Stabilizing the Differential Protection of Transformers Supplied with High Charging Circuit

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69th Annual Conference for Protective Relay Engineers, April 4 - 7, 2016

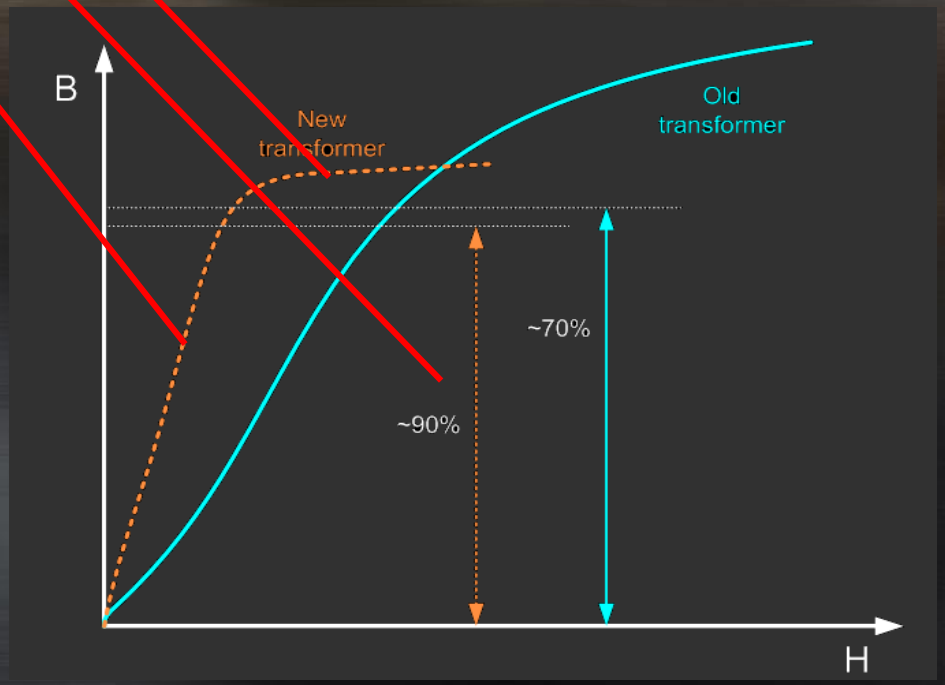
Outline

- Introduction
- Harmonics Analysis and Protection Schemes
- Magnetizing Current Analysis for Transformers Supplied with Underground Cables
- Application of Adaptive Inhibit Scheme
- Validation Simulation Testing
- Conclusions

Introduction

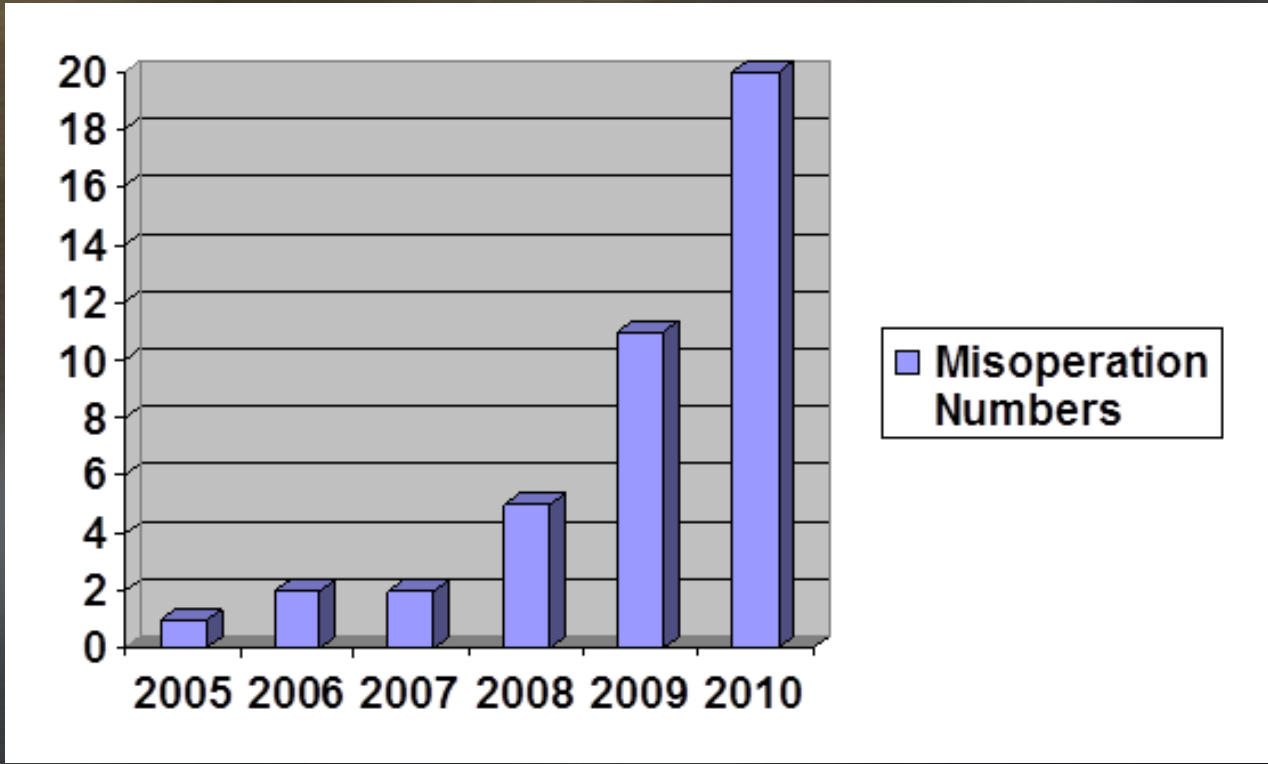
- Newer transformers with improved core material:
  - Higher knee point in terms of the percentage of the saturation level
  - Steeper characteristic in non-saturation region
  - Flatter characteristic in saturation region
  - Higher inrush currents but lower 2nd harmonics at deep saturation

- # of mis-operations in Hydro One grid has gone up as new transformer installation increases



Introduction

- Mis-operations have become more frequent in Hydro One grid in recent years, in which the reduced level of second harmonics in the magnetizing inrush current has been one of the major causes



