Impact of Incipient Faults on Sensitive Protection

Ilia Voloh – GE Grid Solutions

Zhihan Xu – GE Grid Solutions

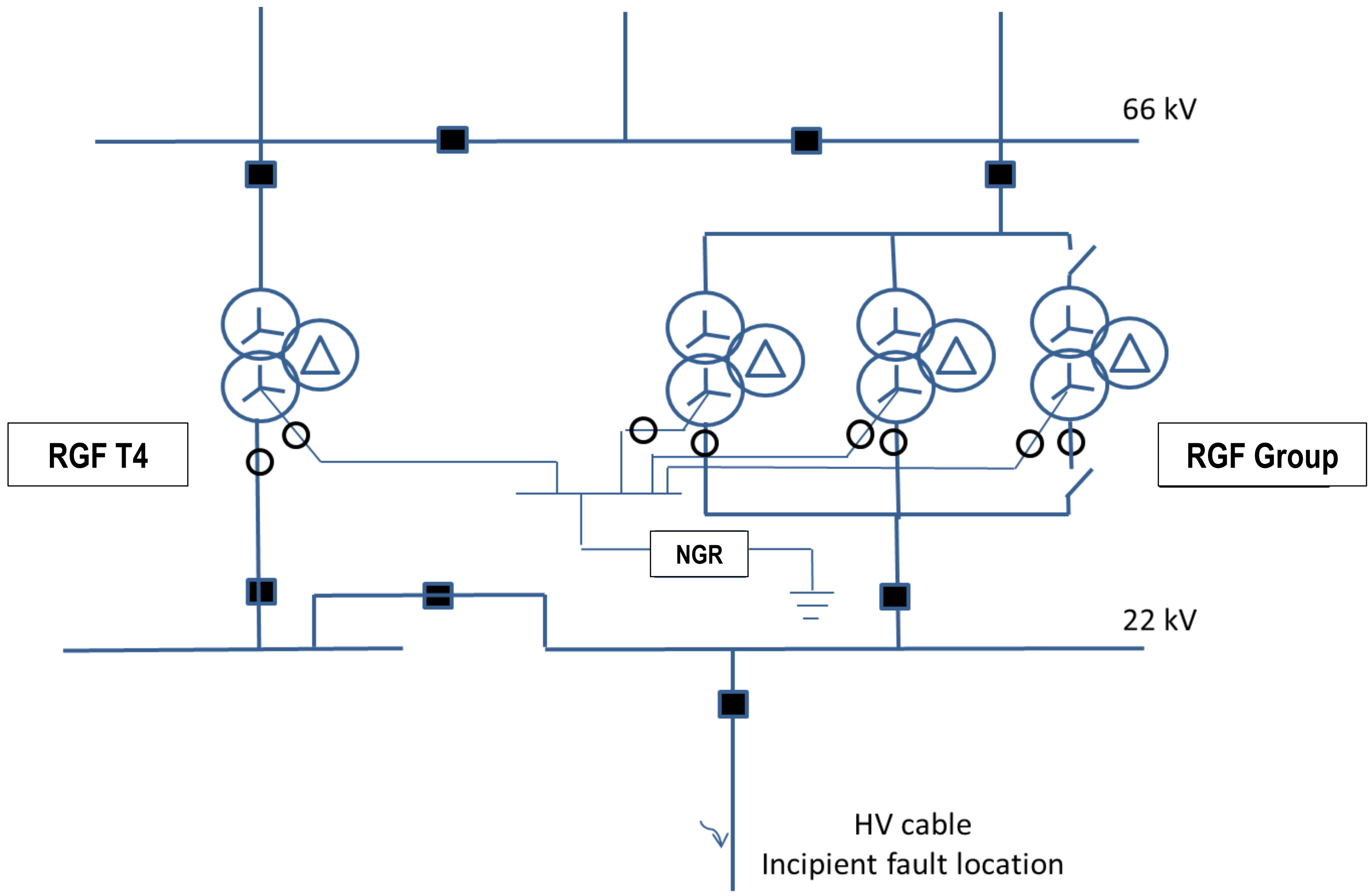
Leonardo Torelli – CSE-Uniserve

The 71st Annual Conference for Protective Relay Engineers

Outline

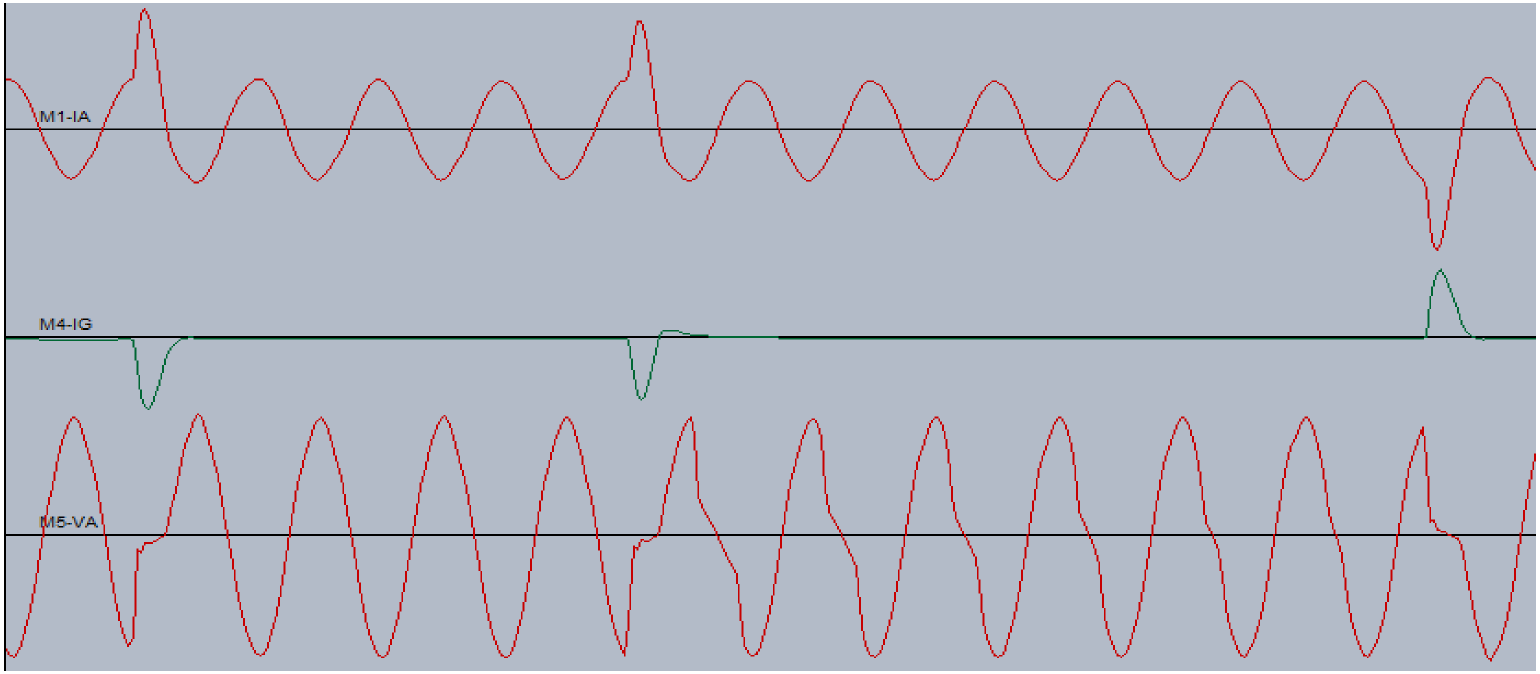
- An interesting field case
- Incipient fault and RGF scheme
- Root cause of misoperation
- Effects on sensitive protection functions
- Solutions

A Field Case



66 kV
RGF T4
RGF Group
NGR
22 kV
HV cable
Incipient fault location

A Field Case



- A typical of incipient fault
- Short time length of about 1/4 cycle
- Appear near the peak of the voltage
- Self-clear at current zero-crossing

Questions

- What happened? Why did a series of incipient faults result in the operation of RGF?
- Will it affect other sensitive protection functions?
- What solution can be applied to improve relay security, but with no jeopardizing on relay dependability?

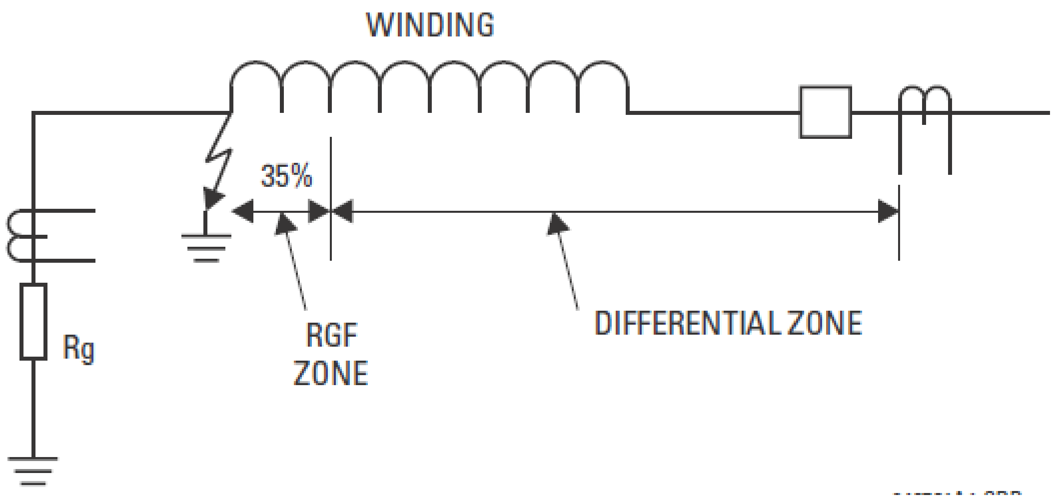
Incipient Faults

- Resulted from a gradual aging process in cables
- Insulation damage can propagate through a section of the insulation, branch into channels, and evolve to a tree-shape damage area

