# ELECTROMECHANICAL DIFFERENTIAL RELAYS MISOPERATION AND INVESTIGATION PART 2

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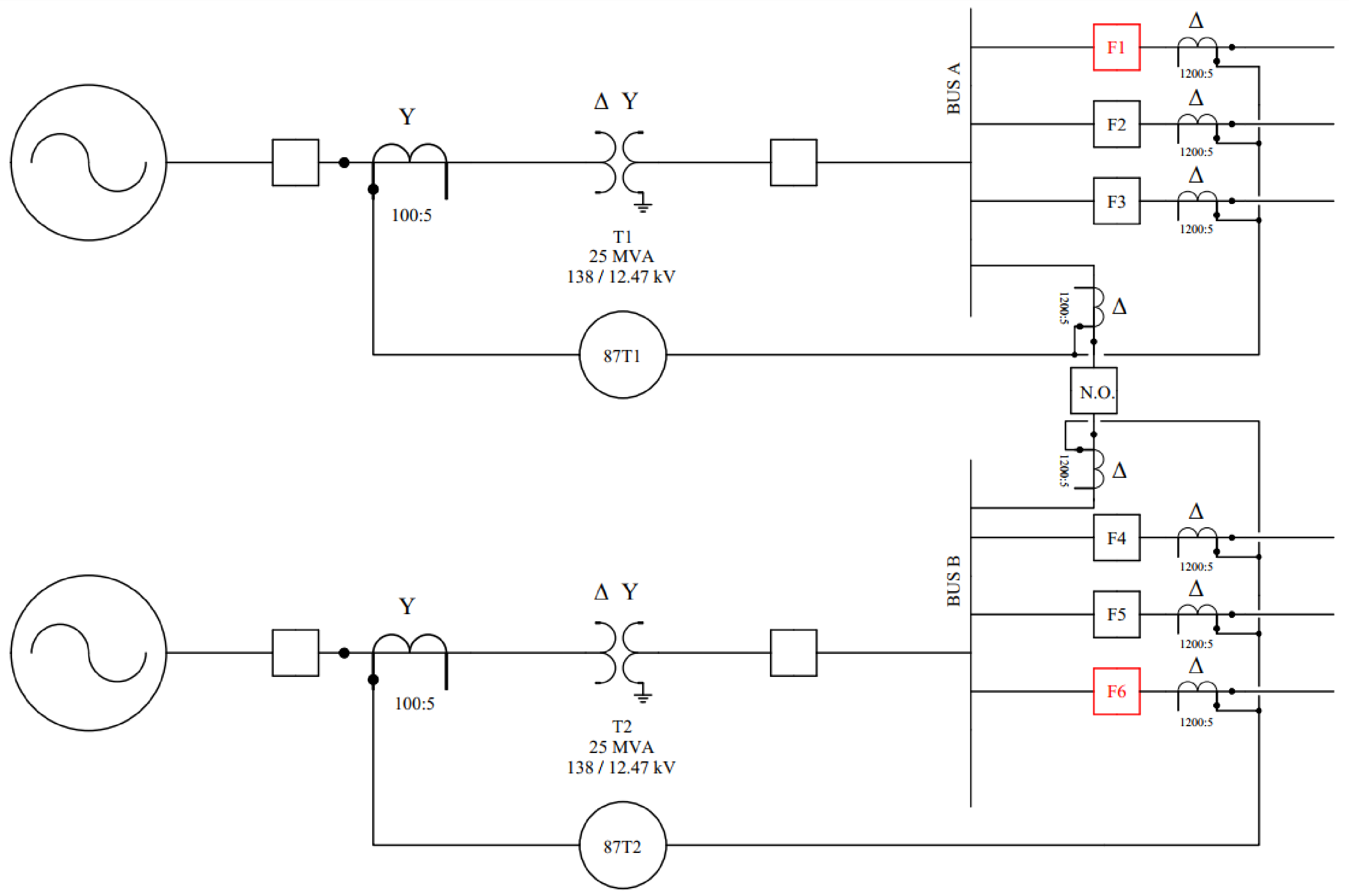
# OBJECTIVES

- Introduction
- Power system diagram
- 87T1 Relay trip
- Investigation and troubleshooting
- 87T1 Mode of operation
    - Scenario 1
    - Scenario 2
    - Scenario 3
    - Scenario 4
- Safety
- Conclusion