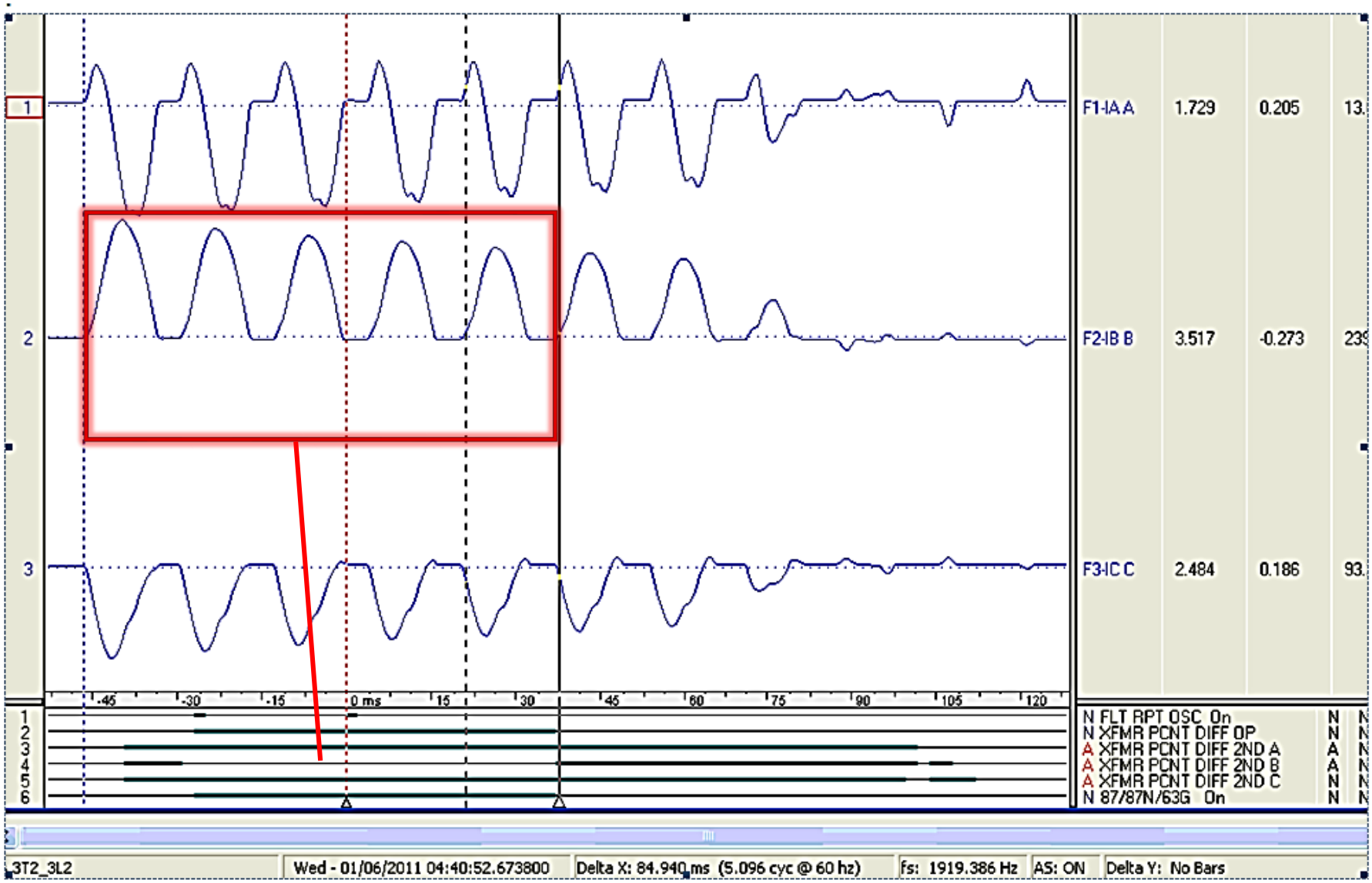
Harmonics Analysis and Differential Protection

- Traditionally, the second harmonic component in the inrush current has been used to distinguish between magnetizing inrush and actual fault
- For most of the energization operations, the ratio of the second harmonic to the fundamental component should be at least 17-20%, which is high enough to restrain the current differential protection
- However, as the adoption of newer transformers in the past two decades, many utilities experienced more false trips on transformer energization due to lower second harmonic inrush current

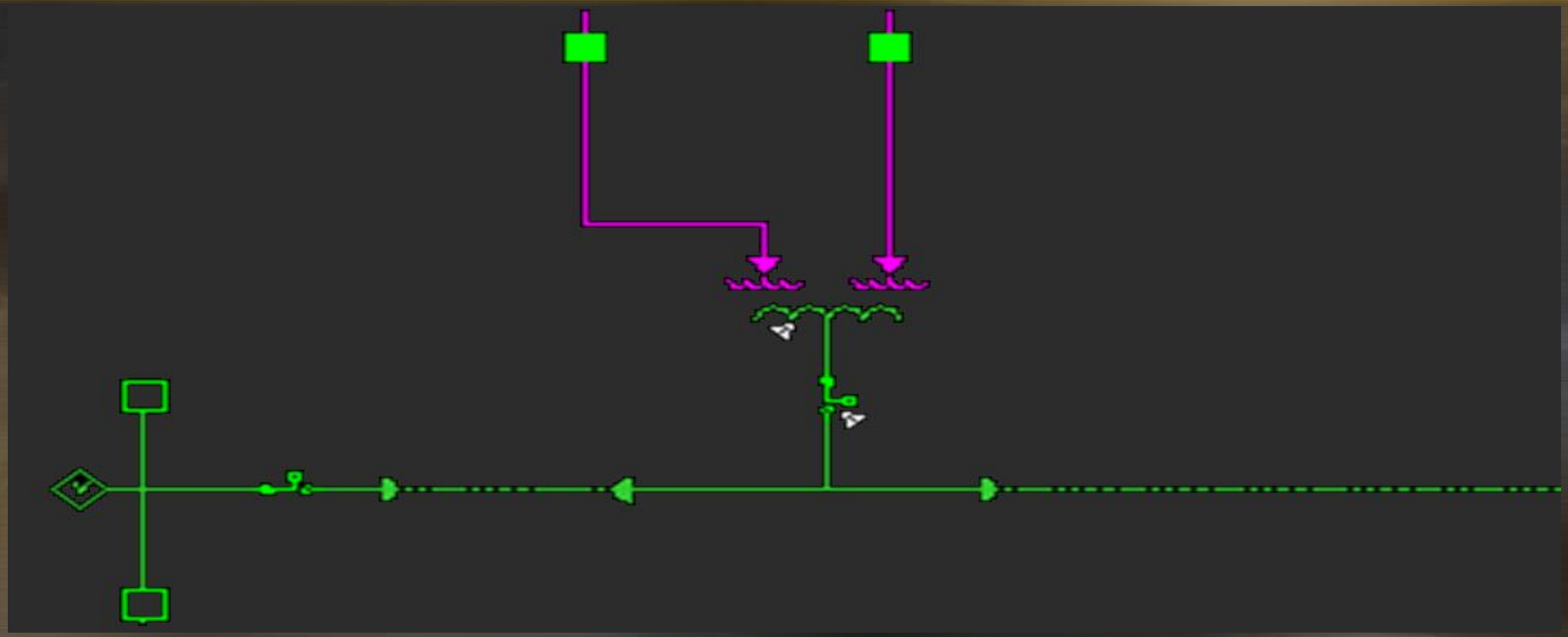
Harmonics Analysis and Differential Protection

- Low second harmonic content typically appears during the first few cycles of energization, after that the second harmonic magnitude will gradually increase as the core recovers from the deep saturation
- During energization, low second harmonic typically only occurs in one phase, i.e. the second harmonic contents in the other two phases are typically high enough to stabilize the differential protection
- Hydro One has significantly mitigated transformer differential element mis-operations by applying cross-blocking and two-out-of-three blocking schemes