- Intermittent
- Shorter fault duration
- Lower fault current
- Develop to permanent faults

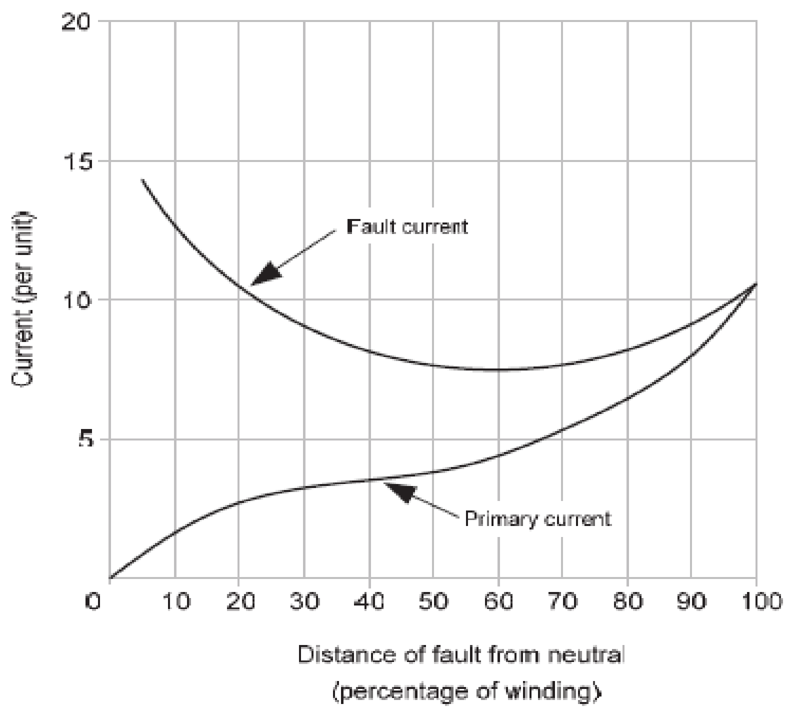
Restricted Ground Fault Protection

- Provide sensitive ground fault detection for faults close to the neutral point of a wye-connected winding.



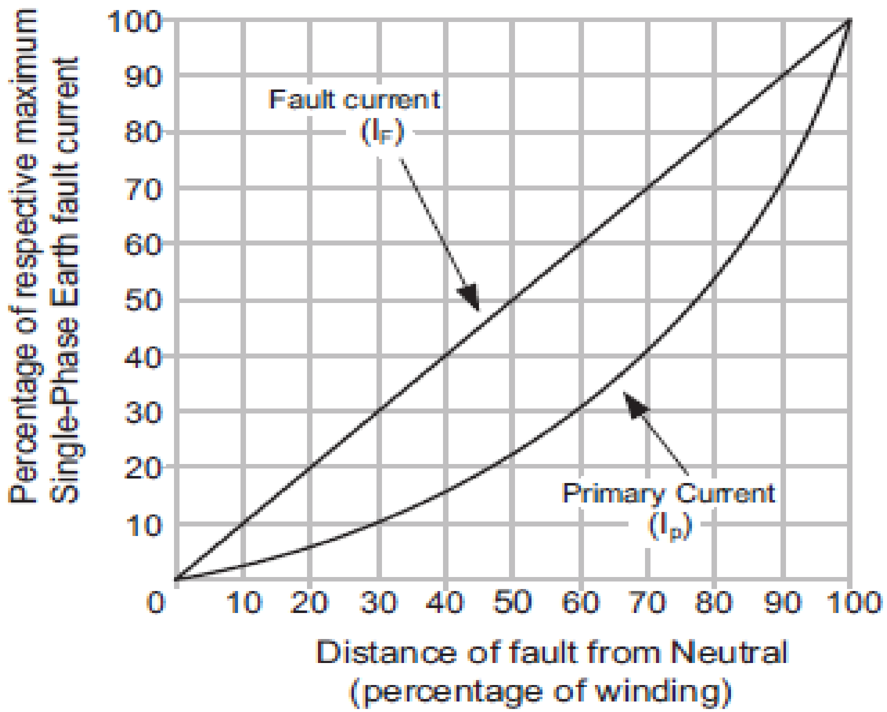
Restricted Ground Fault Protection

- Solidly-grounded wye winding: Fault current depends on impedance in the fault path, fault position on the winding with respect to the neutral point.



Restricted Ground Fault Protection

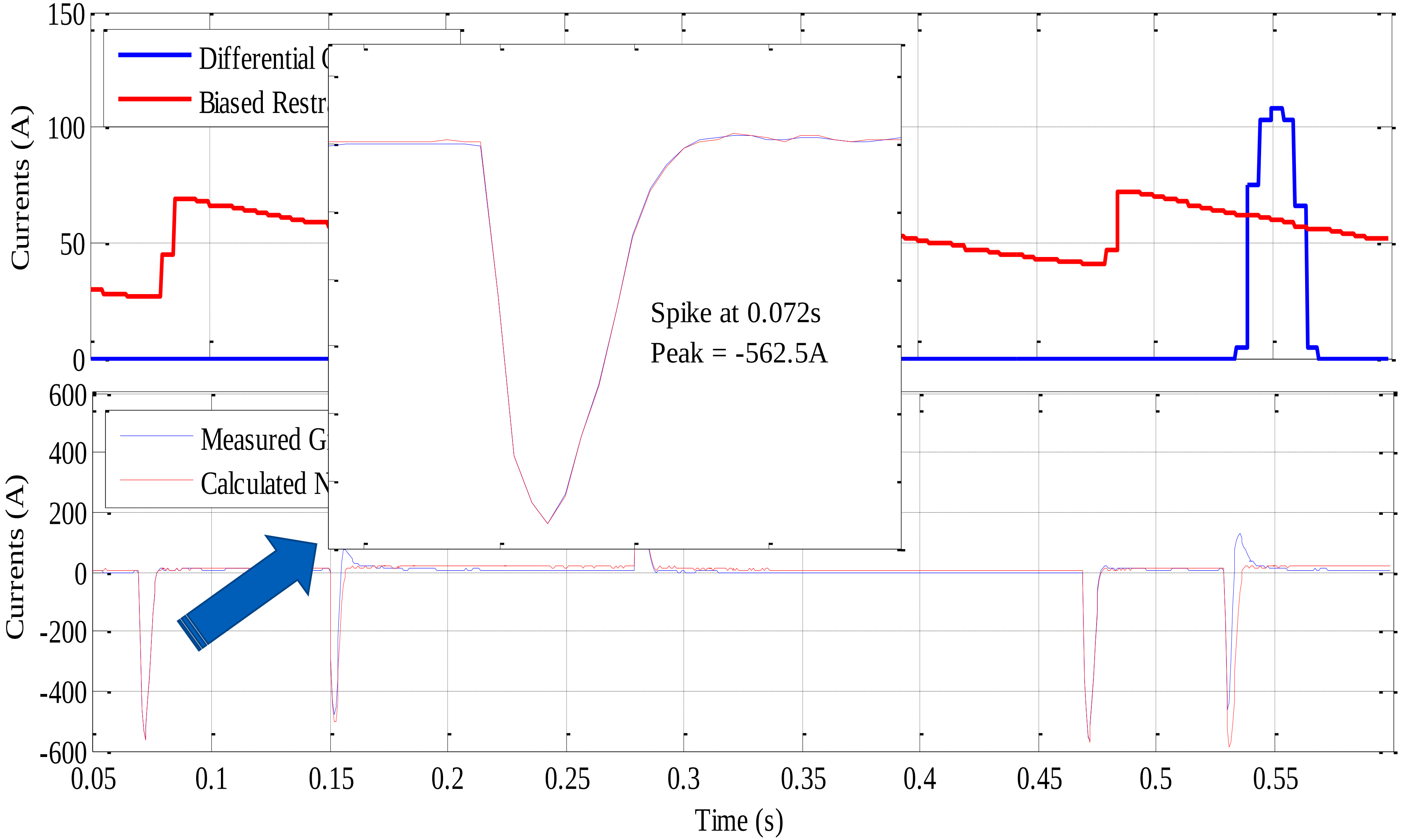
- Impedance grounded wye winding: Fault current depends on value of ground impedance, and fault position on the winding with respect to the neutral point.