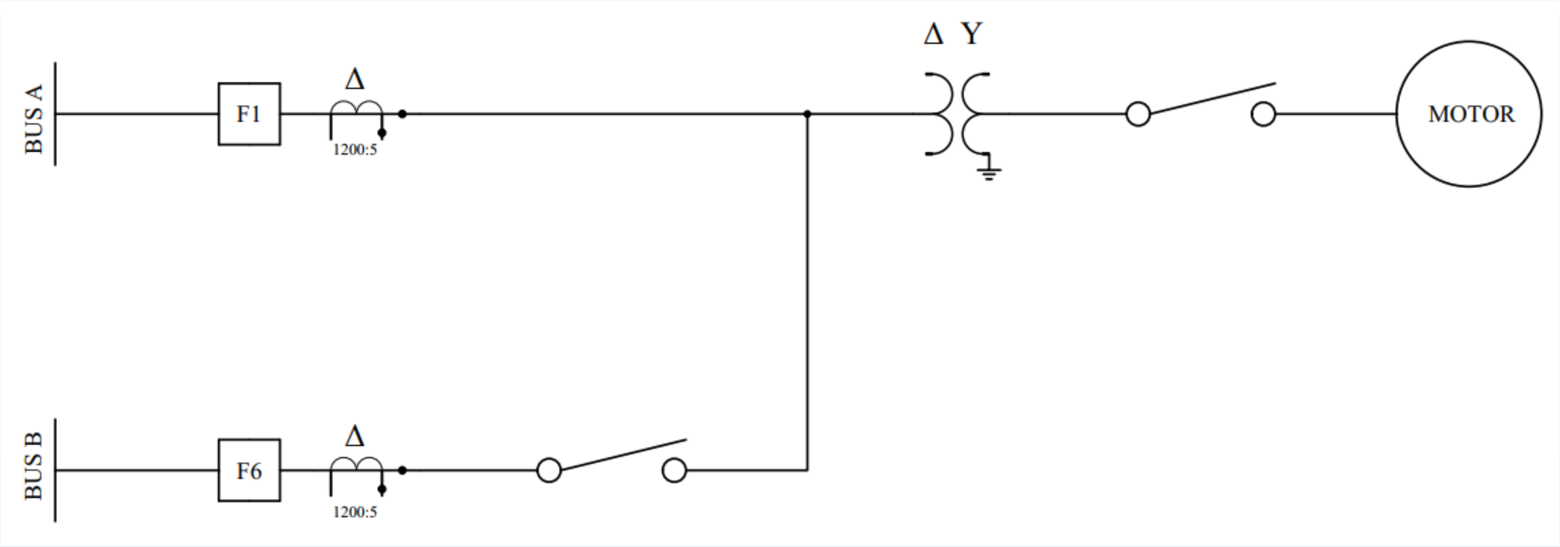
# INTRODUCTION

- Transformer differential protection (87T) is very common on large transformers (KCL method)
- Electromechanical (EM) relays installed 100+ years ago. Many are still in service
- EM relays get replaced by digital relays:
  - Combination of functions into a single relay (27, 59, 50, 51, 87 etc.)
  - Less physical circuits needed
  - Easier troubleshooting, faster restoration times
- Partial site blackout due to improper circuit demolition

# POWER SYSTEM DIAGRAM

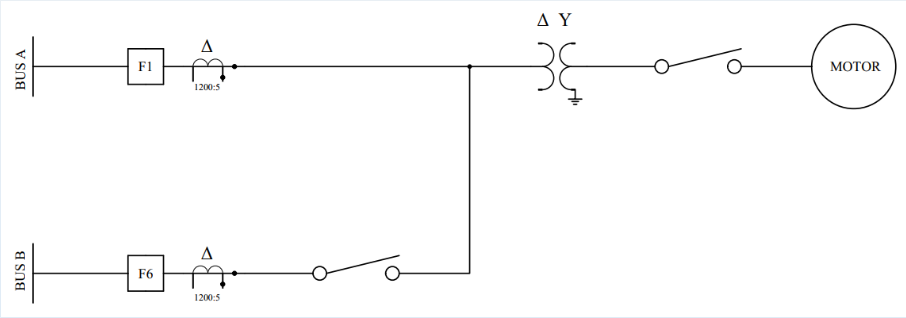


# POWER SYSTEM DIAGRAM



# 87T1 TRIP

- On January 13, 2022, the site experienced a partial blackout.
- Sequence of events
  - The motor was running, it was stopped as part of the process
  - Motor start attempt. 87T1 trip and bus A got de-energized
  - Switching to bus B performed. Motor start attempt and the motor remained energized.



