



Induced Stray Voltages from Transmission Lines

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Introduction

- **Conventional stray voltage sources include unbalanced loads, neutral impedances, and high earth voltage gradients.**
- **Non-conventional sources include triplen harmonic neutral currents and induction from nearby transmission lines.**



Induced Stray Voltages - Parameters

- **Currents in transmission lines**
- **Proximity to distribution line**
- **Length of parallel section**
- **Additive phase angle between induced and load currents in the grounded neutral system**
- **Soil resistivity**



Concern

- **Stray voltage on a single phase tap line (7.2 kV) caused by a 500 kV transmission line**
- **Parallel section – Approximately 1 mile**
- **Average Distribution Pole Spacing – Approximately 350'**
- **Approximately 14 volts at the faucet of a customer at the end of the tap line**



Project Scope

- **NEETRAC and prior measurements**
- **Identification of various sources**
- **Computer modeling and validation with the measured data**
- **Performing studies to evaluate effectiveness of various stray voltage mitigation methods**



Measurements by NEETRAC

- **First set of measurements involved identifying house wiring, secondary neutral and buried 120/240 volt service related sources, if any. None was found.**
- **Second set of measurements included primary profiling from the substation to the customer – phase/neutral currents, NEVs and pole ground resistances**



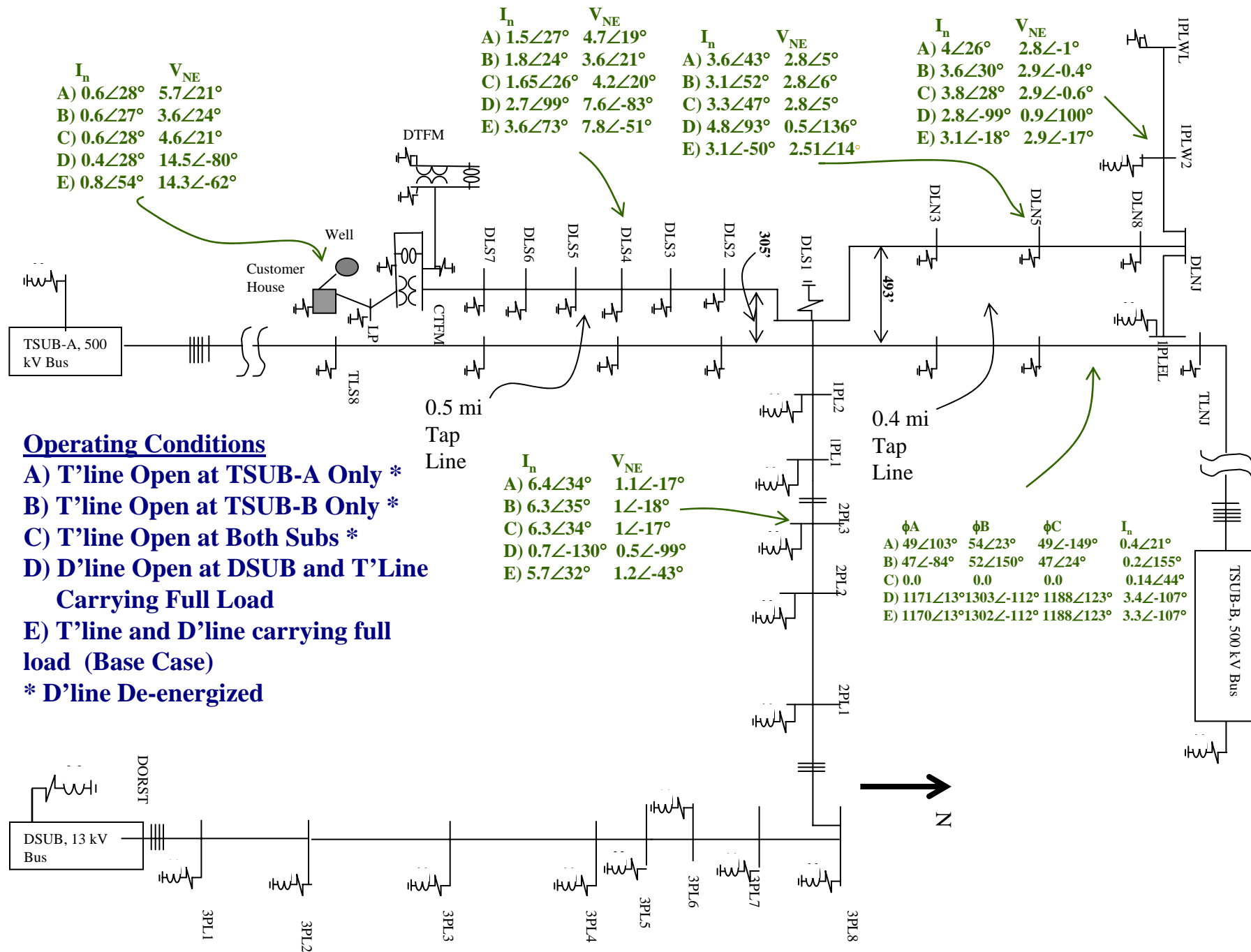
Prior Measurements

- **Prior to NEETRAC's involvement, the utility company measured stray voltages at the customer's faucet both with and without energizing the transmission line.**
- **The measurements indicated that the transmission line contributed approximately 73% of the total stray voltage. The remainder was produced by the load current.**



Computer Modeling

- **Modeled the subject feeder from the substation to the customer including the parallel transmission line.**