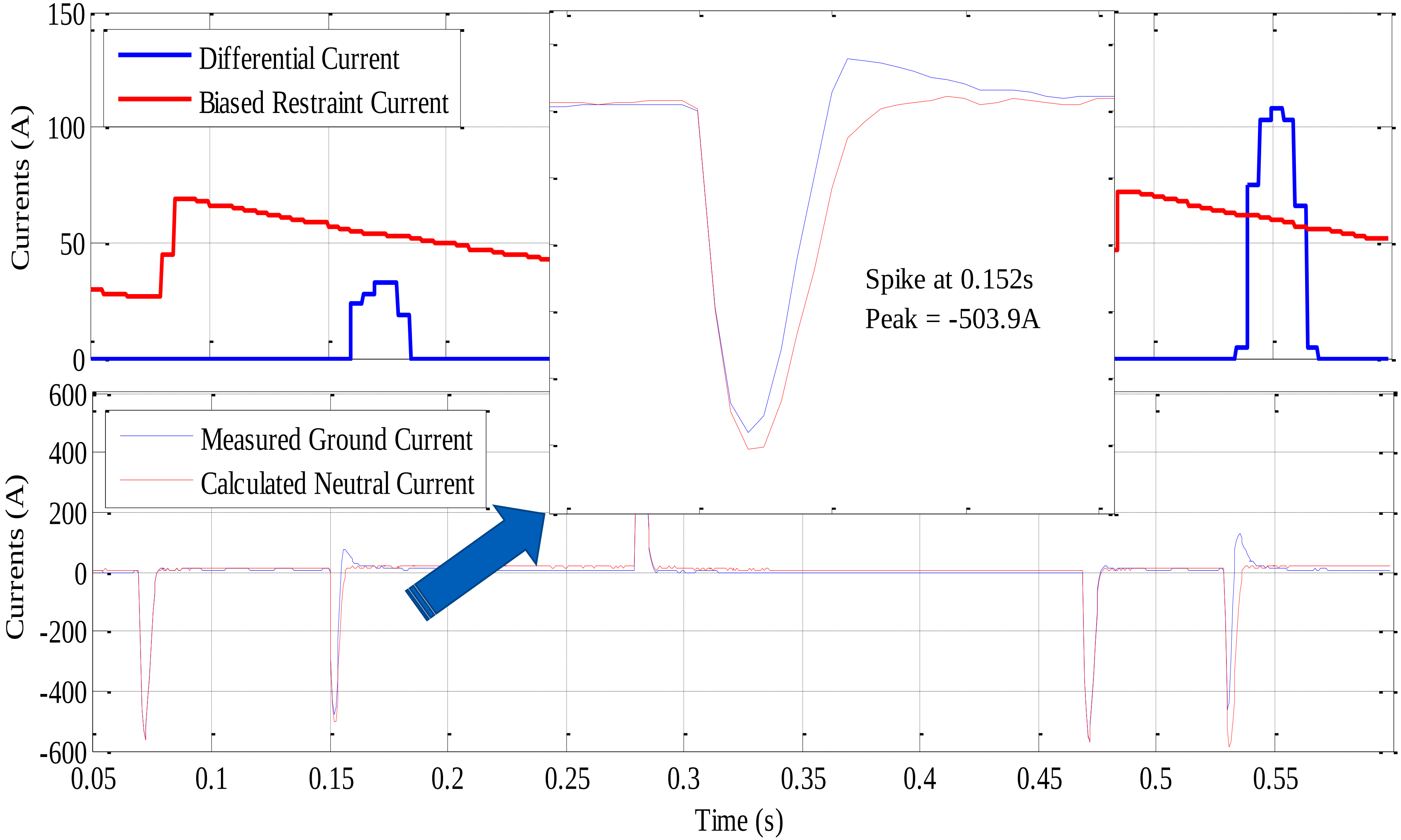
RGF – Security

- Adaptive restraining
  - Dynamically apply zero, negative, and positive-sequence currents as the restraining current
  - Decay restraining current when an external fault gets cleared or a CT saturates heavily
- Three-slope bias characteristic
  - The last slope provides security under through fault conditions
- Angel comparison between zero-sequence current and ground current