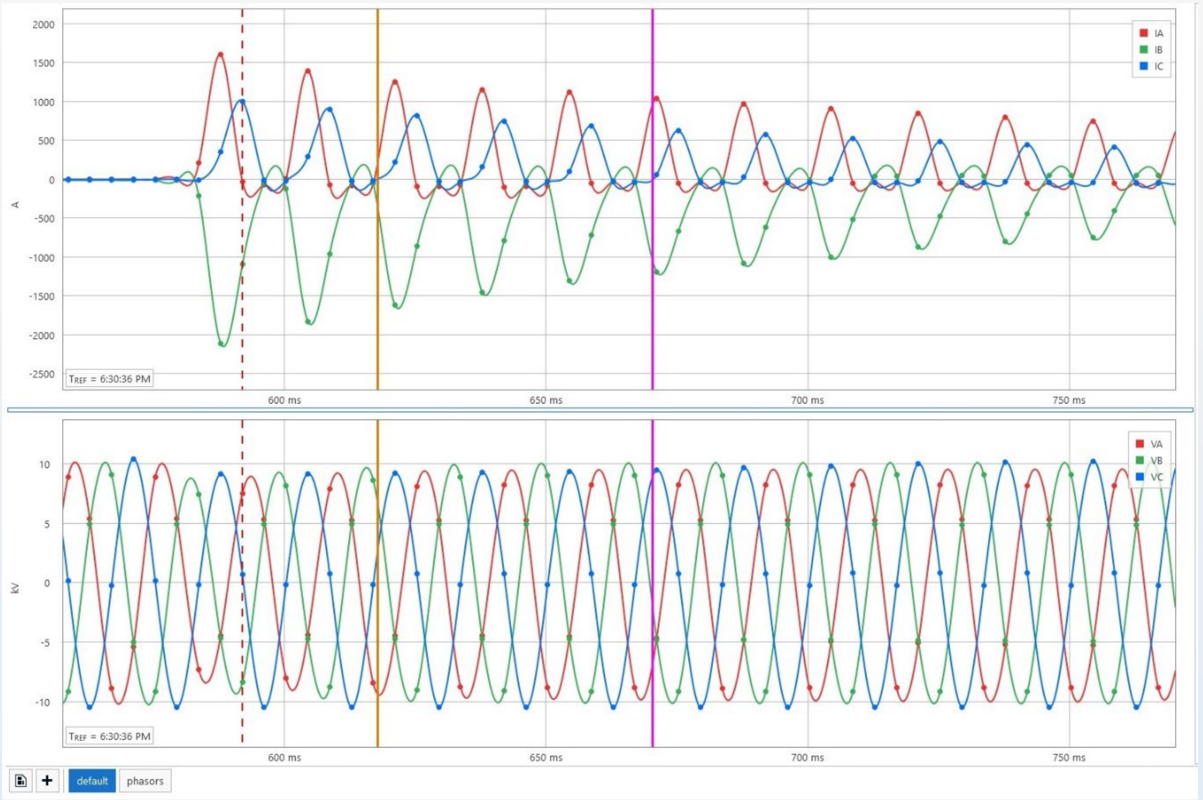
# INVESTIGATION AND TROUBLESHOOTING

- Electromechanical relays do not produce event data

- Transformer 1 had been working
- properly (no fault suspected)

- Feeders 1 and 6 had been
- upgraded – digital relays

- Inrush report from feeder 6



# INVESTIGATION AND TROUBLESHOOTING

- Substation house originally shared with utility
- Utility had recently upgraded their transmission protection and moved it to their own house
- Utility technician “cleaning up” wires at industrial house

# INVESTIGATION AND TROUBLESHOOTING

- Industrial process required the motor to be de-energized during the afternoon
- Start attempt on Bus A at 5:22 pm. 87T1 trip
- Start attempt on Bus B at 6:57 pm. Motor remains in service
- Problem introduced while the motor was energized and running on Bus A