- **Validated the model by comparing the results with the measured data.**
- **Identified the sources by simulating various operating conditions.**



I_n	V_{NE}
A) $0.6 \angle 28^\circ$	$5.7 \angle 21^\circ$
B) $0.6 \angle 27^\circ$	$3.6 \angle 24^\circ$
C) $0.6 \angle 28^\circ$	$4.6 \angle 21^\circ$
D) $0.4 \angle 28^\circ$	$14.5 \angle -80^\circ$
E) $0.8 \angle 54^\circ$	$14.3 \angle -62^\circ$

I_n	V_{NE}
A) $1.5 \angle 27^\circ$	$4.7 \angle 19^\circ$
B) $1.8 \angle 24^\circ$	$3.6 \angle 21^\circ$
C) $1.65 \angle 26^\circ$	$4.2 \angle 20^\circ$
D) $2.7 \angle 99^\circ$	$7.6 \angle -83^\circ$
E) $3.6 \angle 73^\circ$	$7.8 \angle -51^\circ$

I_n	V_{NE}
A) $3.6 \angle 43^\circ$	$2.8 \angle 5^\circ$
B) $3.1 \angle 52^\circ$	$2.8 \angle 6^\circ$
C) $3.3 \angle 47^\circ$	$2.8 \angle 5^\circ$
D) $4.8 \angle 93^\circ$	$0.5 \angle 136^\circ$
E) $3.1 \angle -50^\circ$	$2.51 \angle 14^\circ$

I_n	V_{NE}
A) $4 \angle 26^\circ$	$2.8 \angle -1^\circ$
B) $3.6 \angle 30^\circ$	$2.9 \angle -0.4^\circ$
C) $3.8 \angle 28^\circ$	$2.9 \angle -0.6^\circ$
D) $2.8 \angle -99^\circ$	$0.9 \angle 100^\circ$
E) $3.1 \angle -18^\circ$	$2.9 \angle -17^\circ$

I_n	V_{NE}
A) $6.4 \angle 34^\circ$	$1.1 \angle -17^\circ$
B) $6.3 \angle 35^\circ$	$1 \angle -18^\circ$
C) $6.3 \angle 34^\circ$	$1 \angle -17^\circ$
D) $0.7 \angle -130^\circ$	$0.5 \angle -99^\circ$
E) $5.7 \angle 32^\circ$	$1.2 \angle -43^\circ$

ϕA	ϕB	ϕC	I_n
A) $49 \angle 103^\circ$	$54 \angle 23^\circ$	$49 \angle -149^\circ$	$0.4 \angle 21^\circ$
B) $47 \angle -84^\circ$	$52 \angle 150^\circ$	$47 \angle 24^\circ$	$0.2 \angle 155^\circ$
C) 0.0	0.0	0.0	$0.14 \angle 44^\circ$
D) $1171 \angle 13^\circ$	$1303 \angle -112^\circ$	$1188 \angle 123^\circ$	$3.4 \angle -107^\circ$
E) $1170 \angle 13^\circ$	$1302 \angle -112^\circ$	$1188 \angle 123^\circ$	$3.3 \angle -107^\circ$

Operating Conditions

- A) T'line Open at TSUB-A Only *
- B) T'line Open at TSUB-B Only *
- C) T'line Open at Both Subs *
- D) D'line Open at DSUB and T'Line
- Carrying Full Load
- E) T'line and D'line carrying full load (Base Case)
- * D'line De-energized