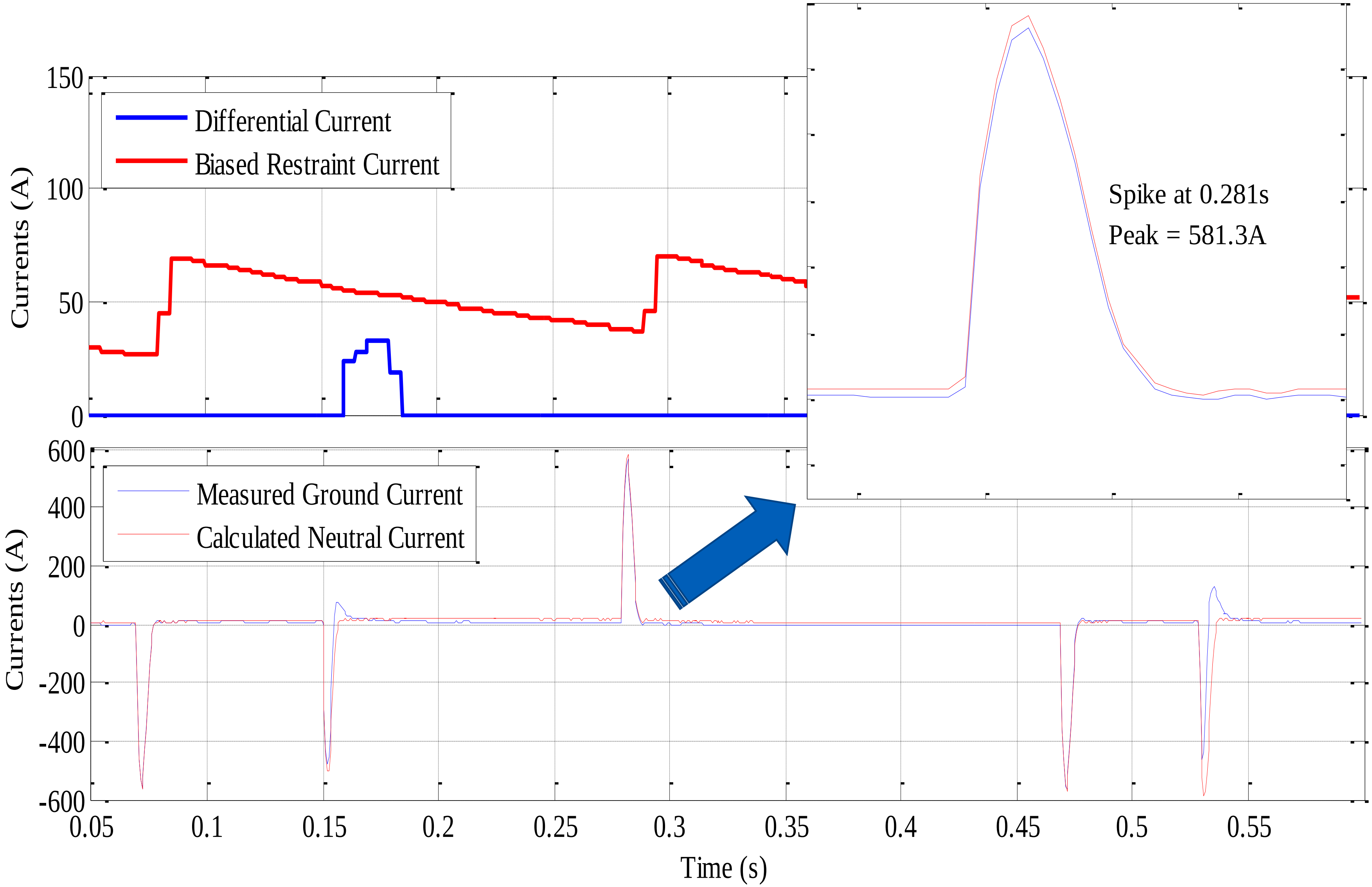
Cause of Misoperation



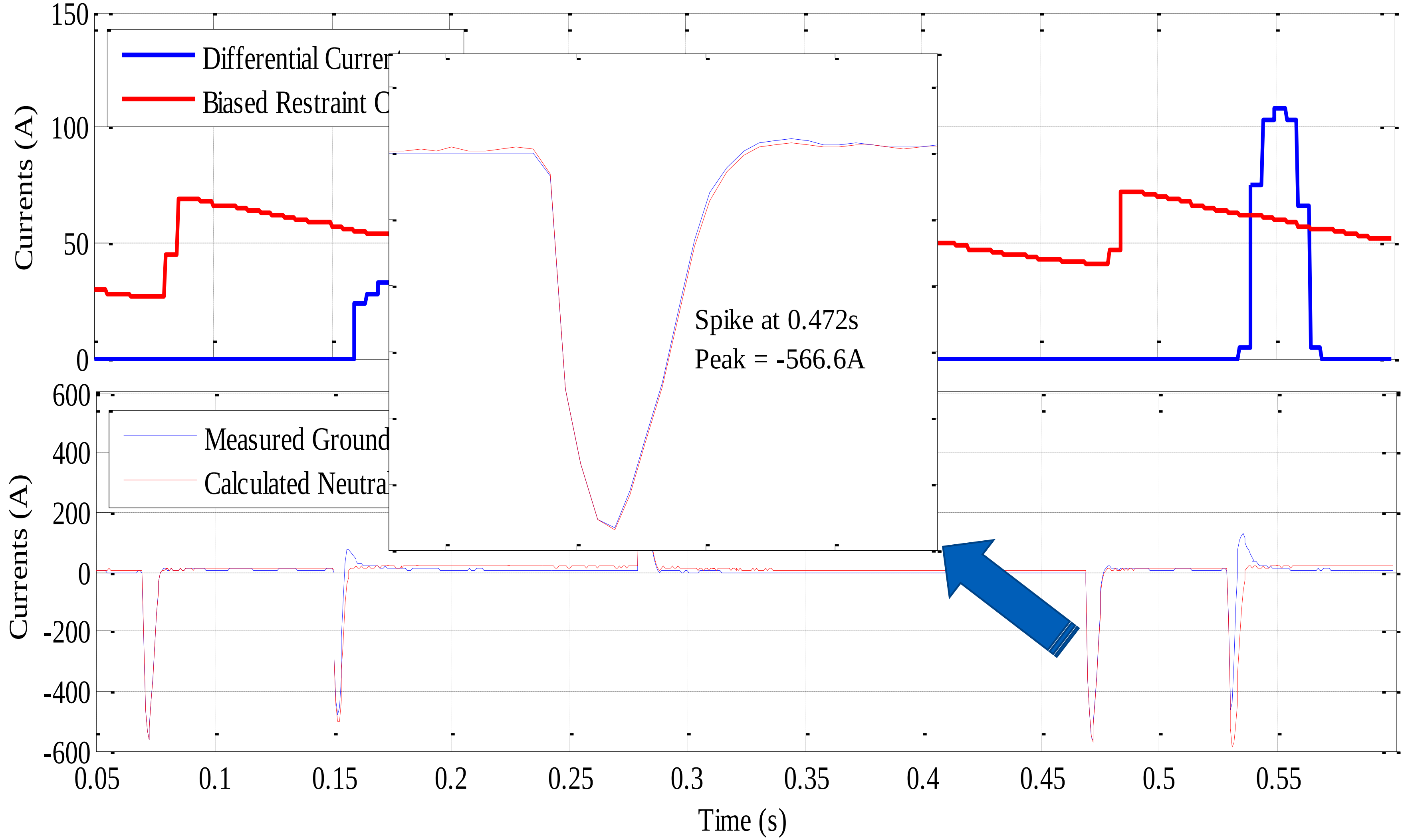
Cause of Misoperation



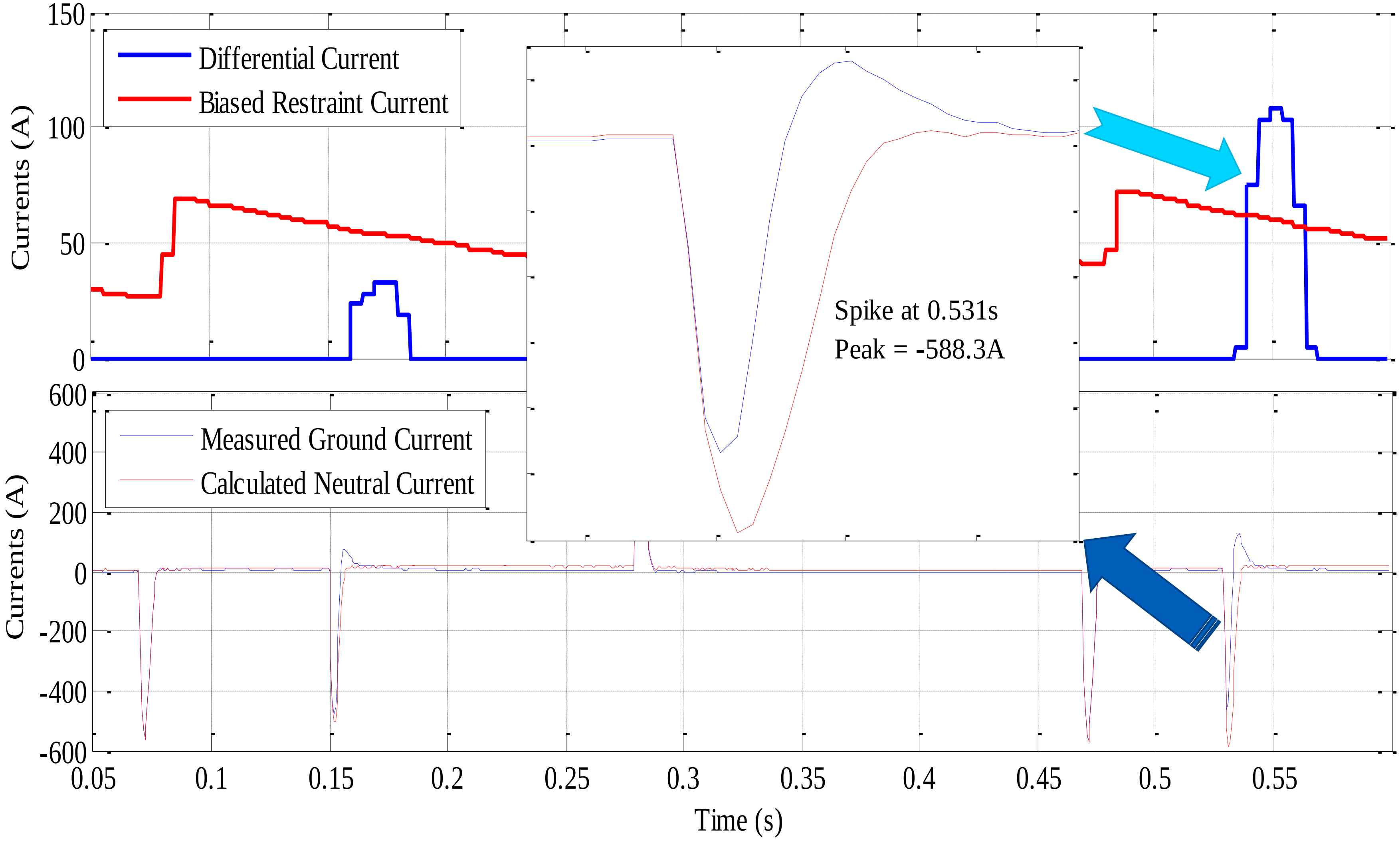
Cause of Misoperation



Cause of Misoperation



Cause of Misoperation



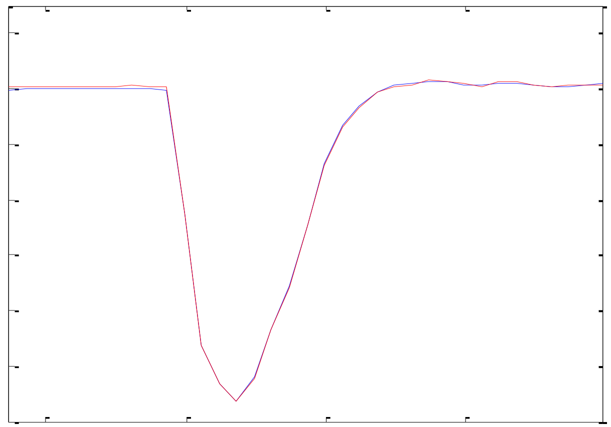
Cause of Misoperation

CT	Phase CT	Ground CT
Ratio	1200:5A	300:5A
Average current seen by CT (primary, rms, A)	450.9	221.8
Maximum current seen by CT (primary, rms, A)	475.8	238.4
Maximum secondary voltage (rms, V)	3.9 (3.9% of Vk)	6.4 (12.8% of Vk)
Maximum current seen by CT (primary, peak, A)	1006	588.3
Maximum secondary voltage (peak, V)	8.2 (8.2% of Vk)	15.8 (31.6% of Vk)

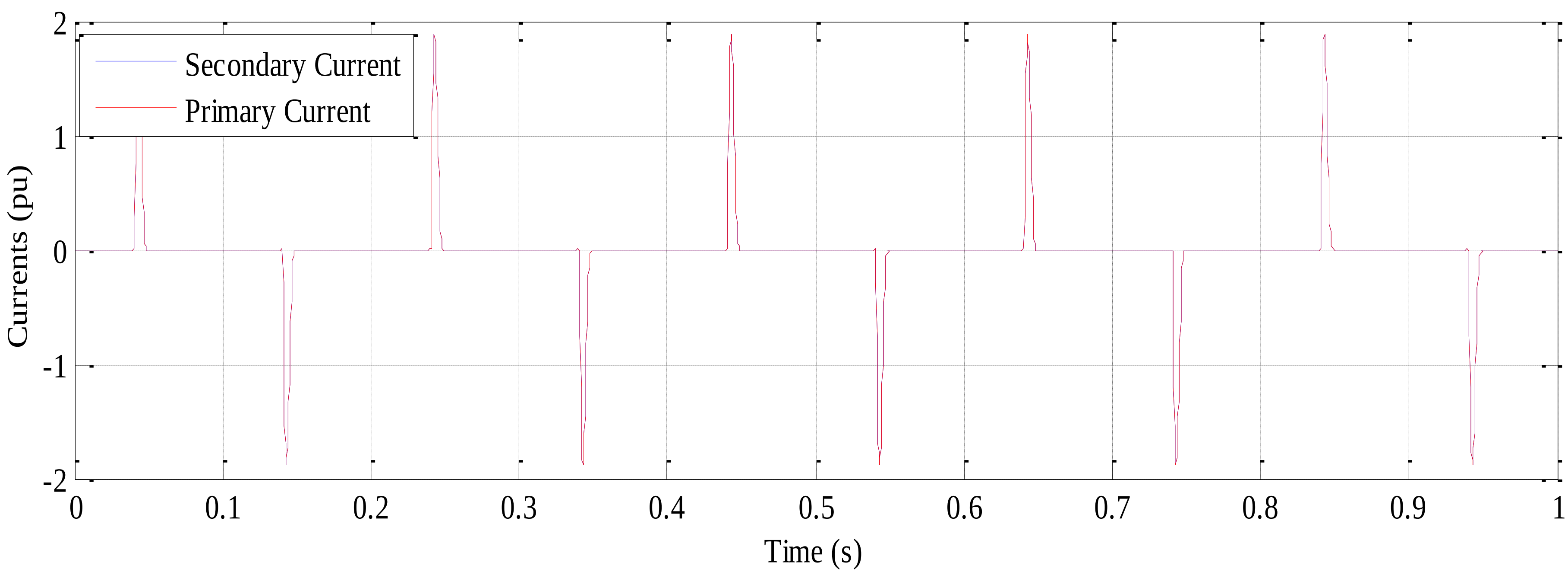
- Not caused by fault current
- No saturation at positive and every first negative spike
- Saturated at the every second negative spike
- Caused by accumulated remanence