# INVESTIGATION AND TROUBLESHOOTING

- Visual inspection at the substation house

- 4-wire bundle had been cut
  and left behind. Colors: red, black, green, white

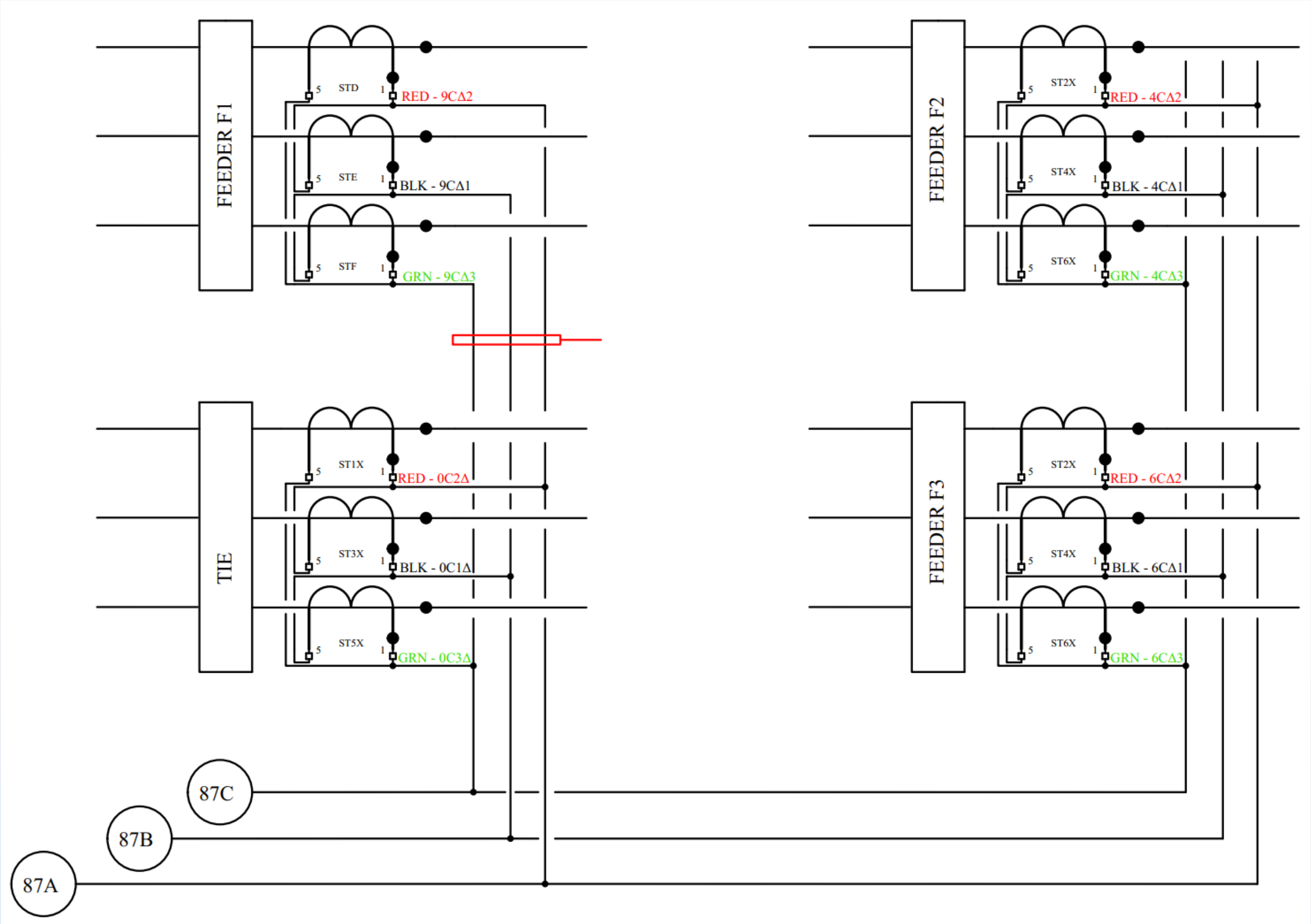
- Cable belongs to terminal
  points 9C1Δ, 9C2Δ, and 9C3Δ

# INVESTIGATION AND TROUBLESHOOTING

- Site personnel questions:
  - What circuit did the 9Δ bundle belong to?
  - Why did the removal of the 9Δ bundle cause a misoperation only ***after*** the motor was energized and de-energized?

