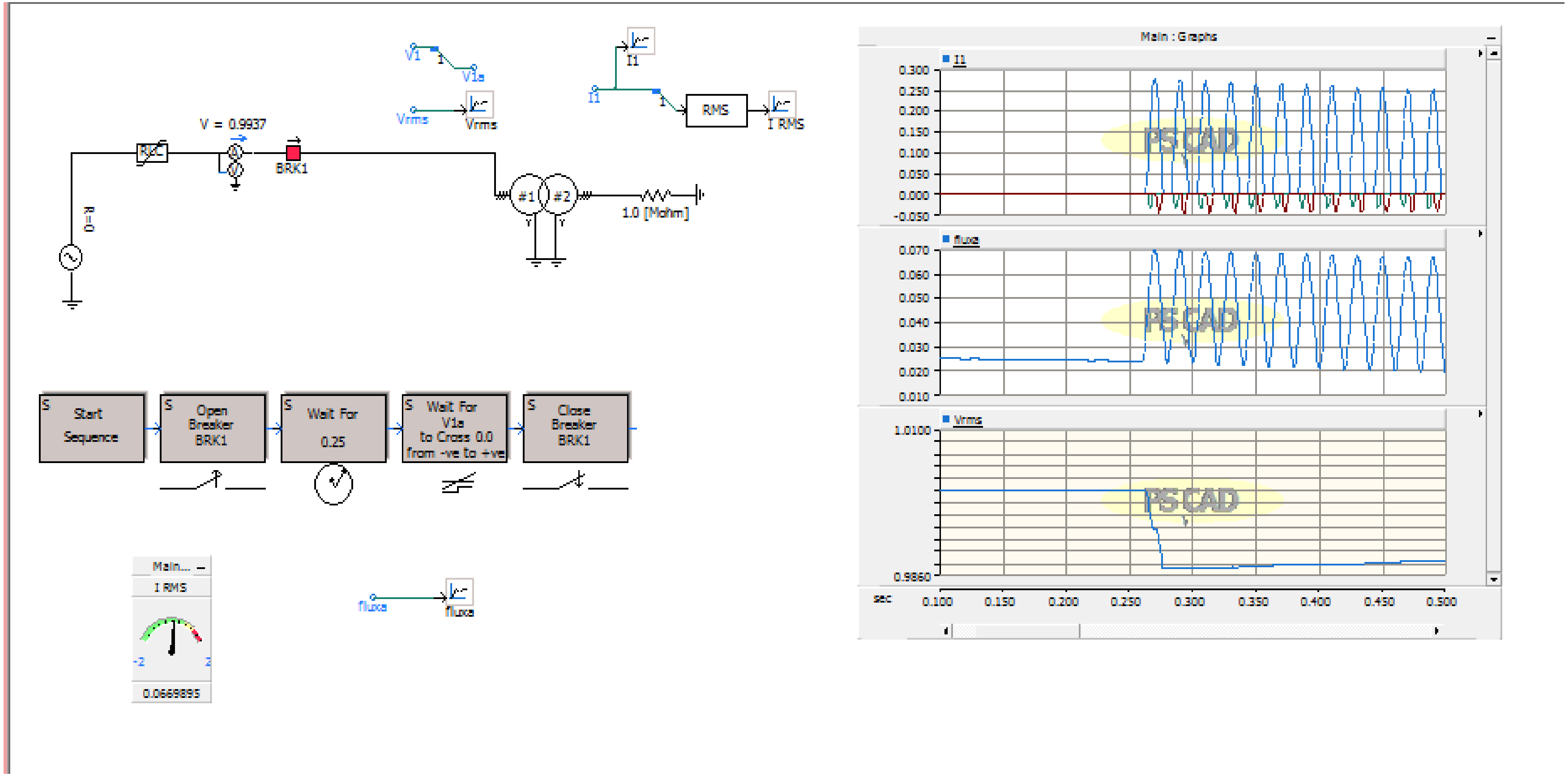
DNO Network Strength

- The DNO's network strength is defined by its fault level (either in kA or MVA).
- Network fault levels usually have a maximum and a minimum value, depending on the system configuration.
- Statistically is it very unlikely that a transformer will be energised at a voltage zero, while the system is at the minimum fault level, so it is usually best to use the maximum fault level. (This is actually recommended in ENA P28)
- It is important to understand the difference between the Point of Connection (POC) and the Point of Common Coupling (PCC).
- The PCC is where other customers connect on the network, so it is the important one!