Harmonics Analysis and Differential Protection



Transformer Supplied with High Charging Circuit

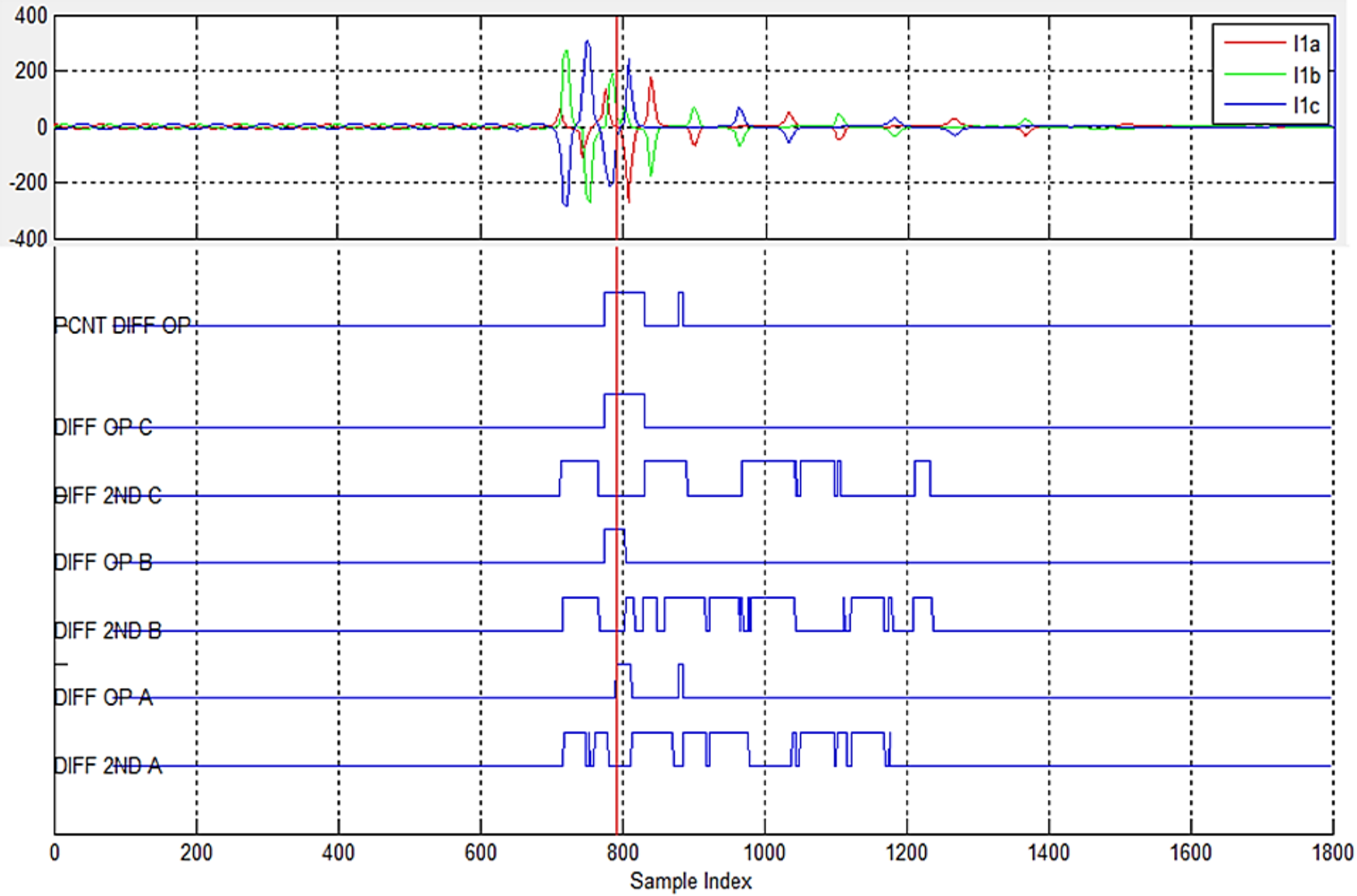


- In metropolitan areas in Hydro One grid, transformers are typically connected through long underground cables
- A series of mis-operations occurred on transformers with such connections during de-energization

Transformer Supplied with High Charging Circuit

- Though no load losses with these kinds of mis-operation cases during de-energization, a lot of unnecessary work were initiated
- After analysis, it has been concluded that these mis-operations were caused by the high charging circuit of the cable interacting with the magnetizing branch of the transformer
- The frequency spectrum analysis on the field data indicates that the 2nd harmonic contents could be low on all 3 phases
- Traditional 2nd harmonics restraint methods (including 2 out of 3, cross-blocking) cannot secure the differential protection

Transformer Supplied with High Charging Circuit



Solution - Adaptive Inhibit Method ?

- It's found incidentally that one transformer IED did not mis-operate for such discharging event, while the other IED protecting the same transformer did mis-operate
- It's noticed that adaptive inhibit method was accidentally enabled in this IED by a contactor in a turnkey project because adaptive inhibit scheme had not been officially adopted in Hydro One transformer protection standard
- Is the adaptive inhibit method the correct way to go?

Introduction to Adaptive Inhibit Method

- Traditional inhibit method uses only magnitude of the second harmonic and the fundamental component
- Adaptive inhibit method uses both magnitude and phase angle relation between the second harmonic and the fundament component in the differential current

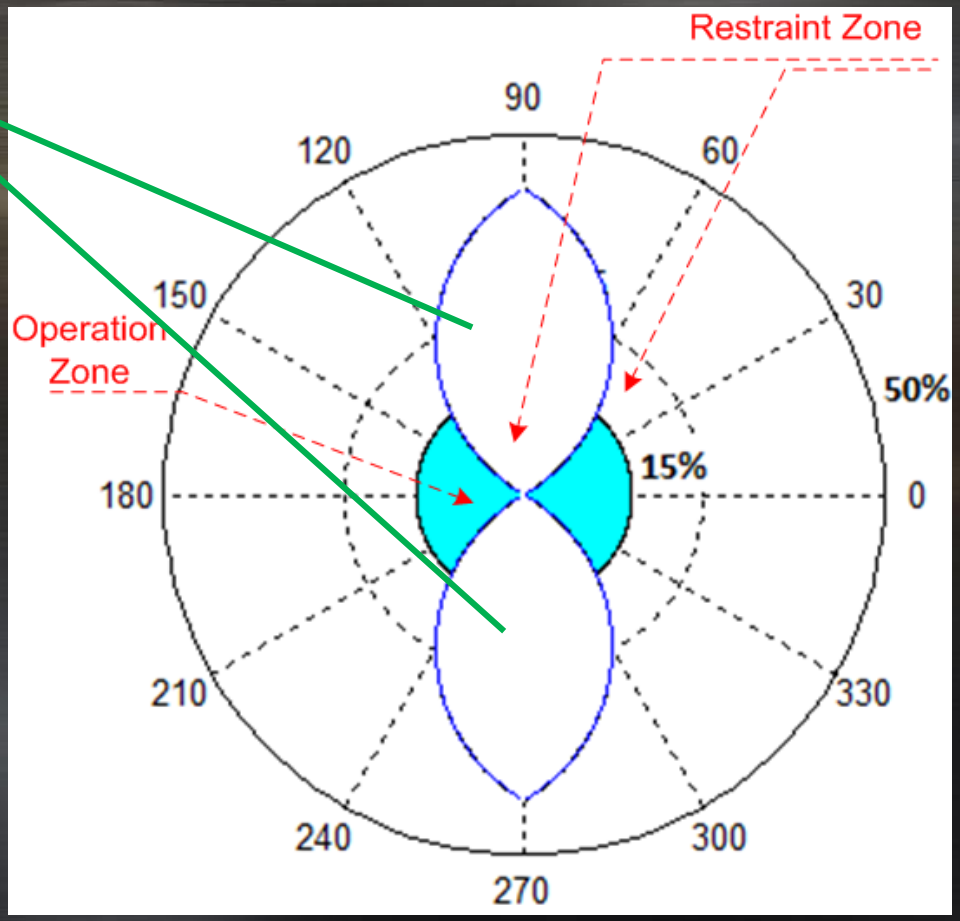
$$I_{21} = \frac{I_2}{I_1 \cdot e^{j\omega t}} = \frac{|I_2|}{|I_1|}(\mathrm{angle}(I_2) - 2 \cdot \mathrm{angle}(I_1))$$