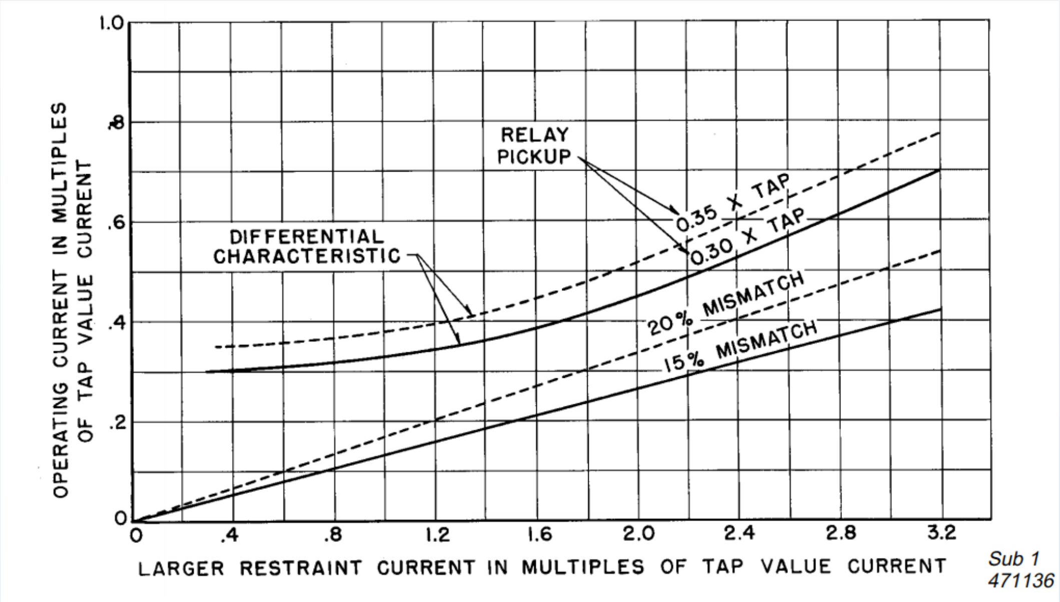
# INVESTIGATION AND TROUBLESHOOTING

- Schematics review
- Colors matched CT circuits code
- Bundle belongs to feeder F1 contribution to 87T1



# 87T1 MODE OF OPERATION

- Per the instruction manual:
  - "The operating current required to close the contact of the differential unit expressed in percent of restraint current varies with the magnitude of the larger restraint current. To use these curves, divide each restraint current by the appropriate tap and enter the horizontal axis using the larger or largest restraint multiple. Then enter the vertical axis, using the difference of the restraint multiples."



# 87T1 MODE OF OPERATION

- Settings:

| SETTING | VALUE |
| --- | --- |
| CT_W1 | 20 |
| CT_W2 | 240 |
| Pickup | 0.3 |
| TAP_1 | 3.2 |
| TAP_2 | 5 |

# 87T1 MODE OF OPERATION

- Four scenarios considered for this analysis:

  - 1. Motor gets energized, all wires connected properly
  - 2. The motor is running, all wires connected properly
  - 3. The motor is running, the 9Δ wires were removed from the system
  - 4. The motor is stopped and gets re-energized with the 9Δ wires lifted

- Inrush current = ~400 A (12.47 kV side), ~36 A (138 kV side)
- Full Load Amps = ~30 A (12.47 kV side), ~2.71 A (138 kV side)