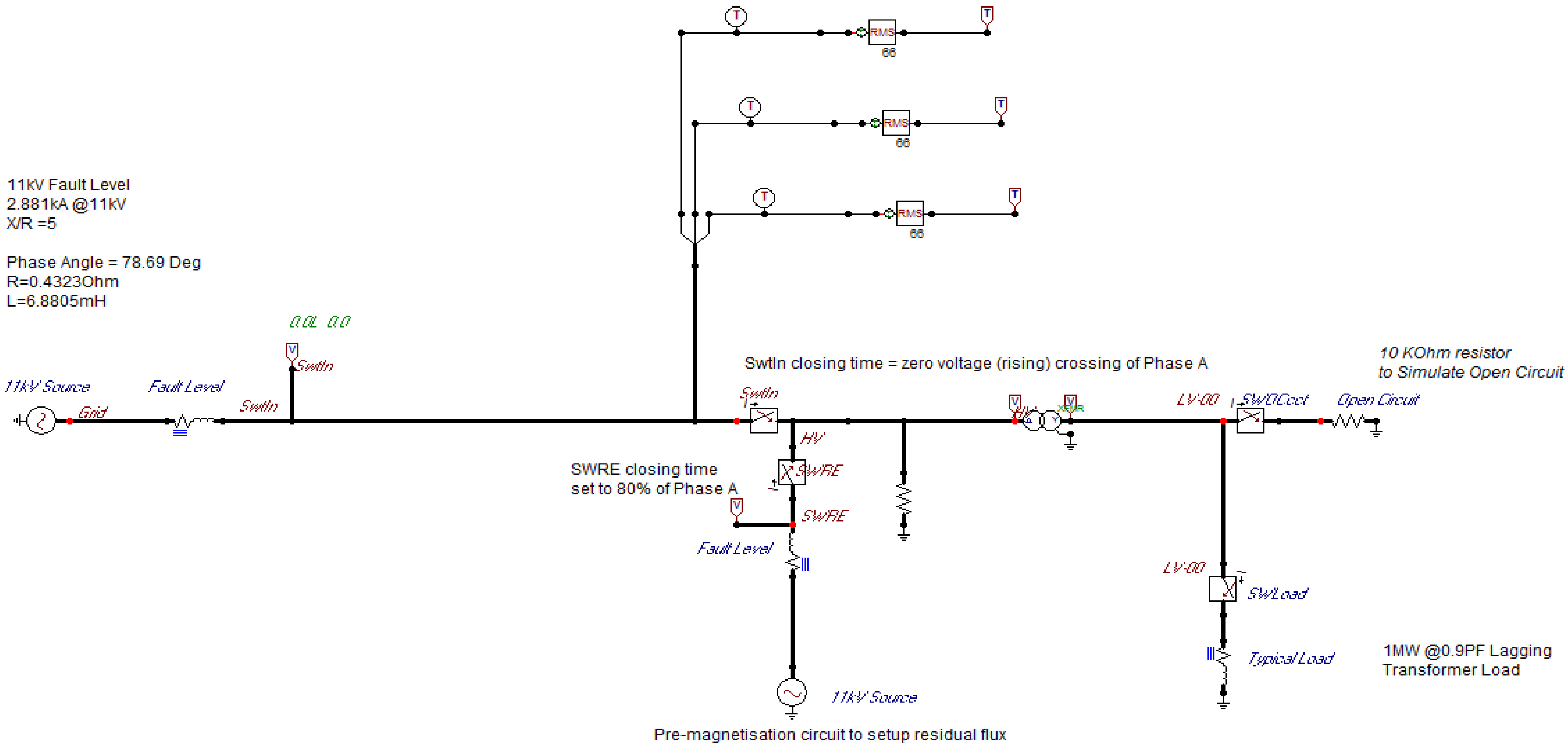
Putting It All Together

- Determining the system response to a transformer energisation event is not simple calculation – use of packages like EMTP-ATP or PSCAD/EMTDC are needed.
- A transformer inrush current is defined by several parameters:
  - Transformer construction and materials,
  - Point on the voltage wave that the transformer is energised,
  - Remnant flux in the transformer.
- The voltage dip experienced by the DNO will depend on:
  - The transformer inrush current,
  - The network strength (fault level),
  - The POC and PCC relationship.

Computer Simulation - PSCAD



Computer Simulation – EMTP-ATP



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Summary

- Meeting the 3% voltage dip limits in ENA P28 can be challenging for large transformers on a rural network – studies should not be thought of as a simple formality.
- The voltage dip depends on the transformer design, residual flux, switching angle and DNO network strength.
- If the voltage dip is too large the DNO can insist on pre-insertion resistors, or a pre-magnetization system. These can be expensive and have a long lead time – not ideal if there is an energisation date coming up.
- How can we help??

What Next?

- All questions welcome!
- SPE’s website has a lot of further information, or contacts us to discuss your issue.
  - www.sp-eng.co.uk
  - info@sp-eng.co.uk
- How can SPE help you with your design?