$$I_{21_MAG} = \frac{|I_2|}{|I_1|}$$

$$I_{21_ANG} = \mathrm{angle}(I_2) - 2 \cdot \mathrm{angle}(I_1)$$

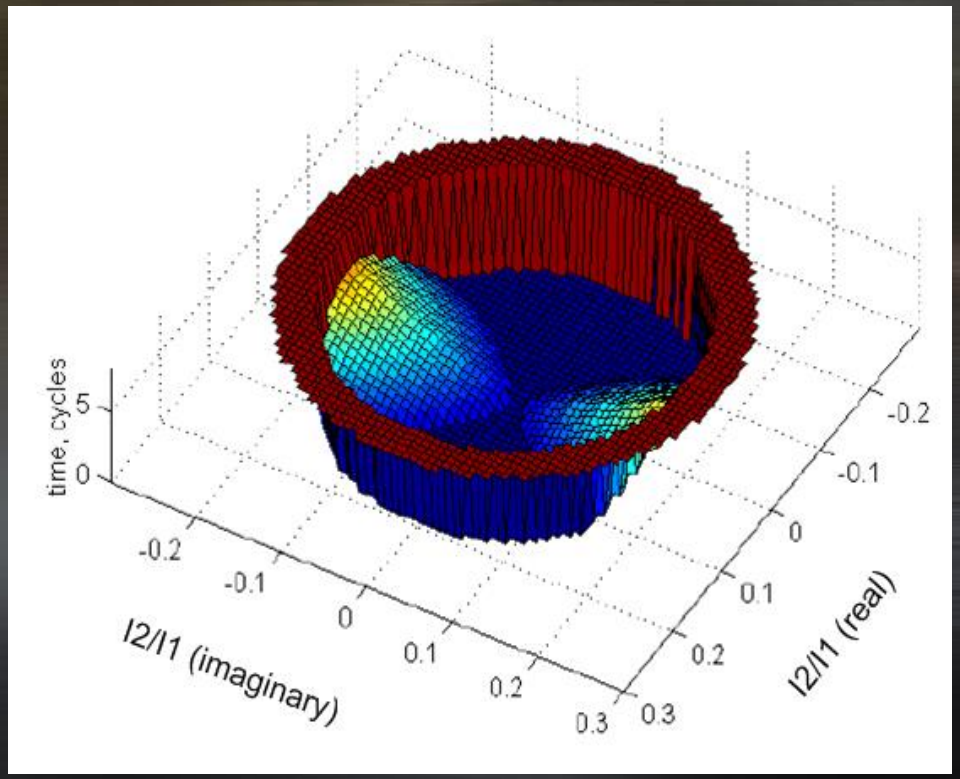
Introduction to Adaptive Inhibit Method

- I_{21_ANG} is close to ±90 degrees region during inrush, and close to 0 and 180 degrees region for internal faults
- Two lenticular shape zones along ±90 are established on the I2/I1 complex plane to block differential elements from tripping



Introduction to Adaptive Inhibit Method

- These two lenticular shape zones dynamically shrink with time, to account for that low 2nd harmonics only occur in the first 4-5 cycles and avoid any possible delay on internal faults

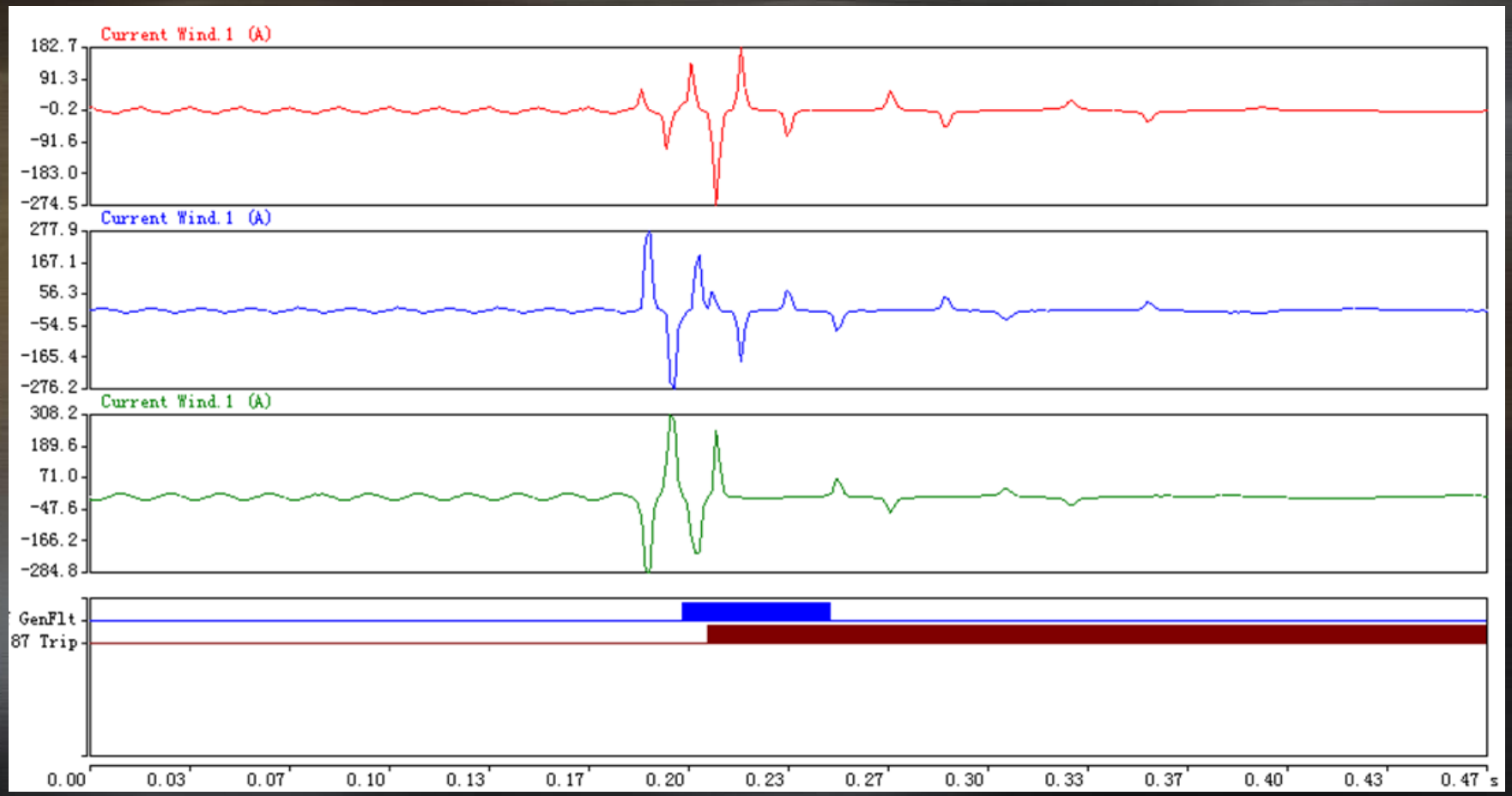


Validation of Adaptive Inhibit Method

- In order to validate the adaptive scheme, numerous simulations were carried out with field event data collected from Hydro One grid
- Three of these simulation cases are shown in this presentation:
  - The first two are the de-energization cases of the transformers with high capacitive charging circuit
  - The third one is an internal fault case