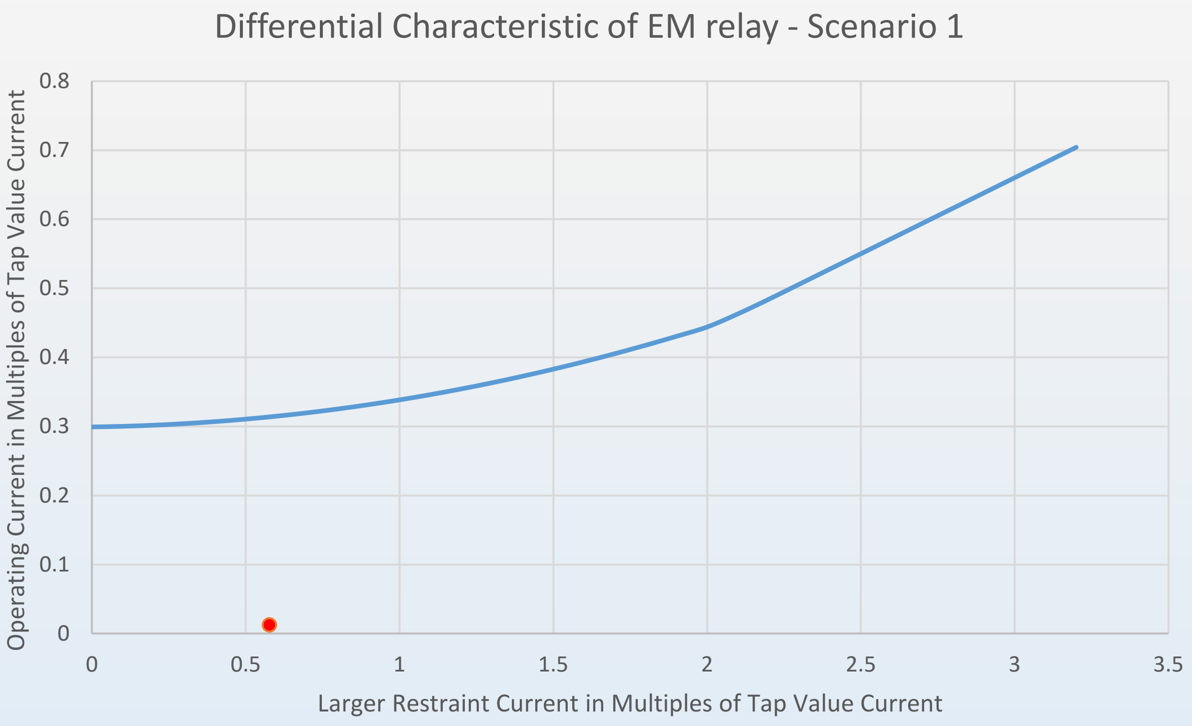
# 87T1 MODE OF OPERATION

- Scenario 1. Motor gets energized, all wires connected properly

| | |
|---|---|
| $I_{RT_1(pu)} = \frac{I_{138kV}}{CT_{W1} * TAP_1} = \frac{36.1}{20 * 3.2} = 0.564\ pu$ | (Equation 1.1) |
| $I_{RT_2(pu)} = \frac{I_{12.47kV} * sqrt(3)}{CT_{W2} * TAP_2} = \frac{400 * 1.732}{240 * 5} = 0.577\ pu$ | (Equation 1.2) |
| $I_{OP(pu)} = \left\| I_{RT_{1(PU)}} - I_{RT_{2(pu)}} \right\| = \|0.564 - 0.577\| = 0.013\ pu$ | (Equation 1.3) |

# 87T1 MODE OF OPERATION

- Scenario 1. Motor gets energized, all wires connected properly



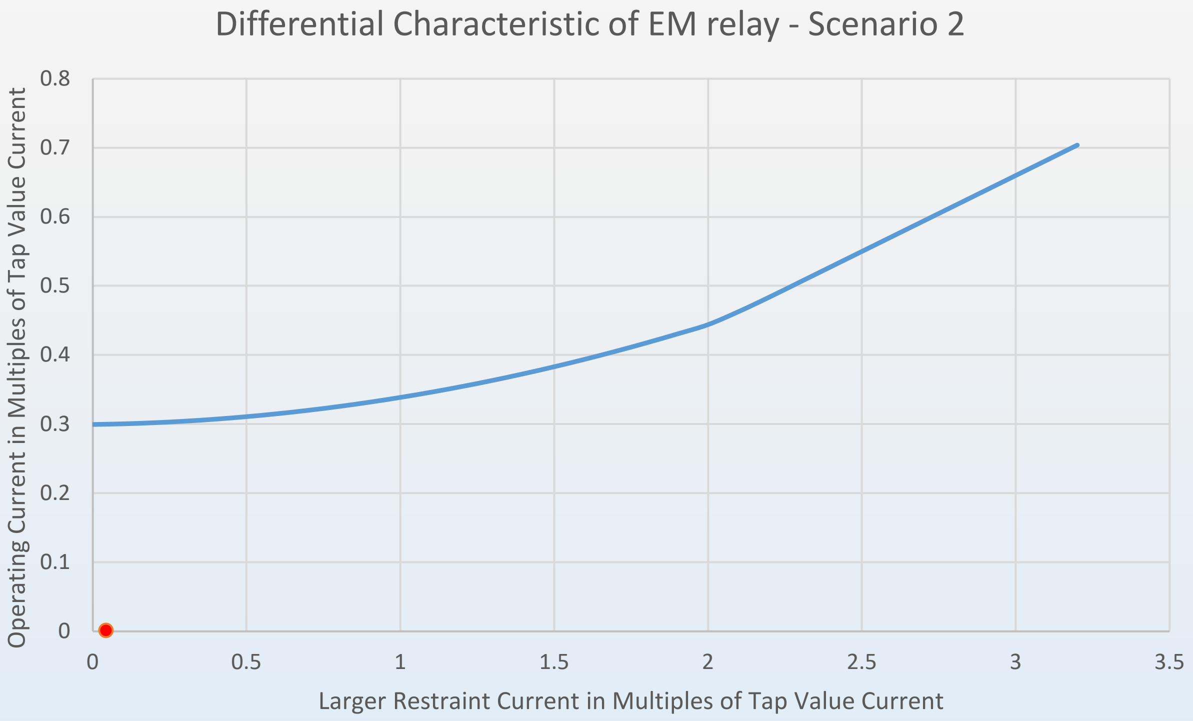
# 87T1 MODE OF OPERATION

- Scenario 2. The motor is running, all wires connected properly

| | |
|---|---|
| $I_{RT_1(pu)} = \frac{I_{138kV}}{CT_{W1} * TAP_1} = \frac{2.71}{20 * 3.2} = 0.042\ pu$ | (Equation 2.1) |
| $I_{RT_2(pu)} = \frac{I_{12.47kV} * sqrt(3)}{CT_{W2} * TAP_2} = \frac{30 * 1.732}{240 * 5} = 0.043\ pu$ | (Equation 2.2) |
| $I_{OP(pu)} = \left\| I_{RT_{1(PU)}} - I_{RT_{2(pu)}} \right\| = \|0.042 - 0.043\| = 0.001\ pu$ | (Equation 2.3) |

