Wind Turbine Step-Up Transformer Design Considerations

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Introduction

ETEL is a company that manufactures distribution transformers and wind turbine generator (WTG) transformers. A typical system incorporating ETEL's WTG transformer involves the Type IV WTG which transfers all the power generated from the turbine through an inverter. A typical transformer steps up the output voltage of the turbine from ~ 690V to ~ 33kV. However, some of these transformers are failing within five years of operation in some cases instead of operating within their full life expectancy of ~ 25 plus years.

ETEL has identified several factors which can lead to the aforementioned deterioration which can be investigated. These include harmonic pollution from the WTG inverter or other sources and various types of overvoltages on the transformers including ground fault overvoltages. The factors that lead to deterioration may not be limited to these.

The aim of this project is to simulate a typical ETEL Type IV WTG transformer and investigate the effects of aforementioned factors such as harmonics and overvoltages which affect the transformer's quality of life.

Work Done

PSCAD-EMTDC was used to model and simulate the Type IV WTG system and associated components. The project was split into three parts:

- Transformer Modelling and Lightning Simulation
- Switching and Ground Fault Overvoltage Simulation
- Inverter Simulation and Harmonic Analysis

A transformer model implementing stray capacitances[1] to model the high frequency response of the transformer due to lightning. Equivalent models for the WTG system were implemented to supplement the transformer model as shown in Figure 1. Lightning strikes were modelled using current sources[2].

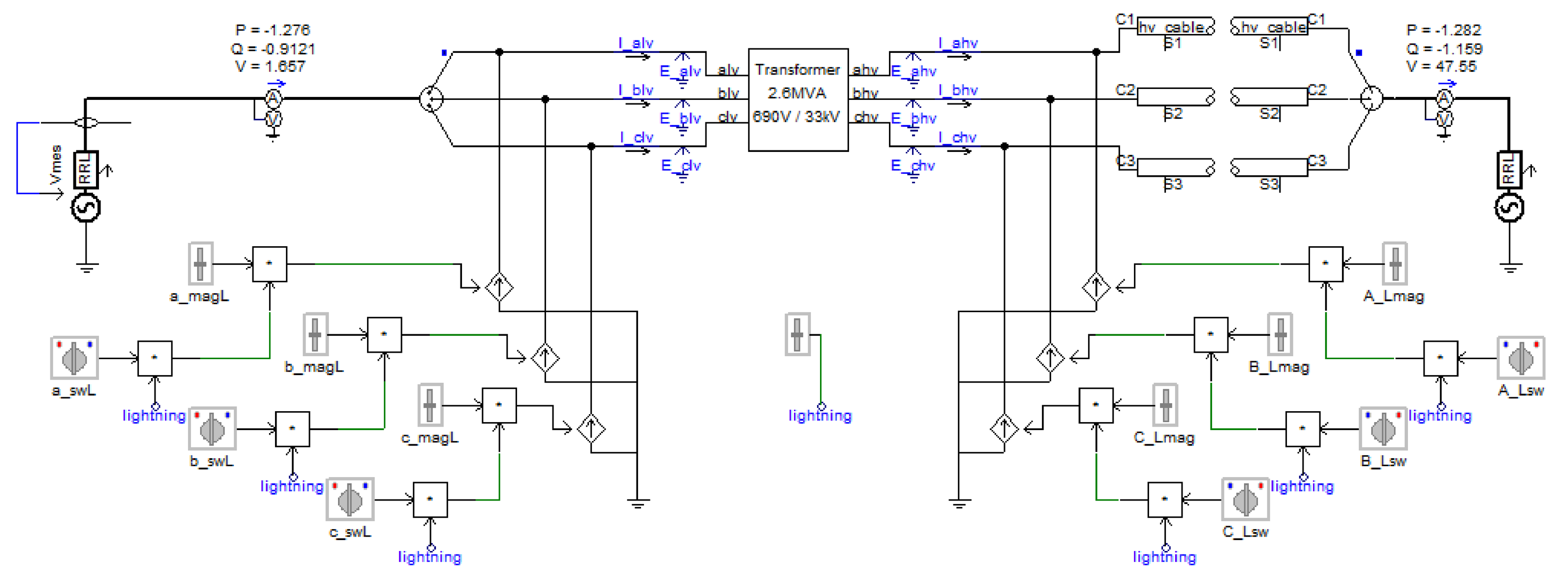

Figure 1. Transformer Model and Lightning Simulation.

