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State of Knowledge and Modeling Capability Regarding Harmonics and Vibrational Effects

Harmonics

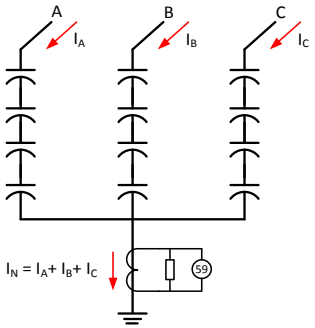
- Analysis of harmonics created by a benchmark GMD event presents some significant challenges that must be resolved by the industry before such studies can be done on a large scale (e.g. Balancing Area). Such analysis requires:
  - Significant modification to existing commercially available computer modeling tools
  - Models and input data that are not widely available
  - Very specialized expertise that is not widely available
  - Significant reliance on approximations and engineering judgment
  - Performance criteria that is aligned with the short duration of benchmark GMD events

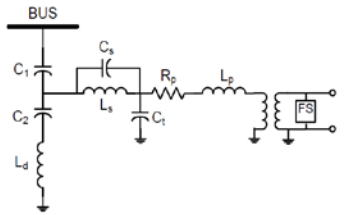
Vibrational Effects

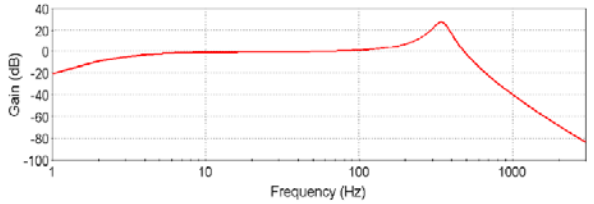
- Although ½ cycle saturation generates considerable noise, the technical community at large is unaware of any transformer failures or reliability issues that have been directly attributable to GIC induced vibration.
- From an assessment standpoint, there are no known commercially available models, computer tools or performance criteria for evaluating the effects of vibration caused by half-cycle saturation of power transformers.

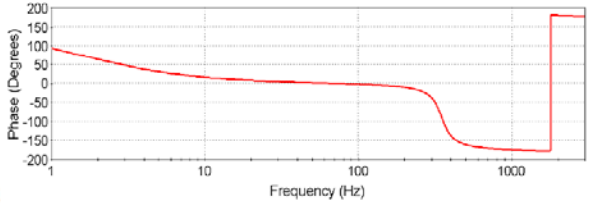
Impacts of Harmonics on Protection Equipment

- The potential impact of harmonic currents on system protection devices is influenced by three principal factors:
  - relay type (e.g. microprocessor, electromechanical, solid-state),
  - the element being protected (e.g. transformer, transmission line, capacitor bank, etc.) and the type of protection scheme employed
  - the frequency response of the instrument transformers that the relays are connected









Impacts on Reactive Power Resources

- Reactive power resources such as capacitor banks and harmonic filters can and will absorb harmonic currents during a benchmark GMD event.
- If the associated protection system misoperates, these resources can trip off-line when they are needed most to support system voltage.
- Other dynamic reactive power sources, e.g. static var compensators (SVCs), also are vulnerable to poor performance during a benchmark GMD event.
- Effects can include additional heating and misoperation of protection systems which can take these resources off-line when they are needed most.
- An assessment of the performance of reactive power resources during a benchmark GMD event is a necessary; however, additional performance criteria and improved computer modeling tools are needed.

Impacts on Generators

- 60 Hz negative sequence and harmonic current flow in the stator of a synchronous generator induces harmonic currents in the rotor which increases rotor heating.
- IEEE Std. C50.13 provides limits for negative sequence current flow in synchronous generators, and has been updated to include harmonic current in the calculation of “equivalent” negative sequence current limits.
- Because most negative sequence relays operate off of fundamental frequency quantities, they are unable to detect the equivalent negative sequence heating caused by the flow of harmonics in the stator winding of the generator.
  - The addition of protective relays that include harmonics in the calculation of an “equivalent” negative sequence current may be needed in some cases.
- Detailed harmonics studies are required to provide an accurate assessment of harmonics that the generator would be exposed to during a benchmark GMD event.
  - Aforementioned modeling challenges apply

System Impacts Related to Reactive Power Demand

- The flow of GIC in the windings of power transformers causes the exciting current to contain a considerable 60 Hz component as well as harmonics.
- The 60 Hz component of the exciting current corresponds to the reactive power absorption of the transformer.
- In effect, all of the transformers experiencing half-cycle saturation appear as large inductive loads to the bulk-power system.
- The result is wide-spread voltage depression that can lead to voltage collapse during a benchmark GMD event if sufficient reactive power resources are not available.

Summary

- The Southern Companies encourage the Commission to approve the proposed TPL-007-1 standard. Approving now:
  - Provides the regulatory certainty needed to allow applicable entities to focus limited resources on the assessment process and on future R&D efforts.
  - Encourages applicable entities, manufacturers and vendors to develop the necessary improvements to assessment techniques, computer modeling tools, mitigation measures, performance criteria, etc.
- Key points:
  - More work is needed to develop commercially available computer modeling tools that can be used to assess the harmonic impacts of benchmark GMD events.
  - Transformer vibration and audible noise that result from half-cycle saturation do not appear to be damaging to power transformers, and; thus, do not need to be considered.
  - The analysis of protection systems is an important aspect of assessing the harmonic impact of a benchmark GMD event on the bulk-power system; however, without the proper computer modeling tools and expertise results can vary widely. Interpretation of results requires considerable expertise and engineering judgment.