CT Saturation Caused by Incipient Fault

- 0.44 cycle spike, repeated every 100ms

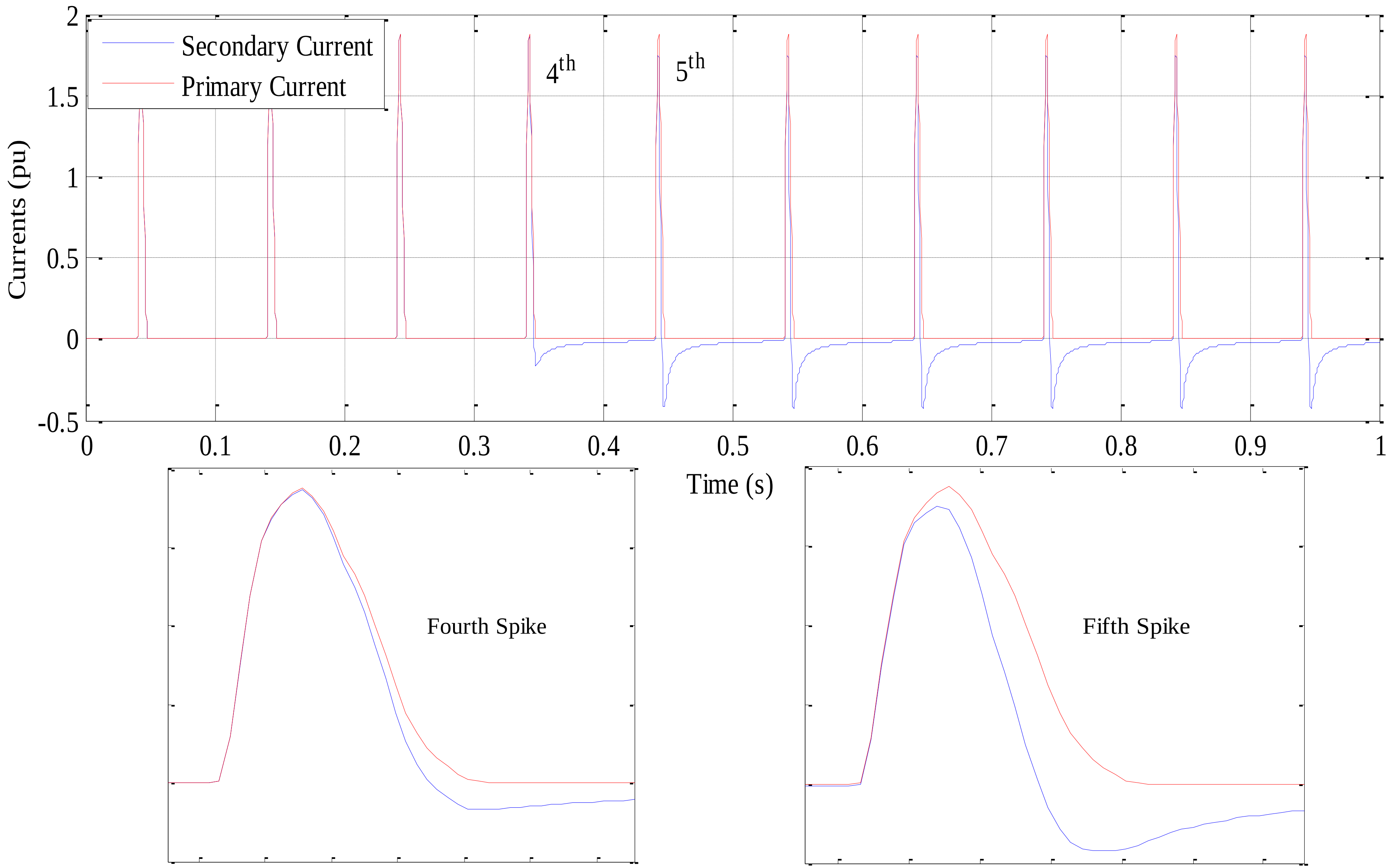


- Scenario 1



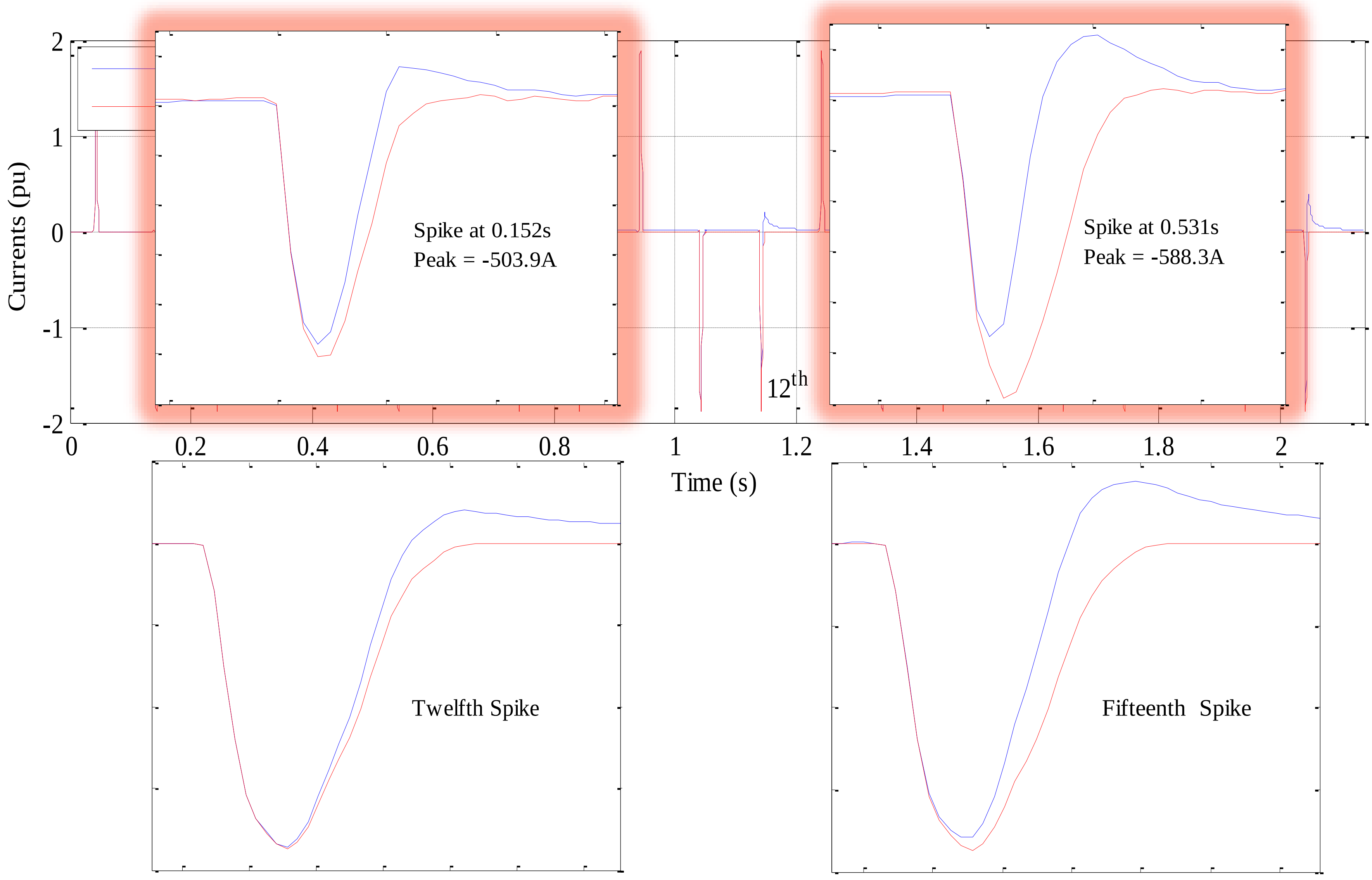
CT Saturation Caused by Incipient Fault

- Scenario 2

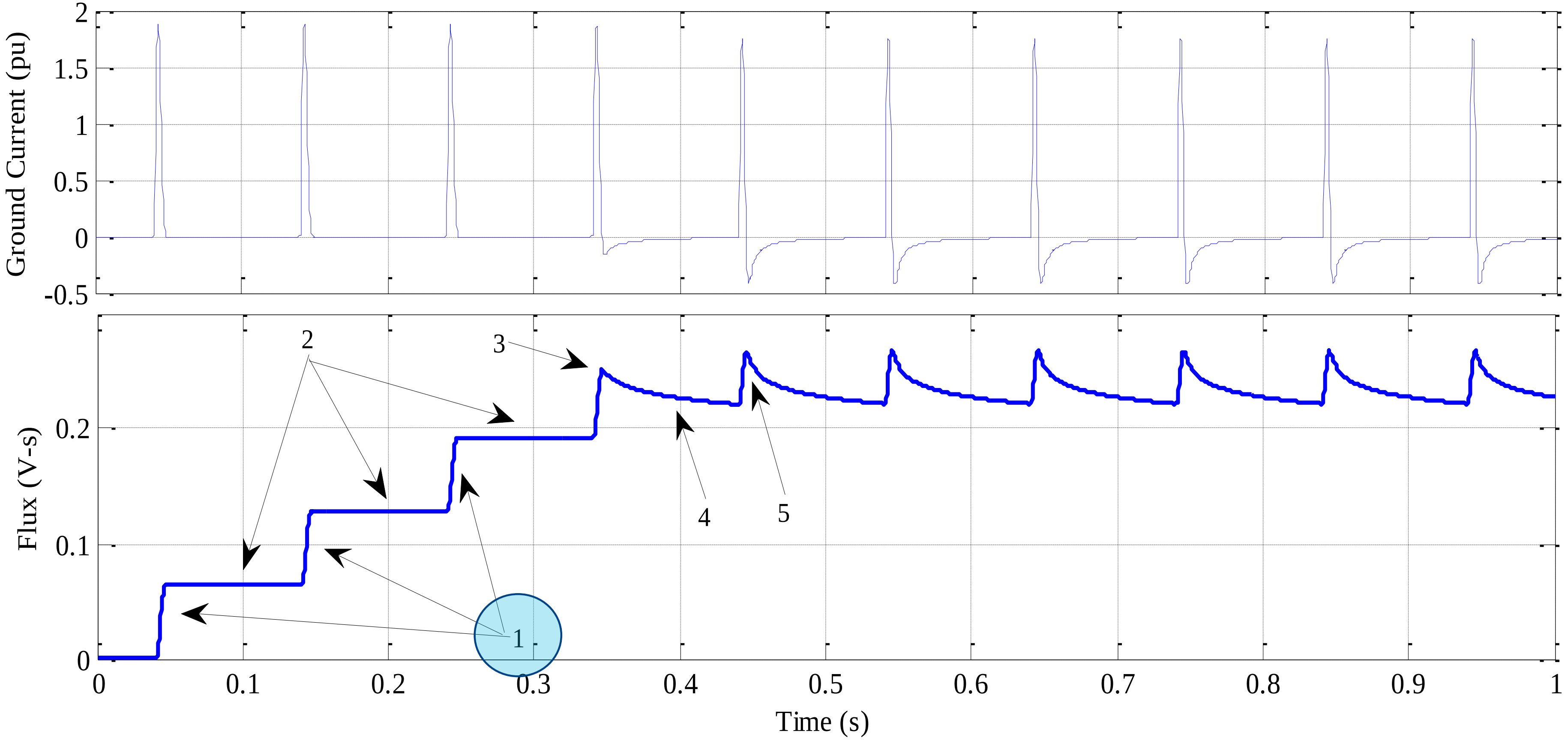