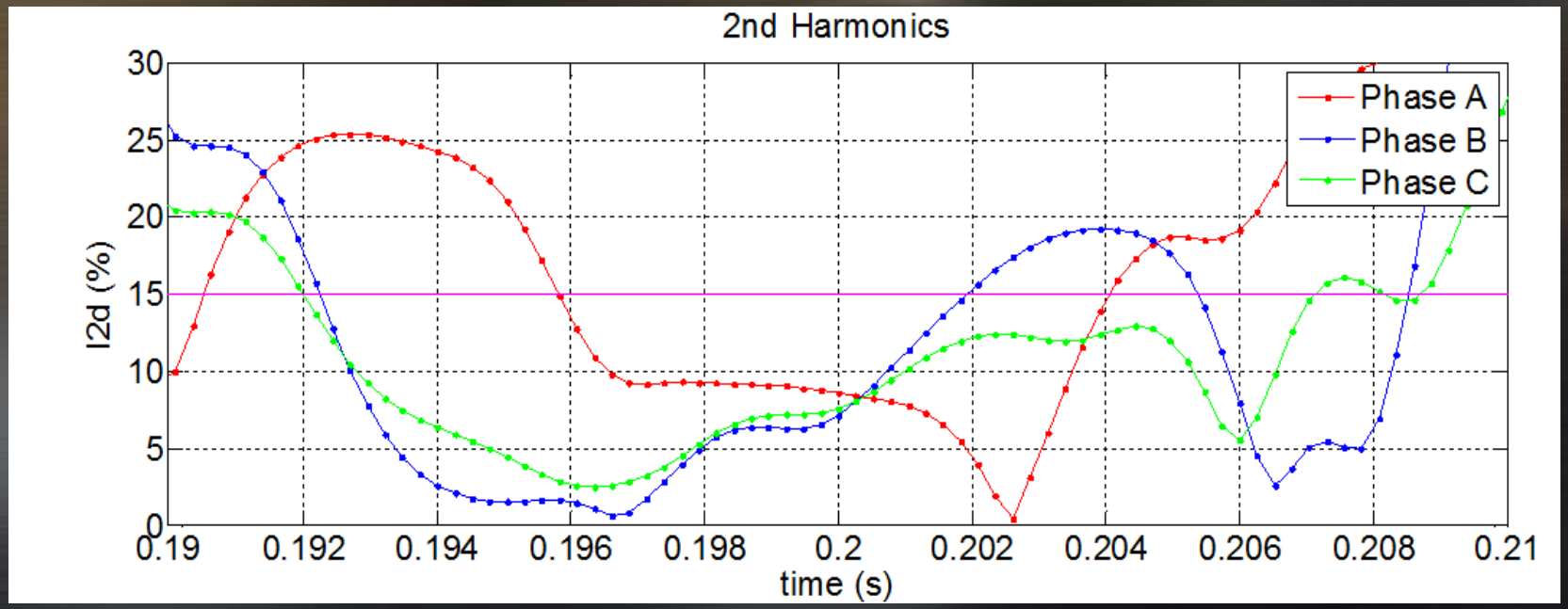
Validation of Adaptive Inhibit Method – Case 1

- 115kV transformer with long underground Cables – Case 1

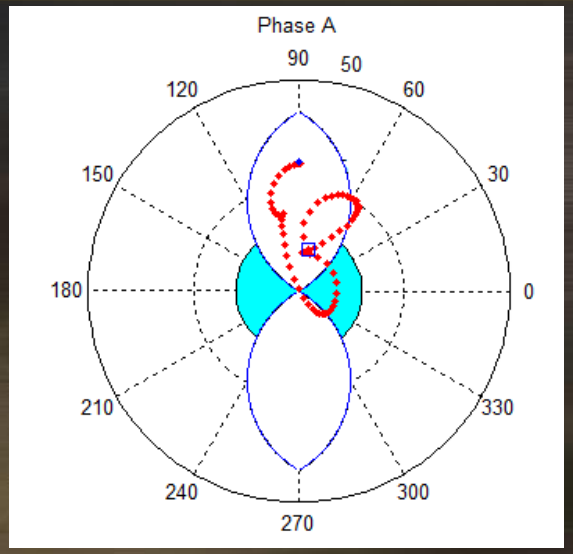


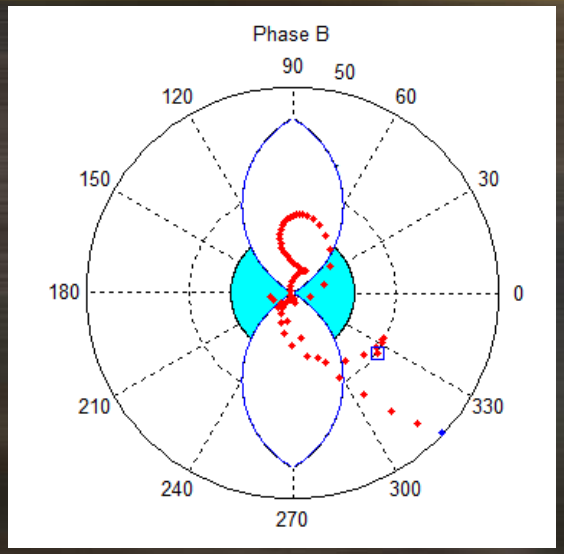
Validation of Adaptive Inhibit Method – Case 1

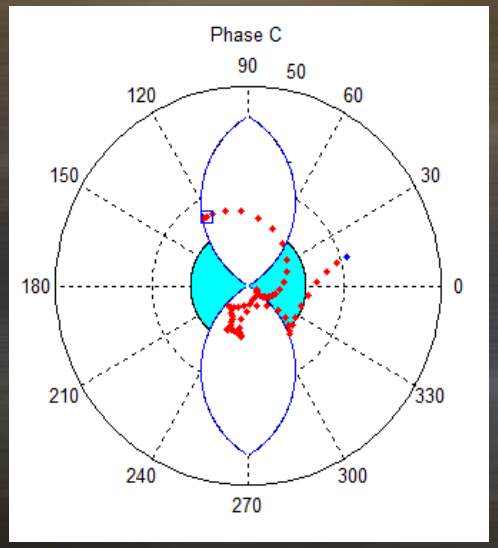
- Frequency spectrum analysis shows that differential current experiences low second harmonic level (lower than 15%) during period 196ms-202ms (6ms) for all three phases, neither 2-out-of-3 nor cross blocking would be able to secure the differential protection