A basic model of the wind turbine generator, transformer and the grid is modelled to study overvoltages and switching transient. The model used for switching transient can be seen in Figure 2. A similar model is used for ground fault overvoltages, the only difference is the ground faults are injected on both the HV and LV side and the breakers are removed.

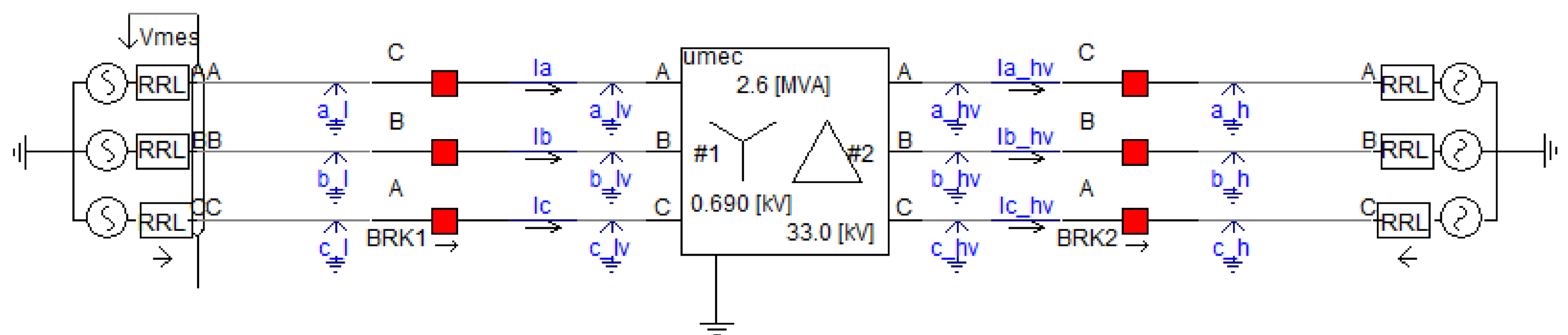

Figure 2. Switching Overvoltage Simulation.

A basic design of the turbine to grid power system was developed consisting of the inverter and ETEL transformer for harmonic analysis of the supply. The resultant voltage and current waveforms were assessed and passed through a fast Fourier transform to get the harmonic distortion generated. These were then compared to real life harmonic values from Meridian's wind farm at West Wind to test for accuracy. With these levels of distortion at varying frequencies the winding and core losses caused by the harmonics can be calculated, estimating the transformer's temperature rise and degradation.

Results

Figure 3 shows the system response to a 30kA lightning impulse applied to one phase on the high voltage side of the transformer. Oscillatory responses can be attributed to incumbent capacitances and inductances in the system. Both current and voltage magnitudes are notably high.