Evaluation of Mitigation Methods

Install neutral isolators

- **Initially, blocker ratings will be exceeded during high loading conditions.**
- **Replaced with 3 kV surge arrester with reduction in stray voltage from 14.3 volts to 0.01 volts.**
- **The primary NEV increased from 14.3 volts to 15.7 volts.**



Evaluation of Mitigation Methods

Move the tap line away

- **The tap line would have to be relocated approximately 2,500' from the transmission line to reduce the stray voltage by 40%. This result is partly due to extremely high soil resistivity in the area.**
- **Besides the cost, this solution was impractical for existing customers.**



Evaluation of Mitigation Methods

Install 5 Ohms ground well at each pole

- **Study showed that the stray voltages can be reduced by 40%.**
- **Drilling a ground well at eight locations is expensive.**
- **There is no guarantee that the resistance will be reduced to 5 Ohms.**



Evaluation of Mitigation Methods

Convert the tap to a three phase line and balance the load.

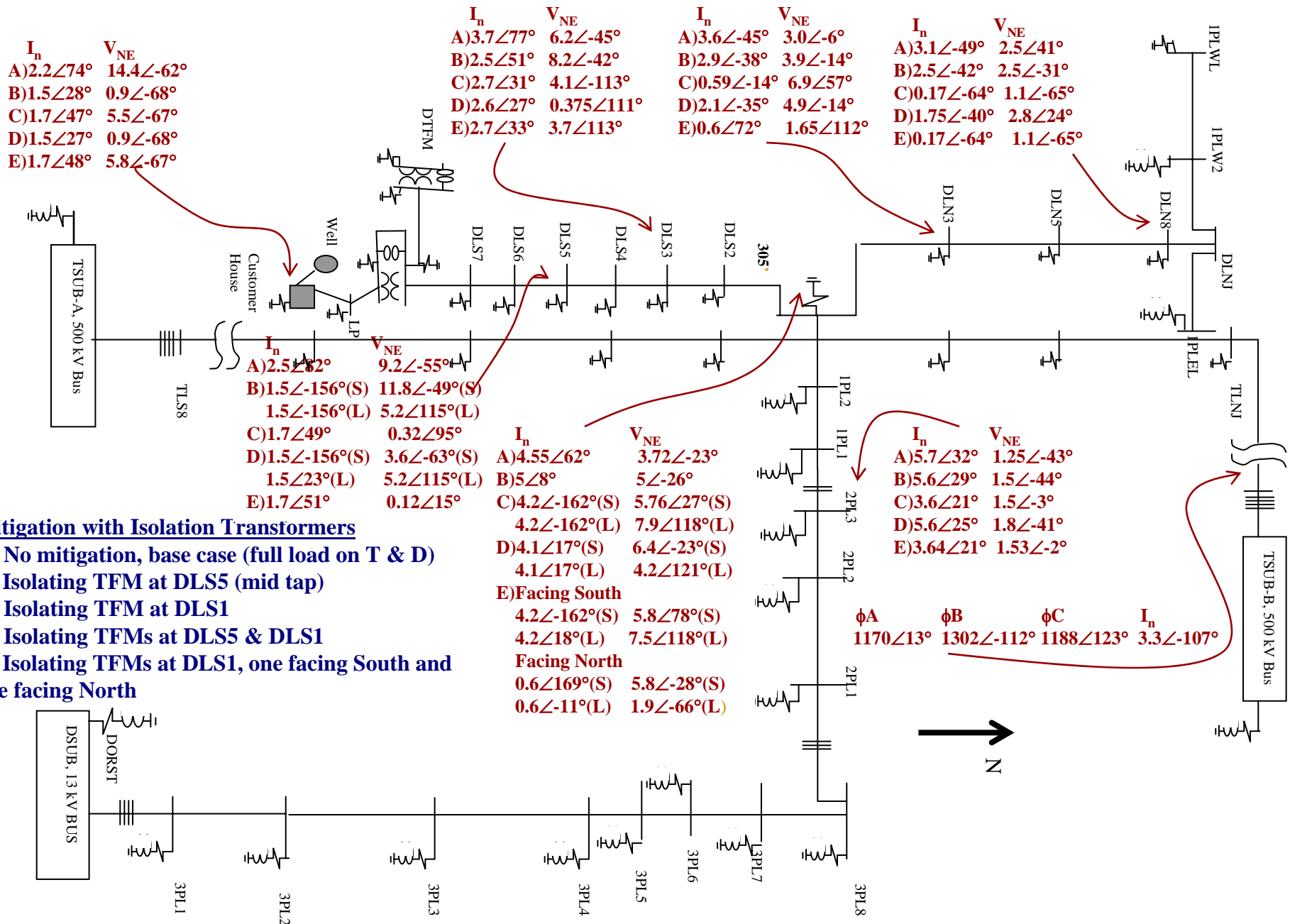
- **The NEV at the customer's transformer pole increased from 14.3 volts to 16.3 volts.**