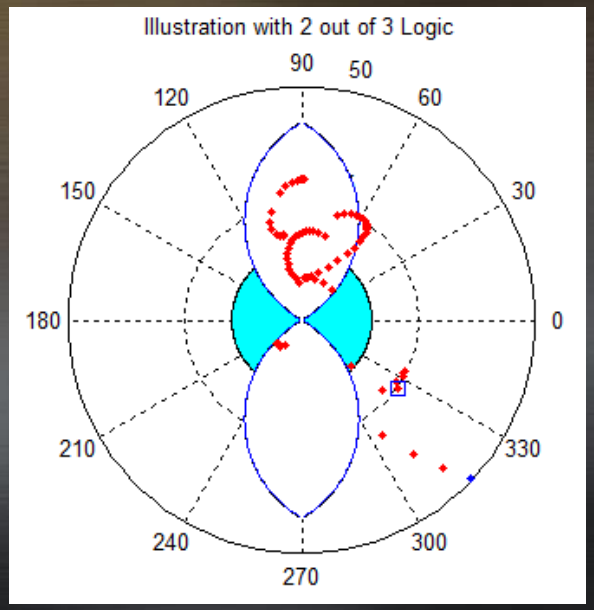


Validation of Adaptive Inhibit Method – Case 1





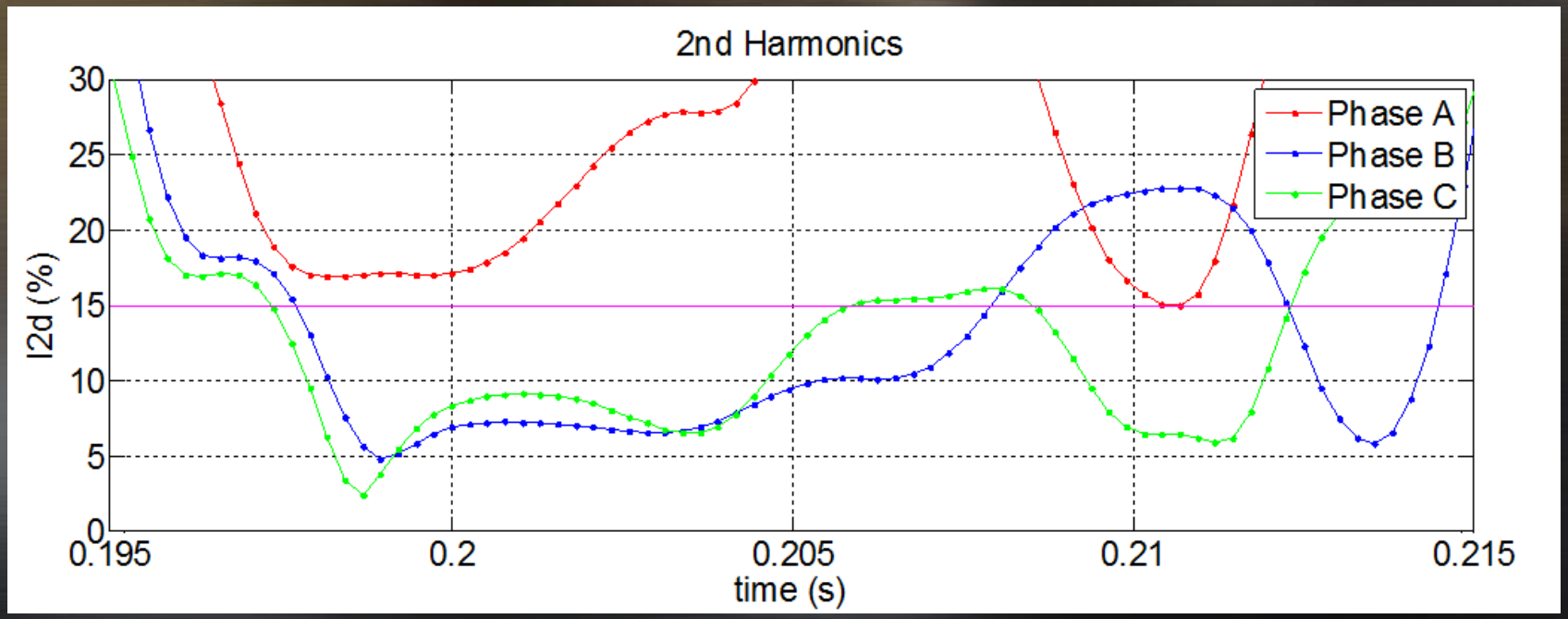




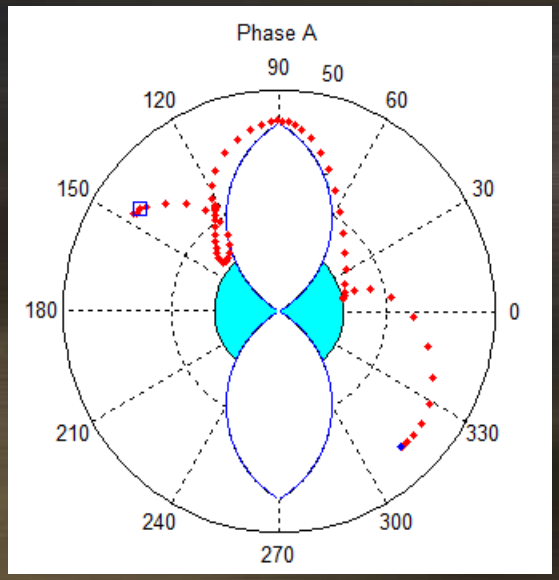
- With enabling the two-out-of-three blocking logic in the adaptive inhibit method, the differential element misoperation shall be avoided

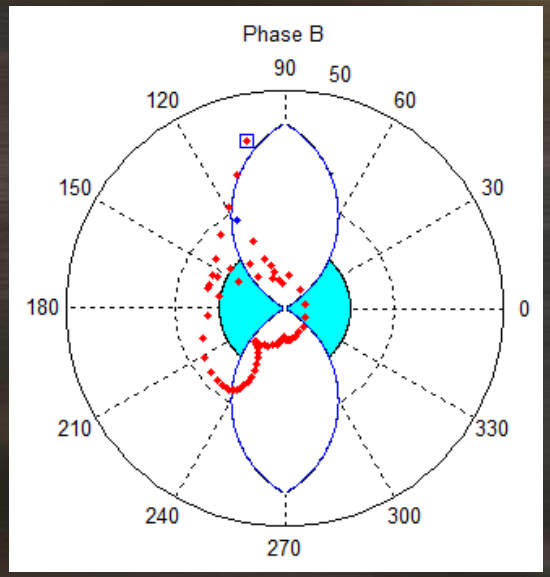
Validation of Adaptive Inhibit Method – Case 2

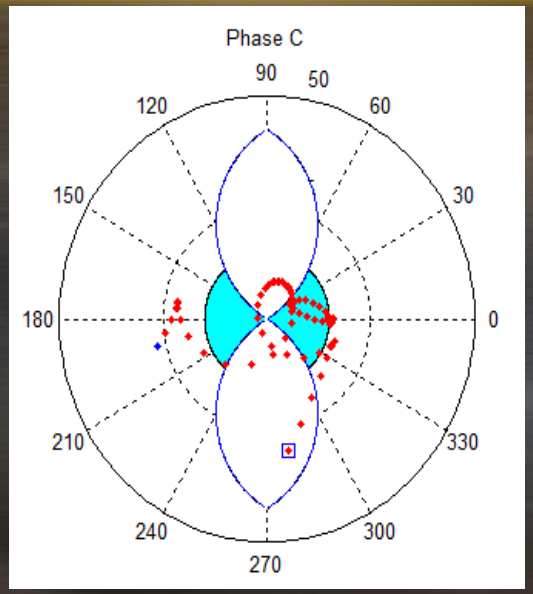
- 115kV transformer with long underground cables – Case 2
- 2-out-of-3 logic was not able to secure the differential protection