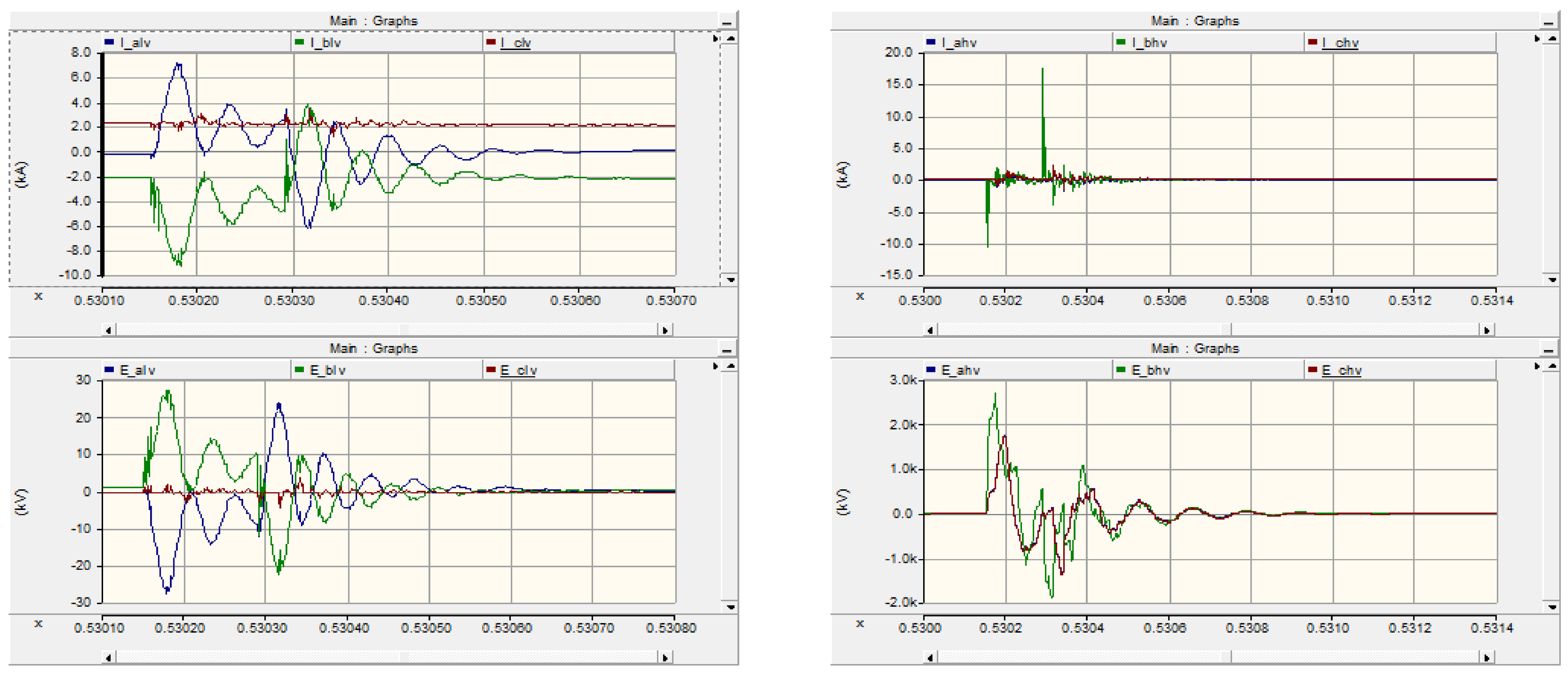

Figure 3. Lightning Response (LV response on left, HV response on right).

Table 1 shows the results obtained from the switching transient model. The simulation is ran such that an event (opening or closing of breaker) occurs after every 0.5s. There are transients detected at different events as shown below.

	Breaker 1 Opened	Breaker 2 Opened	Breaker 1 Closed	Breaker 2 Closed
LV Current	Current decreases to 0	Current remains 0	Current increases slightly and takes some time to oscillates in phase	Transient detected, but current recovers and oscillates in phase
HV Current	Current decreases to a smaller value	Current decreases to 0	Current remains 0	Transient detected, but current recovers and oscillates in phase
LV-Gen	Transient detected, voltage decrease then increase (back to original value)	No effect	No effect	Switching transient detected
LV-Tx & HV-Tx	No effect	Transient detected, voltage decrease but still oscillates in phase	Voltages increase back to its' original values	Switching transient detected
HV-Grid	No effect	No effect	No effect	Some switching transient detected

Table 1. Switching Transient Response Descriptions.

The measured values below represent the mean current distortion at every order of the 50Hz harmonic for each phase over a 22 hour period. These results show large distortion in the 3rd, 5th, 7th and 11th harmonics from non-linear loads and the rectifier. Additional excess distortion appears around the 45th, 47th and 49th harmonic, which is to be expected as the switching frequency is present in the 50th harmonic (2.5kHz).