# 87T1 MODE OF OPERATION

- Scenario 2. The motor is running, all wires connected properly



# 87T1 MODE OF OPERATION

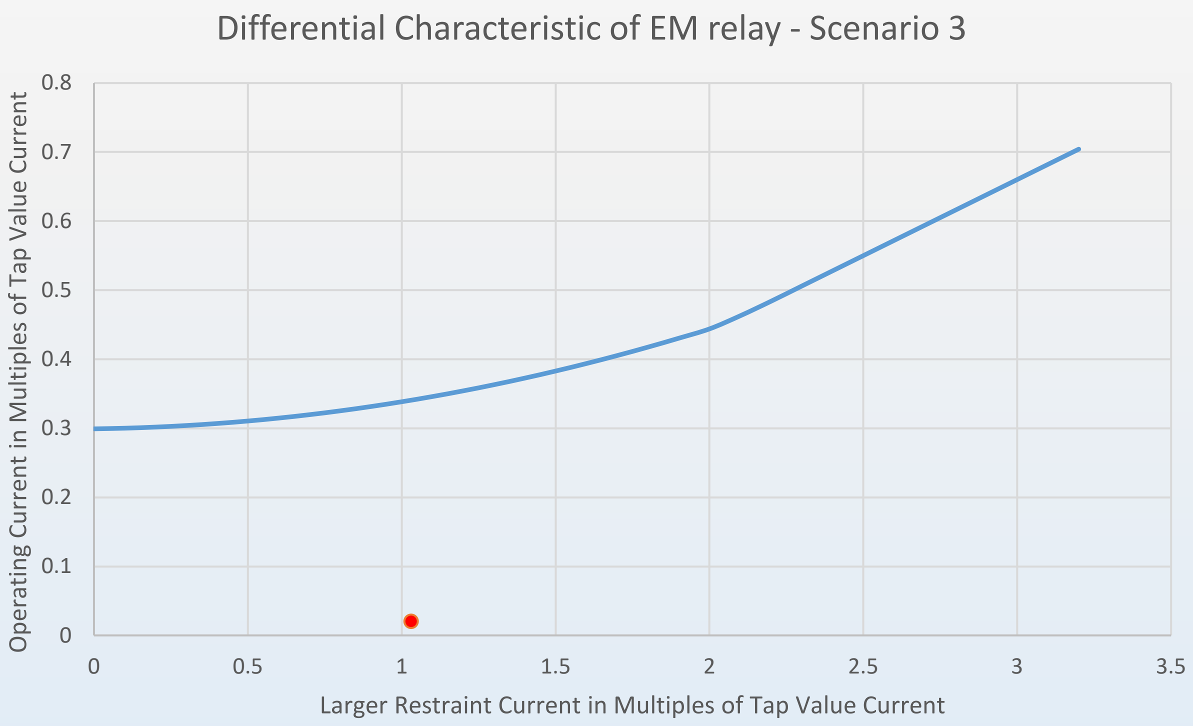
- Scenario 3. The motor is running, the 9Δ wires were removed from the system

| | |
|---|---|
| $I_{RT_1(pu)} = \frac{I_{138kV}}{CT_{W1} * TAP_1} = \frac{65.96}{20 * 3.2} = 1.03\ pu$ | (Equation 3.1) |
| $I_{RT_2(pu)} = \frac{I_{12.47kV} * sqrt(3)}{CT_{W2} * TAP_2} = \frac{700 * 1.732}{240 * 5} = 1.01\ pu$ | (Equation 3.2) |
| $I_{OP(pu)} = \left\| I_{RT_{1(PU)}} - I_{RT_{2(pu)}} \right\| = \|1.03 - 1.01\| = 0.02\ pu$ | (Equation 3.3) |

- Note: Prior to removal of wires, Bus A was carrying ~730 A. After the removal, the relay lost the 30 A motor contribution.