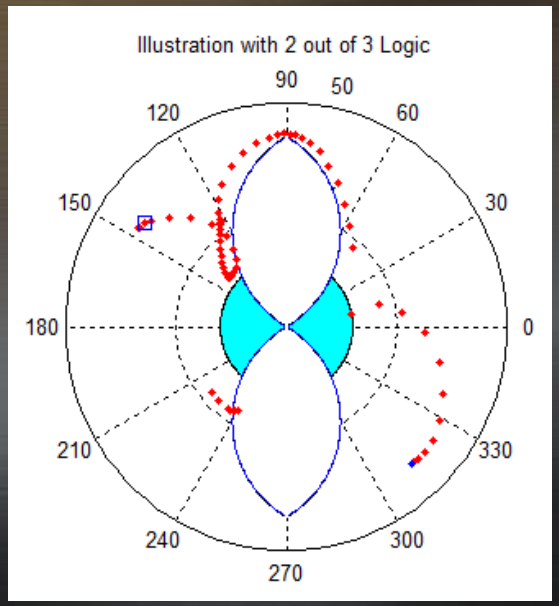


Validation of Adaptive Inhibit Method – Case 2





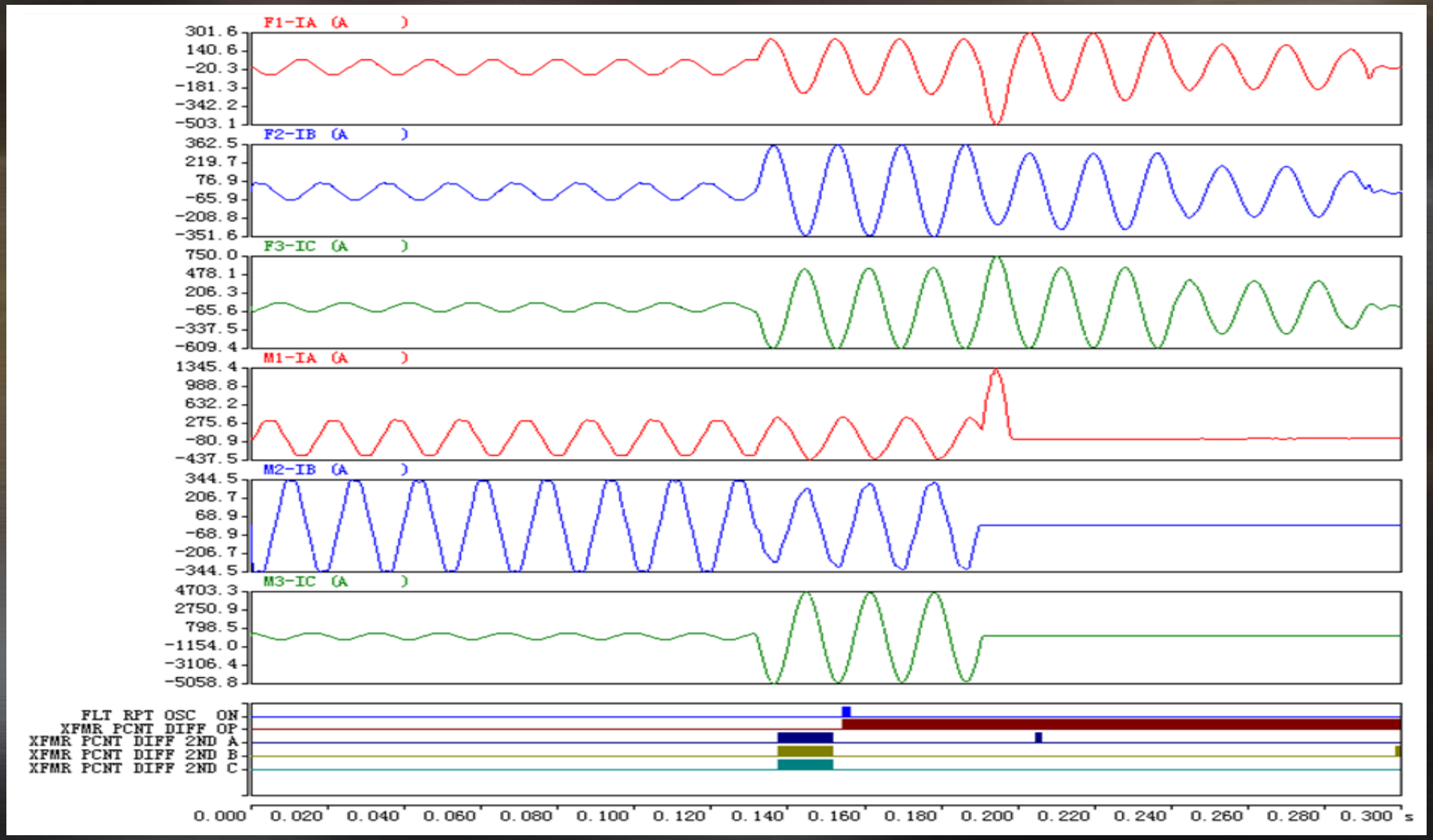




- With enabling the two-out-of-three blocking logic in the adaptive inhibit method, the differential element misoperation shall be avoided

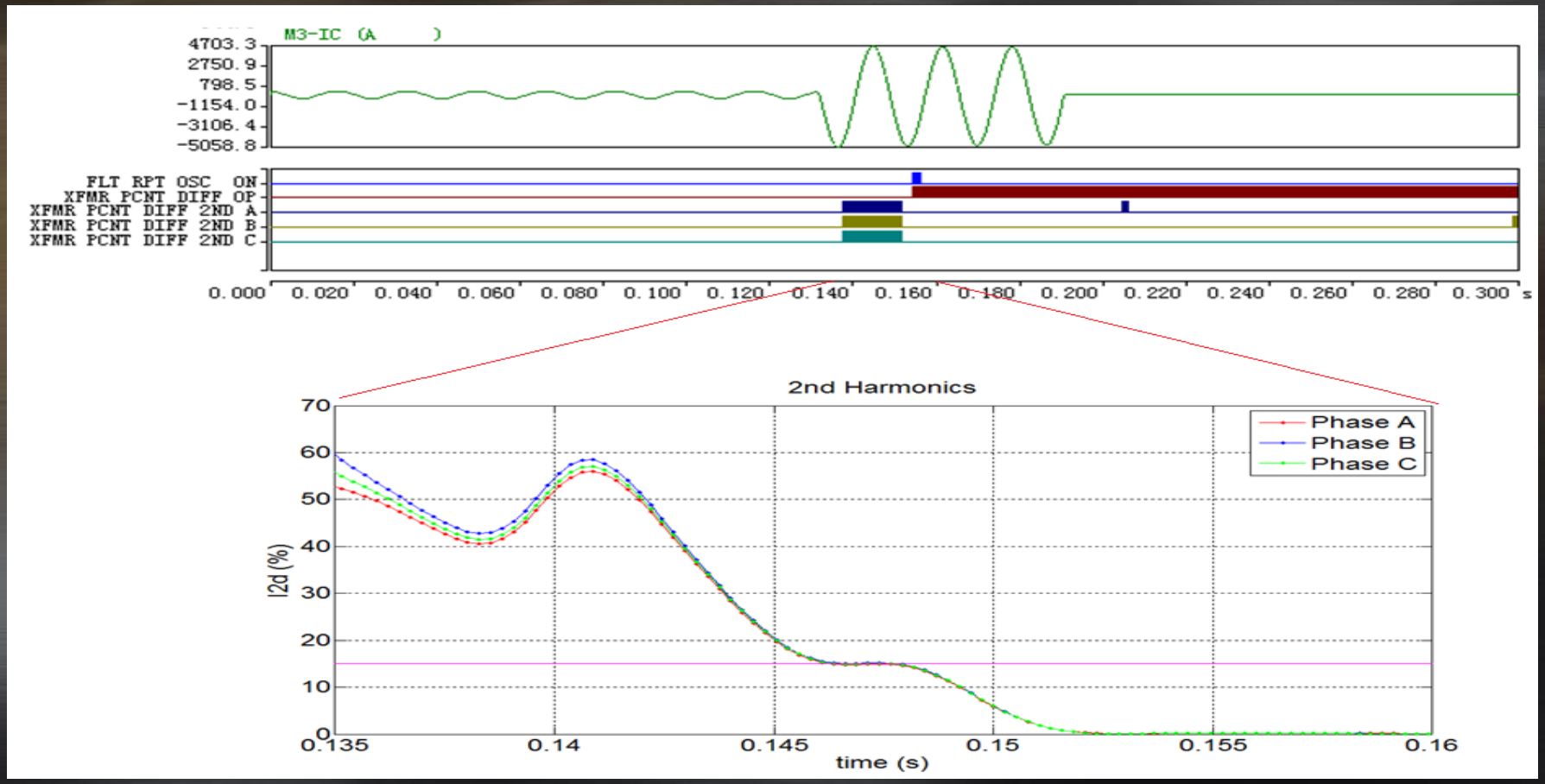
Validation of Adaptive Inhibit Method – Case 3