CT Saturation Caused by Incipient Fault

- Scenario 3

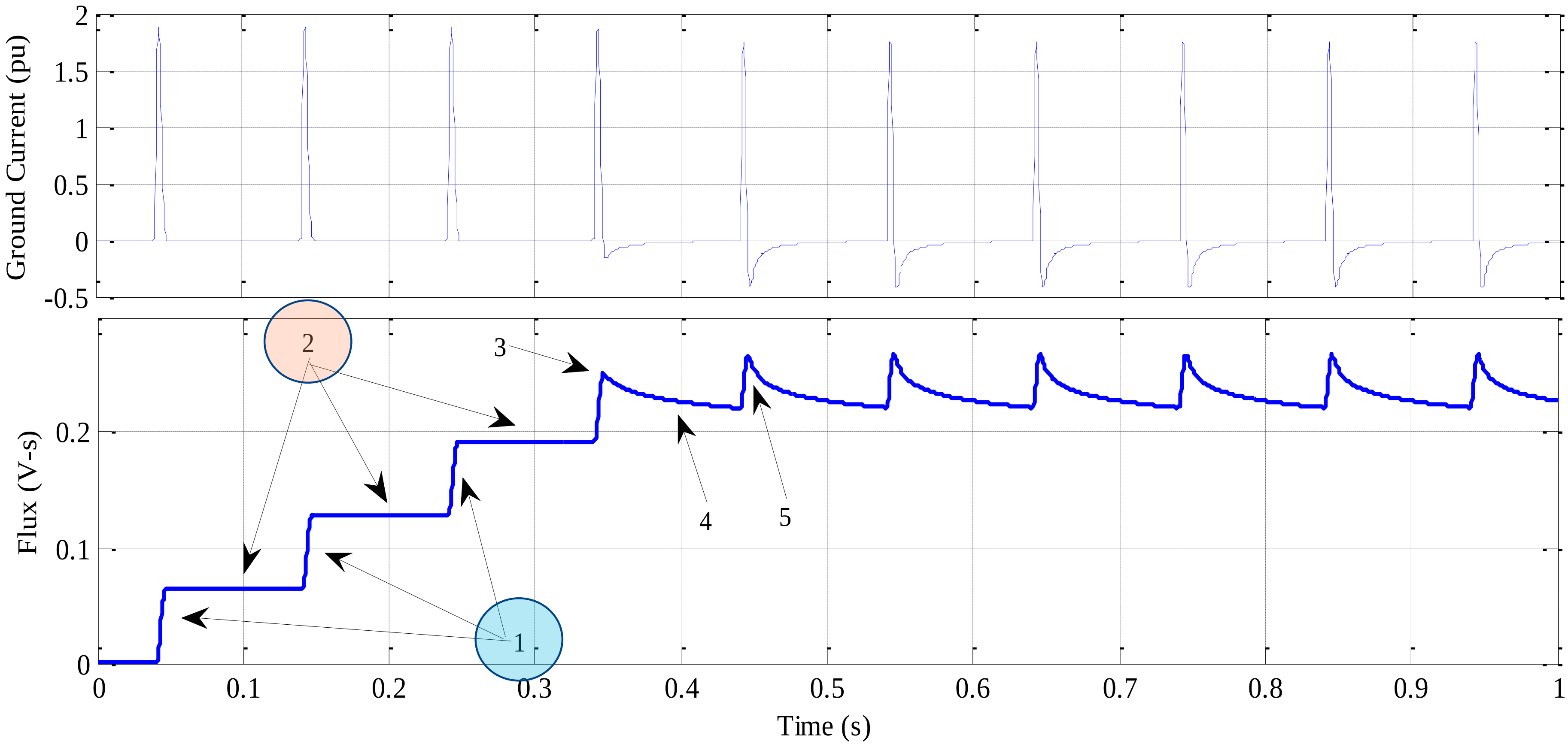


CT Saturation Caused by Incipient Fault



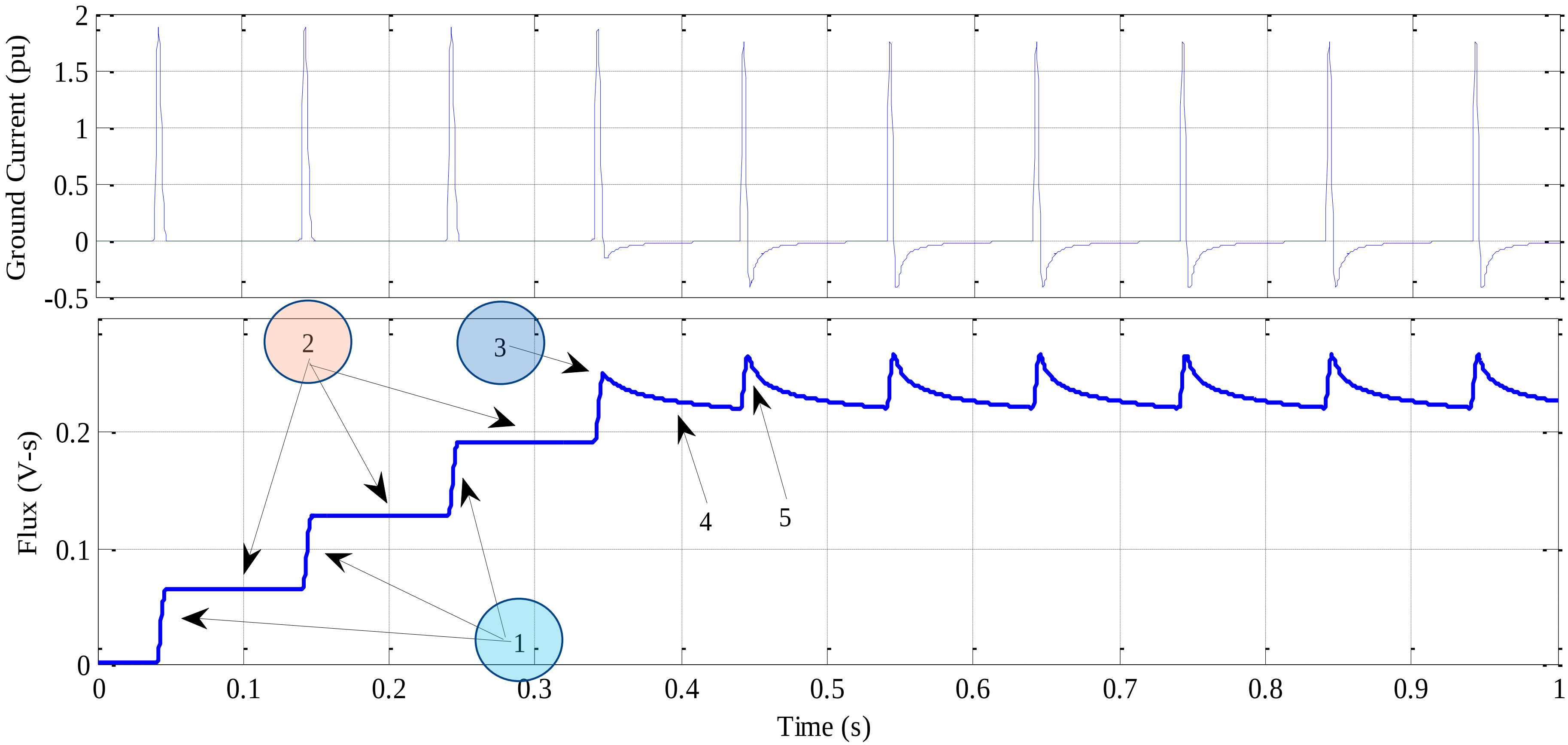
- Stage 1: Flux linkage increases when a positive pulse is injected. Each pulse would boost the flux level by 0.0645 V-s.