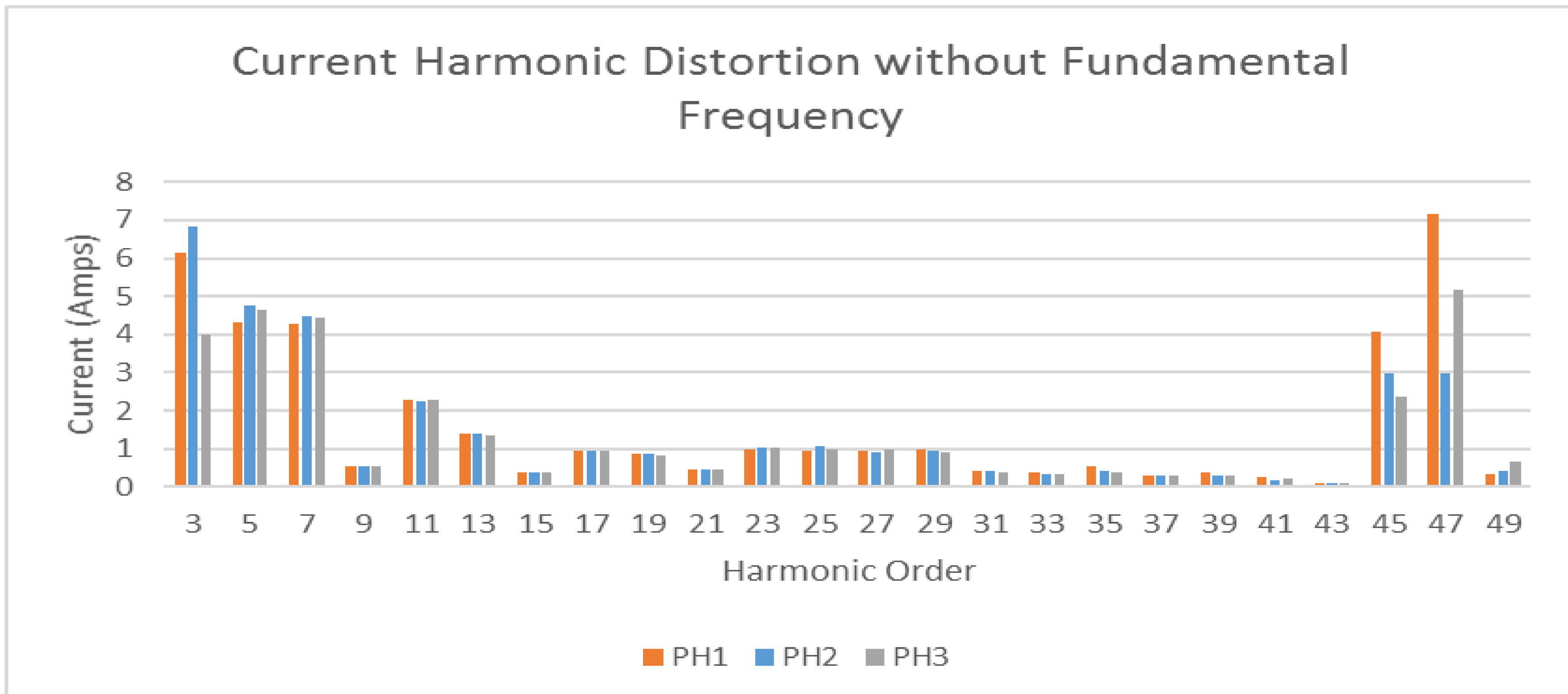

Figure 4. Current Harmonic Analysis.

Conclusions

Significant overvoltages are possible when unshielded from lightning. There are no overvoltages when ground fault occurs. However, there are switching transients following the opening and closing of breakers.
The harmonic simulation was correct in identifying harmonics around the 50th order however it is not enough to simulate other distortions alone. Further simulation is required

References

1. Martinez, J.A. et al. "Parameter Determination For Modeling System Transients—Part III: Transformers IEEE PES Task Force On Data For Modeling System Transients Of IEEE PES Working Group On Modeling And Analysis Of System Transients Using Digital Simulation (General Systems Subcommittee)". *IEEE Transactions on Power Delivery* 20.3 (2005): 2051-2062. Web.
2. *Guideline For Numerical Electromagnetic Analysis Method And Its Application To Surge Phenomena*. [Paris] (21 rue d'Artois, 75008): CIGRÉ, 2013. Print.