Evaluation of Mitigation Methods

Install isolation transformers on the tap line

- **Breaks the length of the parallel section**
- **Effective solution for the entire tap**
- **Cable TV or telephone shields across the isolation transformers must be isolated to increase mitigation effectiveness.**
- **Proper fuse coordination is required.**



I_n V_{NE}
 A) 2.2∠74° 14.4∠-62°
 B) 1.5∠28° 0.9∠-68°
 C) 1.7∠47° 5.5∠-67°
 D) 1.5∠27° 0.9∠-68°
 E) 1.7∠48° 5.8∠-67°

I_n V_{NE}
 A) 3.7∠77° 6.2∠-45°
 B) 2.5∠51° 8.2∠-42°
 C) 2.7∠31° 4.1∠-113°
 D) 2.6∠27° 0.375∠111°
 E) 2.7∠33° 3.7∠113°

I_n V_{NE}
 A) 3.6∠-45° 3.0∠-6°
 B) 2.9∠-38° 3.9∠-14°
 C) 0.59∠-14° 6.9∠57°
 D) 2.1∠-35° 4.9∠-14°
 E) 0.6∠72° 1.65∠112°

I_n V_{NE}
 A) 3.1∠-49° 2.5∠41°
 B) 2.5∠-42° 2.5∠-31°
 C) 0.17∠-64° 1.1∠-65°
 D) 1.75∠-40° 2.8∠24°
 E) 0.17∠-64° 1.1∠-65°

I_n V_{NE}
 A) 2.5∠82° 9.2∠-55°
 B) 1.5∠-156°(S) 11.8∠-49°(S)
 1.5∠-156°(L) 5.2∠115°(L)
 C) 1.7∠49° 0.32∠95°
 D) 1.5∠-156°(S) 3.6∠-63°(S)
 1.5∠23°(L) 5.2∠115°(L)
 E) 1.7∠51° 0.12∠15°

I_n V_{NE}
 A) 4.55∠62° 3.72∠-23°
 B) 5∠8° 5∠-26°
 C) 4.2∠-162°(S) 5.76∠27°(S)
 4.2∠-162°(L) 7.9∠118°(L)
 D) 4.1∠17°(S) 6.4∠-23°(S)
 4.1∠17°(L) 4.2∠121°(L)
 E) Facing South
 4.2∠-162°(S) 5.8∠78°(S)
 4.2∠18°(L) 7.5∠118°(L)
 Facing North
 0.6∠169°(S) 5.8∠-28°(S)
 0.6∠-11°(L) 1.9∠-66°(L)

I_n V_{NE}
 A) 5.7∠32° 1.25∠-43°
 B) 5.6∠29° 1.5∠-44°
 C) 3.6∠21° 1.5∠-3°
 D) 5.6∠25° 1.8∠-41°
 E) 3.64∠21° 1.53∠-2°

ϕ_A ϕ_B ϕ_C I_n
 1170∠13° 1302∠-112° 1188∠123° 3.3∠-107°

Mitigation with Isolation Transformers

- A) No mitigation, base case (full load on T & D)
- B) Isolating TFM at DLS5 (mid tap)
- C) Isolating TFM at DLS1
- D) Isolating TFMs at DLS5 & DLS1
- E) Isolating TFMs at DLS1, one facing South and one facing North



Conclusions

- **Stray voltages due to induction can be significantly higher compared to those due to load currents.**
- **Stray voltages due to induction are typically spread along the parallel section serving several customers.**
- **Most of the traditional mitigation means will not be effective.**



Conclusions

- **Installation of one or more isolation transformers along the parallel section is an effective solution for the customers served by the tap.**
- **For effective mitigation, Cable TV and telephone shields must be isolated across the isolation transformers.**