CT Saturation Caused by Incipient Fault



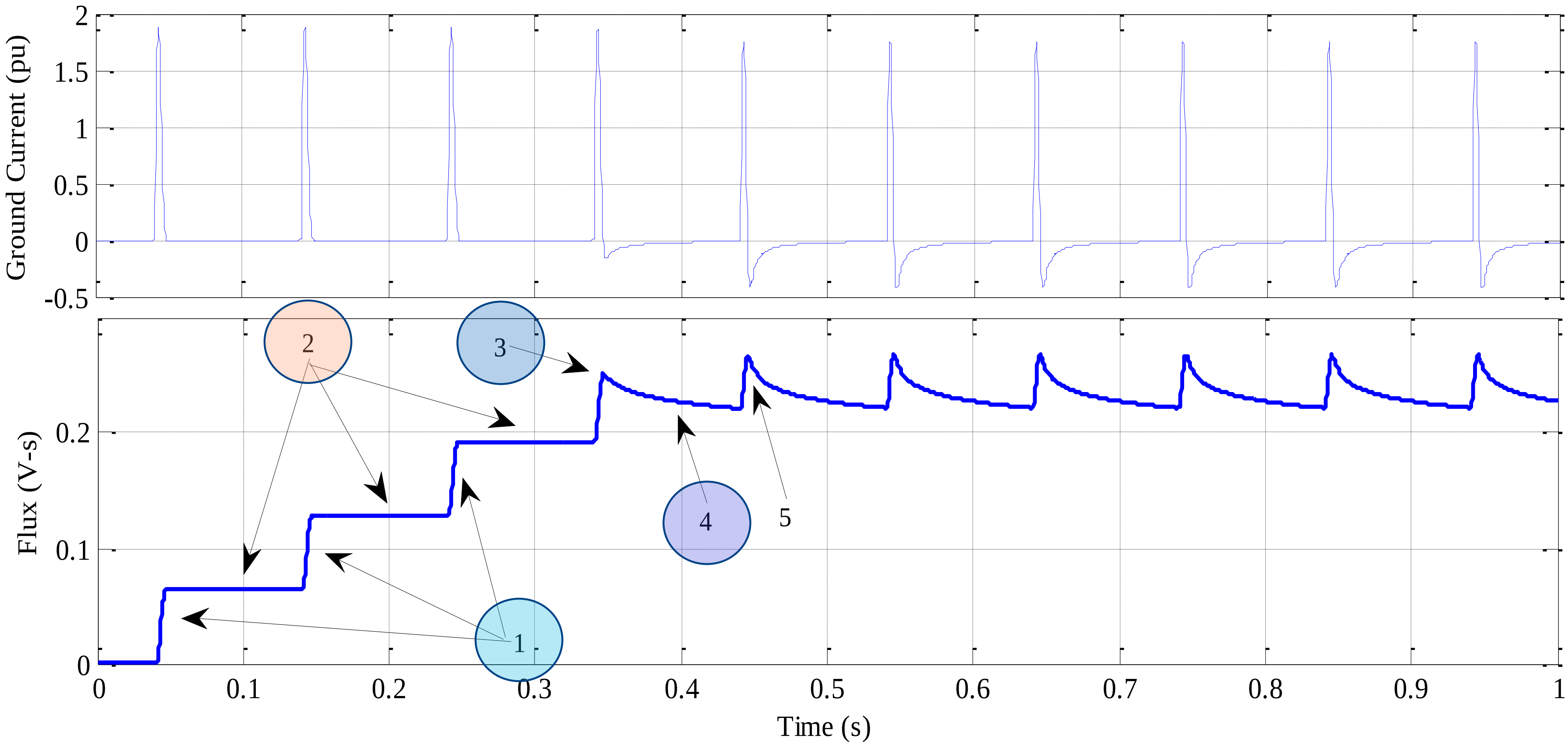
- Stage 2: when the injection disappears, the flux linkage would not decay because flux does not exceed the residual flux (around 0.156 V-s).

CT Saturation Caused by Incipient Fault



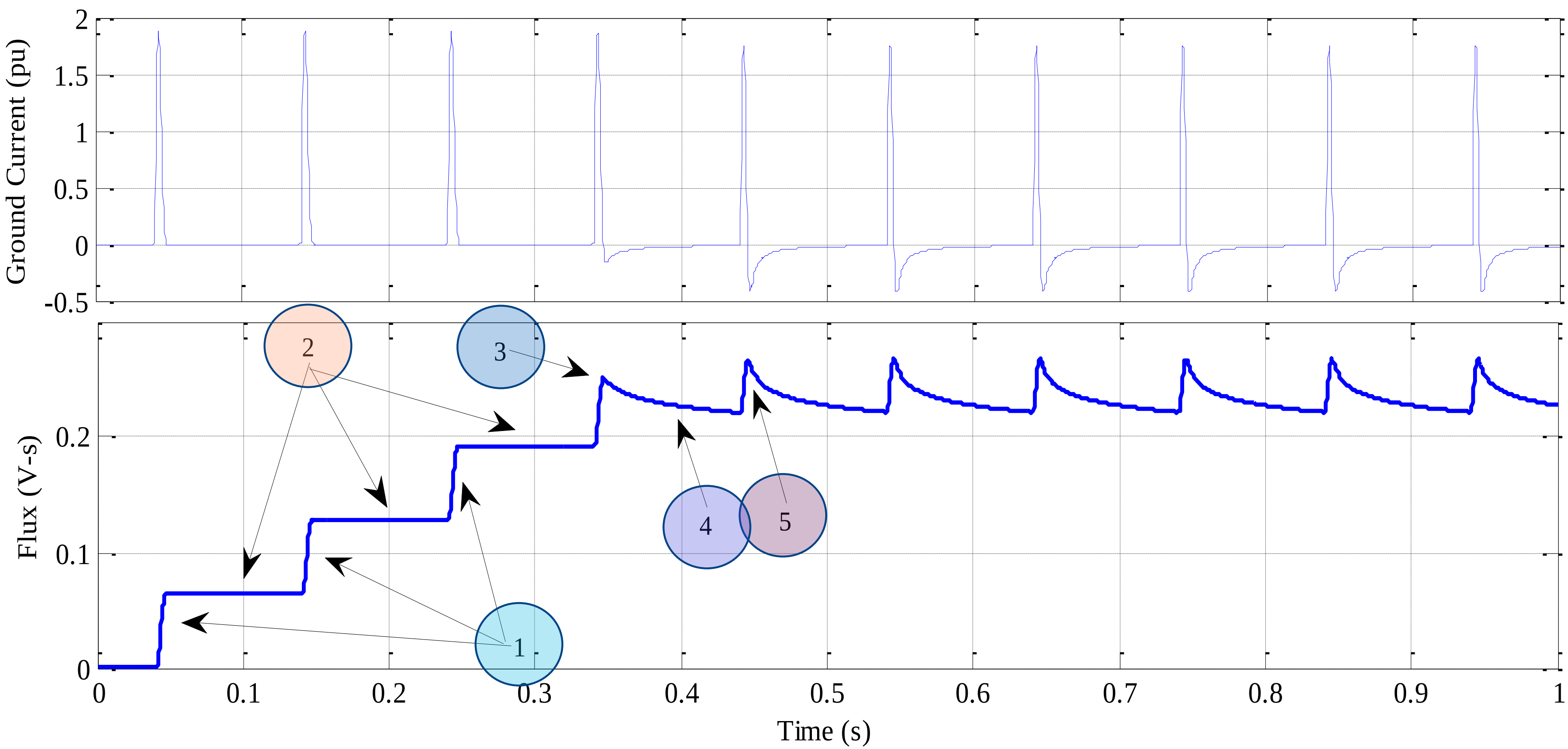
- Stage 3: Ground CT enters the saturation because the accumulated flux linkage (0.2512 V-s) exceeds the saturation flux (0.24 V-s).

CT Saturation Caused by Incipient Fault



- Stage 4: Once entering the saturation zone, the magnetic flux starts decaying to the residual flux level following primary current interruption.

CT Saturation Caused by Incipient Fault



- Stage 5: For the fifth spike and above, the stages 3 and 4 above repeat. The saturation degree becomes stable.

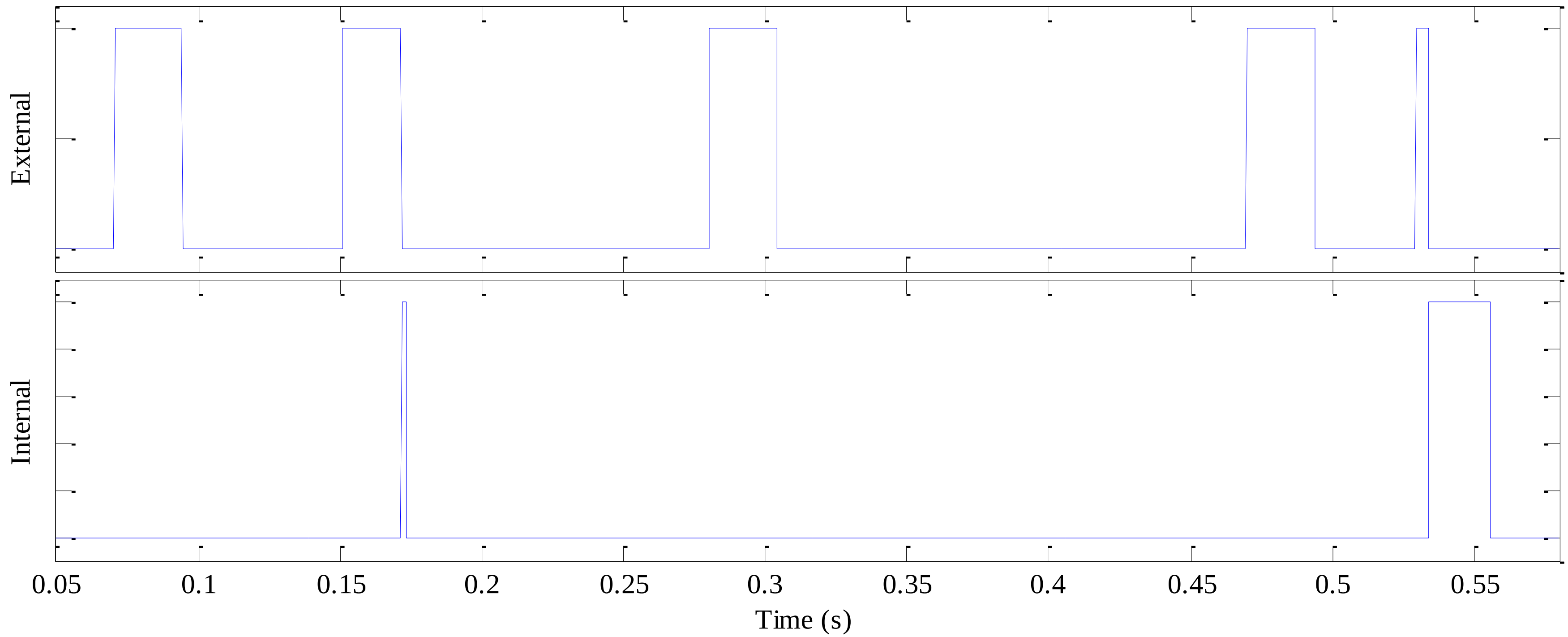
Neutral Directional OC

- Traditional 67N is analyzed
- There may have different methods and/or increase security by adding security counts or other techniques

- Polarizing V0 and operating I0
- Indicate the correct direction for all five incipient faults

