PROTECTION CONSIDERATIONS FOR AN IMPROPERLY INSTALLED ON-LOAD TAP CHANGER

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OBJECTIVES

• Introduction
• On-Load Tap Changer (OLTC) theory
• Power system description
• OLTC installation issues
• Relay event data collection and analysis
• Relay settings recommendations
• OLTC installation testing procedure
• Aftermath
• Conclusion
INTRODUCTION

• Power transformers are widely used: Interconnect solar farms to utility grid
• Tap changers used to control voltage variation due to grid voltage fluctuation
• On-Load Tap Changers (OLTCs) are used to match grid’s voltage automatically
OLTC THEORY

• Add or remove turns to the windings on either side of the transformer

• A No-Load Tap Changer (NLTC) requires the system to be de-energized

• An OLTC allows a tap change while the system is energized using a “make-before-break” concept using resistors/reactors, bypass switches, selector switches, and a vacuum interrupter (VI).
OLTC THEORY – SYSTEM OF INTEREST

- 32-step, 26.4 kV rated
- *Simplified* schematic shown
- OLTC components:
  - P1 & P4: Selector (mobile) switches
  - P2 & P3: Bypass switches
  - Vacuum Interrupter: Breaks current
  - Reversing switch: Doubles the number of taps (irrelevant to this presentation).
Initially, current flows in parallel from the bypass switches to the selector switches (P2 – P1 and P3 – P4).
OLTC THEORY – MODE OF OPERATION

- Bypass switch P3 opens and that forces current to flow through the vacuum interrupter.
• The vacuum interrupter opens and breakers the current.

• Note: Because the break operation happens in the vacuum interrupter, the oil is not affected by the arc produced during the operation.
OLTC THEORY – MODE OF OPERATION

• Selector switch P4 advances to the next tap
The vacuum interrupter recloses to allow current flow.

OLTC THEORY – MODE OF OPERATION
• The bypass switch P3 closes and that completes the tap operation
OLTC INSTALLATION ISSUES

- Prior OLTC to be replaced due to leaks
- New OLTC was installed and the transformer was energized
- Solar inverters began to “trip offline randomly”
- Same behavior observed for a few days
OLTC INSTALLATION ISSUES

- Due to concern, oil samples were obtained...
- Comments from the sample company: “LTC Emergency Condition. Immediate remedial action needed”.

<table>
<thead>
<tr>
<th>Sample Date</th>
<th>06/07/2019</th>
<th>04/29/2019</th>
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<tbody>
<tr>
<td>Top Oil Temp °C</td>
<td></td>
<td>22</td>
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<tr>
<td>Hydrogen (H2)</td>
<td>9000</td>
<td>0</td>
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<tr>
<td>Oxygen (O2)</td>
<td>8760</td>
<td>2070</td>
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<td>Nitrogen (N2)</td>
<td>50100</td>
<td>13100</td>
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<td>Methane (CH4)</td>
<td>2990</td>
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<td>Carbon Monox. (CO)</td>
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<td>Ethane (C2H6)</td>
<td>206</td>
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<tr>
<td>Carbon Dioxide</td>
<td>297</td>
<td>248</td>
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<tr>
<td>Ethylene (C2H4)</td>
<td>6240</td>
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<tr>
<td>Acetylene (C2H2)</td>
<td>23800</td>
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<td>Total Gas</td>
<td>101462</td>
<td>15434</td>
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<td>COMB GAS</td>
<td>42305</td>
<td>16</td>
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<td>EST TCG %</td>
<td>26.12</td>
<td>0.08</td>
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<tr>
<td>C2H4/ C2H2</td>
<td>0.26</td>
<td>0.00</td>
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<tr>
<td>Comb Gas Rate</td>
<td>ppm/day</td>
<td>1,084.33</td>
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RELAY EVENT DATA COLLECTION AND ANALYSIS

• To facilitate the investigation, the 87T relay was programmed to capture relevant data.

• Several events were triggered daily
RELAY EVENT DATA COLLECTION AND ANALYSIS

- B-phase current drops to mostly zero; A- and C-phase currents at 180 degrees.
- B-phase voltage swell.
- Larger harmonic content at B-phase.
RELAY EVENT DATA COLLECTION AND ANALYSIS

• Same behavior in primary and secondary currents.

• Seen as a through fault?
RELAY EVENT DATA COLLECTION AND ANALYSIS

- Operate current remains at nearly zero (external fault)
- Relay restrains for this type of disturbance
RELAY EVENT DATA COLLECTION AND ANALYSIS

• B-phase voltage swell >30%
RELAY EVENT DATA COLLECTION AND ANALYSIS

• Sequence components shown during the disturbance
## RELAY EVENT DATA COLLECTION AND ANALYSIS

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<tbody>
<tr>
<td>VB RMS (kV)</td>
<td>21.8</td>
<td>21.9</td>
<td>26.1</td>
<td>25.8</td>
<td>21.95</td>
<td>22</td>
<td>21.47</td>
<td>26.5</td>
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<td>%VNOM</td>
<td>109.5</td>
<td>110.1</td>
<td>131.2</td>
<td>129.6</td>
<td>110.3</td>
<td>110.6</td>
<td>107.9</td>
<td>133.2</td>
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<td>V2 RMS (kV)</td>
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<td>1.7</td>
<td>1.86</td>
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<td>%VNOM</td>
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<td>I2W (A)</td>
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<td>0.89</td>
<td>73</td>
<td>55</td>
<td>0.73</td>
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<td>I1W (A)</td>
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<td>3.92</td>
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<td>70</td>
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<td>W - %I2/I1</td>
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<td>I2T (A)</td>
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<td>1.7</td>
<td>147</td>
<td>109</td>
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<td>172</td>
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<td>T - %I2/I1</td>
<td>20.2</td>
<td>19.7</td>
<td>85.5</td>
<td>79</td>
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<td>23</td>
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<td>I2U (A)</td>
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<td>3rd harmonic</td>
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<td>6.07</td>
<td>3.75</td>
<td>3.95</td>
<td>2.85</td>
<td>10</td>
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</tbody>
</table>
RELAY SETTINGS RECOMMENDATIONS

• Overvoltage (59) trip on the LV side:
  • Level 1: 20%, no delay
  • Level 2: 10%, small time delay

• Alarm based on values from the previous table

• Note: 59 trip is used to detect site disturbances, not utility variation
OLTC INSTALLATION TESTING PROCEDURE

Raise:
• Operate the OLTC in the raise direction from neutral to open P3 and P4
• Use a continuity tester to verify that P3 - P4 are a closed circuit
• Use a continuity tester to verify that P3-P2, P3-P1, P4-P2, & P4-P1 are an open circuit

Lower:
• Operate the OLTC in the lower direction from neutral to open P1 and P2
• Use a continuity tester to verify that P1 – P2 are a closed circuit
• Use a continuity tester to verify that P3-P2, P3-P1, P4-P2 & P4-P1 are an open circuit
AFTERMATH
CONCLUSION

- OLTCs are essential for automated voltage regulation
- Testing is required when replacing OLTCs to ensure leads have been connected properly
- Alarming recommended to identify issues
- Overvoltage protection recommended to prevent further damage
QUESTIONS?