# 87T1 MODE OF OPERATION

- Scenario 3. The motor is running, the 9Δ wires were removed from the system



# 87T1 MODE OF OPERATION

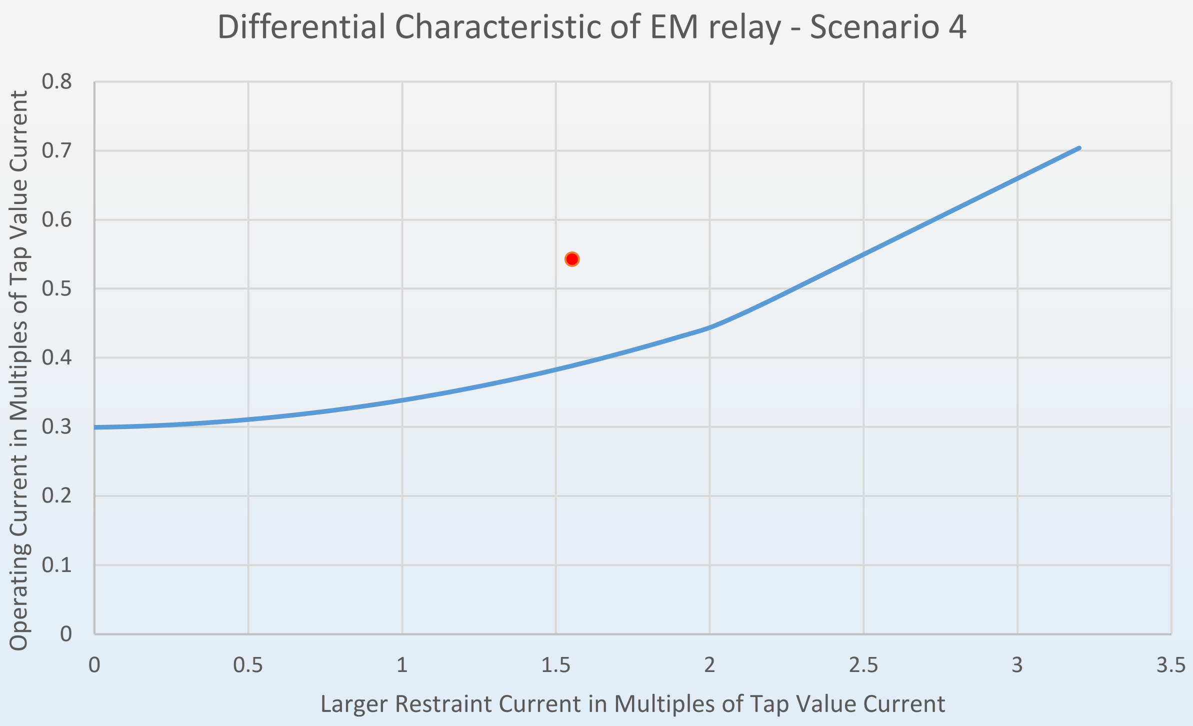
- Scenario 4. The motor is stopped and gets re-energized with the 9Δ wires lifted

| | |
|---|---|
| $I_{RT_1(pu)} = \frac{I_{138kV}}{CT_{W1} * TAP_1} = \frac{99.39}{20 * 3.2} = 1.55\ pu$ | (Equation 4.1) |
| $I_{RT_2(pu)} = \frac{I_{12.47kV} * sqrt(3)}{CT_{W2} * TAP_2} = \frac{700 * 1.732}{240 * 5} = 1.01\ pu$ | (Equation 4.2) |
| $I_{OP(pu)} = \left\| I_{RT_{1(PU)}} - I_{RT_{2(pu)}} \right\| = \|1.55 - 1.01\| = 0.54\ pu$ | (Equation 4.3) |

- Note: Primary side contribution is 1,100 A on the 12.47 kV side (400 A + 700 A) reflected to 138 kV.

# 87T1 MODE OF OPERATION

- Scenario 4. The motor is stopped and gets re-energized with the 9Δ wires lifted



# SAFETY

- Energizing an open CT (on the secondary) is a critical safety concern
- Extreme saturation and high excitation voltage
- Possible damage to CTs, relays, wiring insulation, severe injury (loss of limb/death).
- In this case, the feeder F1 CTs were damaged and eventually replaced. No injury to utility personnel.

# SAFETY

- Current verification through amp clamp meter.

# CONCLUSION

- Electrical equipment replacement requires full knowledge of the electrical circuits.
- Request schematics (one-line, 3-line, controls) prior to site visit
- Removing incorrect wires can lead to a nuisance trip (economic cost, environmental impact), as well as severe injury to electric workers.

# QUESTIONS?