- 230kV transformer internal fault

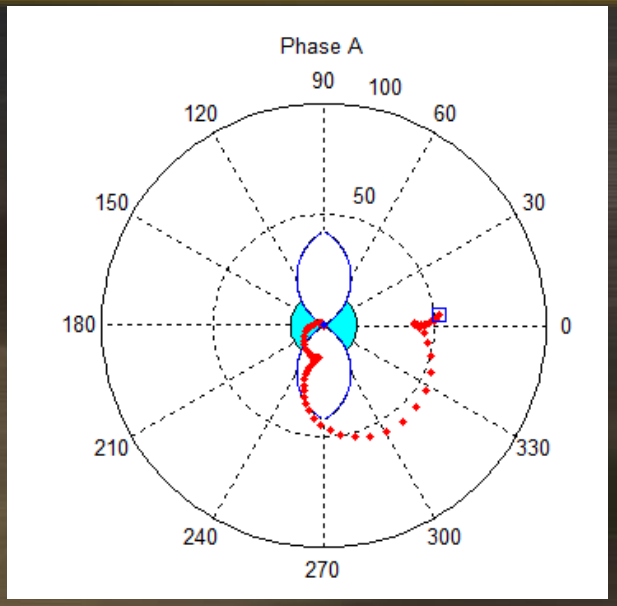


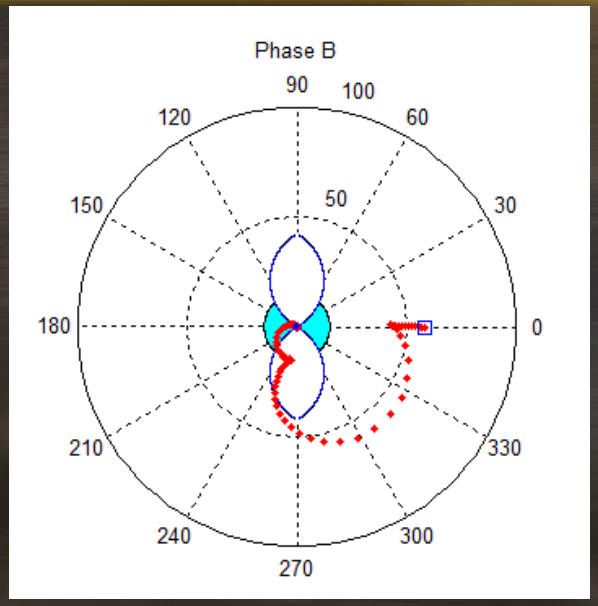
Validation of Adaptive Inhibit Method – Case 3

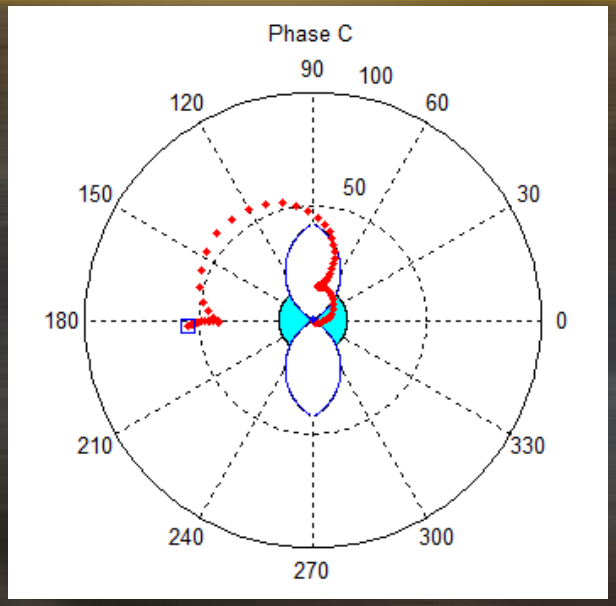
- After the pre-fault to fault transition period, 2nd harmonics drop to below 15% at t=147ms, and then stay very low (almost 0%) after t=155 ms

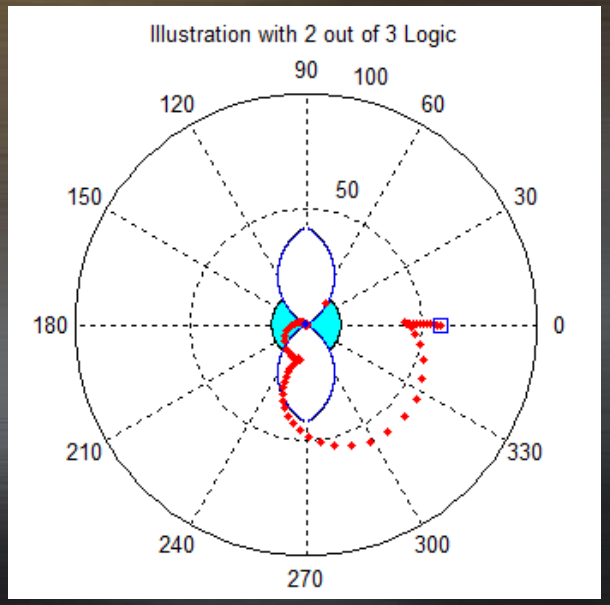


Validation of Adaptive Inhibit Method – Case 3









- I_{21} trajectories travel from blocking zone (2nd harmonic over 15%) to the origin (0%) through the operation zone either from 0 degree line or 180 degree line for all 3 phases, which indicates that there is no additional delay to the differential protection element

Conclusions

- The differential protection misoperations on 115kv and 230kV transformers supplied with long capacitive charging circuits during de-energization had been a challenging issue for Hydro One grid
- An occasional event revealed that adaptive inhibit method could avoid such misoperations. Thereafter, numerous simulations validation testing was carried out on actual event data collected from Hydro One grid, and concluded:
  - Adaptive inhibit method with 2-out-of-3 logic is a practical solution to overcome these mis-operation problems

Summary

- The adaptive inhibit method has high security under the magnetizing inrush condition caused with high capacitive charging effect
- The adaptive inhibit method also has the same dependability as the traditional inhibit method for actual internal faults within the transformer differential protection zone under both energization and normal load condition, without or only with minimal additional delay

Thank You

Questions?