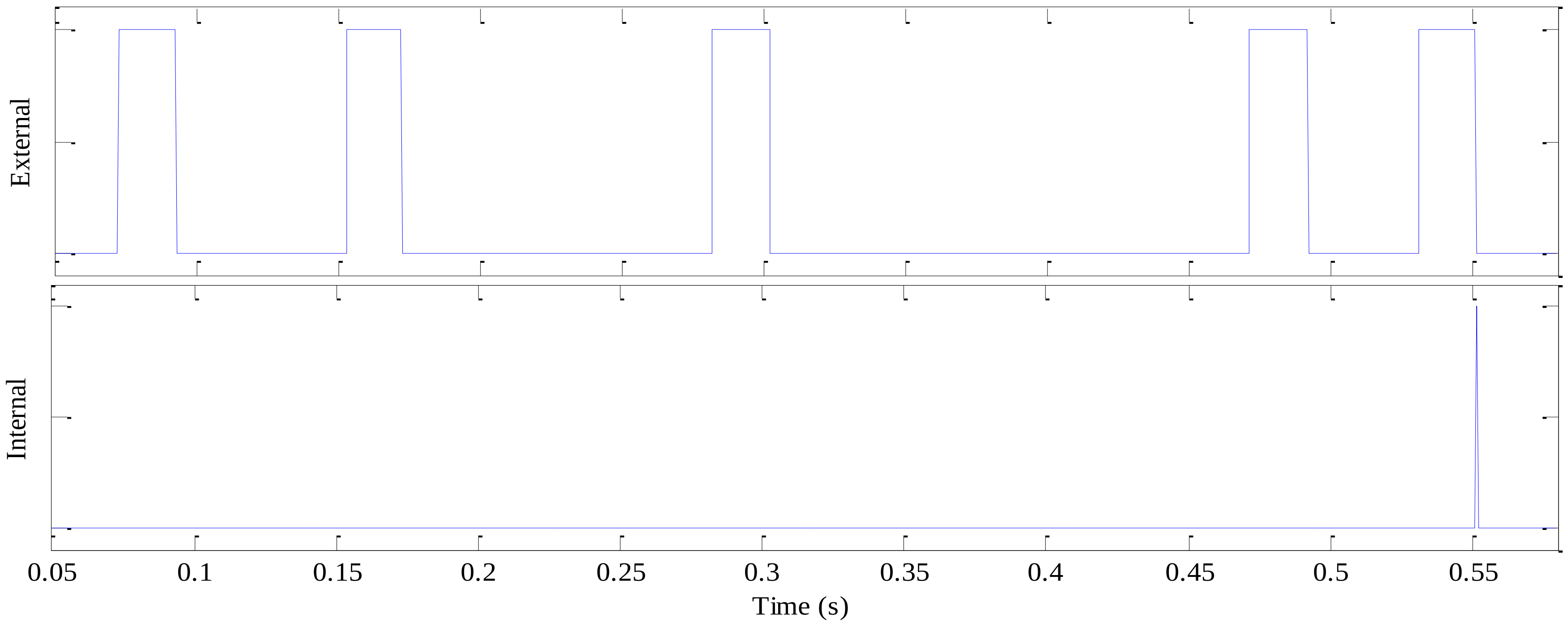
Neutral Directional OC

- Polarizing V0 and operating IG
- Give the wrong direction while ground CT enters saturation



Neutral Directional OC

- Polarizing IG and operating I0
- Give the wrong direction for a short duration while ground CT experiences heavy saturation

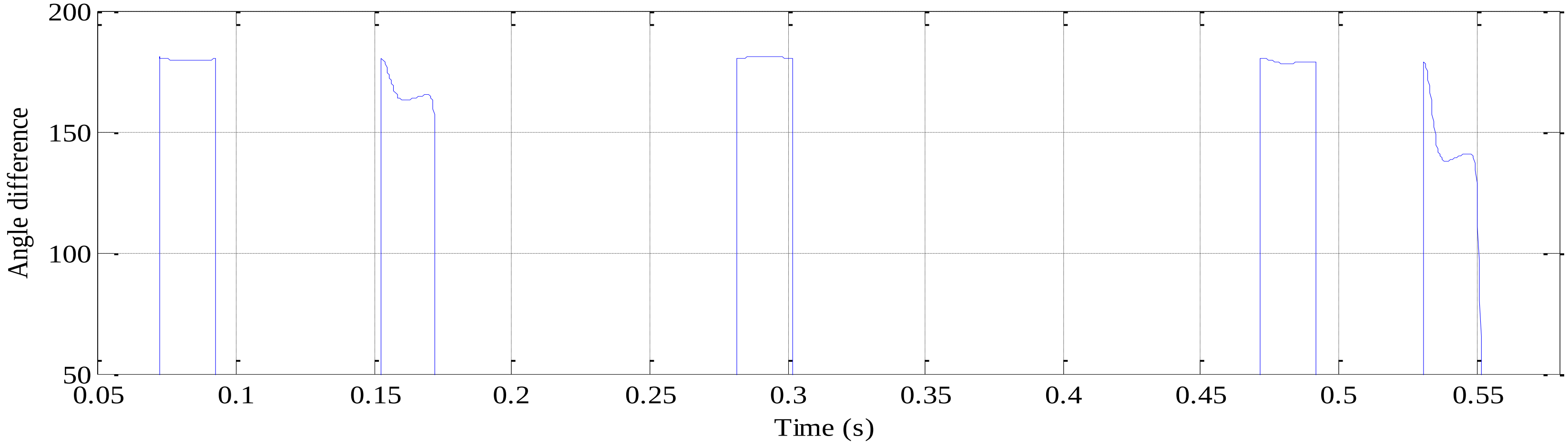


Solutions

- Neutral directional overcurrent check
  - Use the zero-sequence voltage as the polarizing signal and the zero-sequence current as the operating current
  - Avoid the combination of zero-sequence voltage and measured ground current
  - Consider VT location and LV-side breaker status.

Solutions

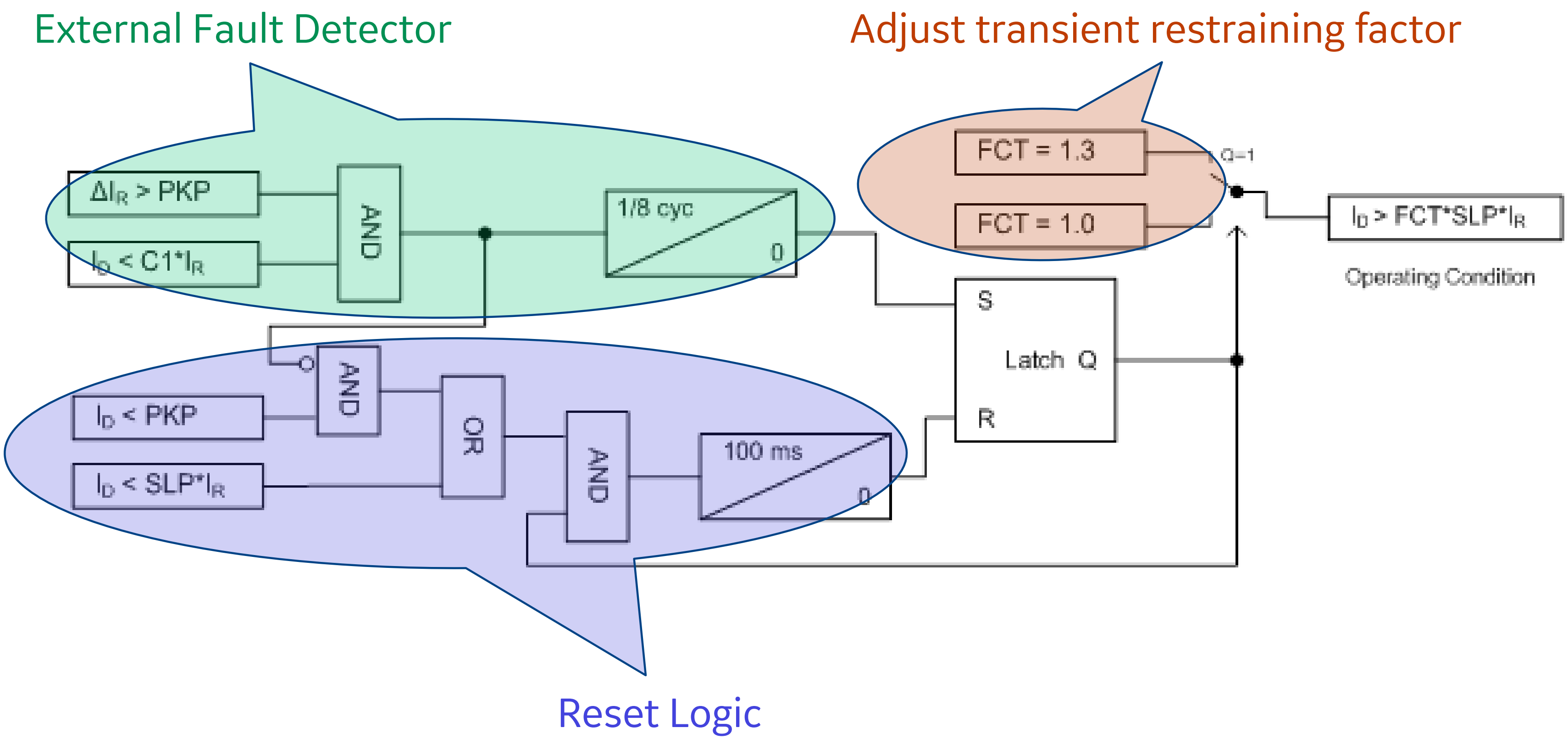
- IN and IG angle difference supervision



- Restrict the IG and IN angle difference operating region from the typical ±90 to ±60 degrees
- Add security counts
- Incorporate a transition logic: if the external direction is indicated for at least 0.75 cycle, the prospective internal indication is delayed by one cycle

Solutions

- Transient restraining factor



Conclusions

- Why RGF may misoperate due to the presence of incipient faults
- How a sequence of incipient faults may cause ground CT saturation
- What effects of incipient faults on sensitive protections
- What solutions can be applied to improve the security of the RGF scheme

Thank You

Questions?