Neutral Isolators for Stray Voltage Mitigation
Stray Voltage

- Normally refers to the neutral-to-earth voltage (NEV) that can exist in a dairy facility

- Some or all of this voltage can also exist between:
  - Metallic structures and ground
  - Cow contact points and ground
  - Between cow contact points
Stray Voltage Sources

- On Farm
- Off Farm
Typical “On Farm” Sources

- Unbalanced 120V loads
- Insulation leakage in electrical equipment
- Improper wiring
- Cow trainers, electric fences, etc.
- Switching large electrical loads
- High resistance grounds
Typical “Off Farm” Sources

- Primary neutral-to-earth voltage caused by:
  - Under sized neutrals
  - High resistance neutral connections
  - High resistance neutral grounds
Off Farm Neutral-To-Earth Voltage

- Contributes to On-farm neutral-to-earth voltage
- Should be minimized (mitigated) when necessary
Typical Single-Phase Transformer Installation

- Primary
- Primary Neutral
- Primary Ground
- Fuse
- Arrester
- Distribution Transformer
- Service Entrance
- Secondary Neutral
- Service Entrance Ground
1982 - 1984

- 1982 – Initial recognition by DEI that off-farm source of NEV must be mitigated (Wis. Pub. Service)
- Neutral Isolator concept proposed to WPS
  - Initial ac fault tests conducted on WPS system
- Initial NIs then built and evaluated in a hi-power test lab
  - With support from WPS, WPL(Alliant), and NSP(XCEL)
- NI first introduced March 1983
- 1984 edition of NESC added Section 97D2 allowing isolation
Functions of a Neutral Isolator

- Minimize the power utility contribution to on-farm stray voltage
- While retaining the safety aspects of solidly connected primary-to-secondary neutrals
Functions of a Neutral Isolator-cont.

- Under “Normal” conditions, primary and secondary neutrals are isolated
- Under “Abnormal” conditions, primary and secondary neutrals are re-connected
  - Abnormal condition: Any condition that causes the voltage across the isolator to exceed a predetermined threshold (e.g. AC fault, lightning)
Neutral Isolator

- A voltage triggered switch
- If “V” < switching threshold,
  - Switch open, neutrals isolated, no current flow
- If “V” > switching threshold,
  - Switch closed, neutrals connected, current flows
- Threshold voltage: 36Vp (25Vrms) initially, since 1996, 45 Vp (32 Vrms)
Neutral Isolator Operation
Voltage < Switching Threshold

- Neutrals isolated at all times
- No current flow
Neutral Isolator Operation
Voltage < Switching Threshold
Neutral Isolator Operation

Voltage at Switching Threshold

Switching Threshold Voltage

Voltage

Time

Neutrals isolated
No current flow

Neutrals Connected
Current flow
Neutral Isolator Operation
Voltage at Switching Threshold

≈ 45V Peak
Neutral Isolator Operation

Voltage > Switching Threshold

Switching Threshold Voltage

Voltage

Time

Neutrals isolated
No current flow

Neutrals Connected
Current flow
Neutral Isolator Operation
Voltage > Switching Threshold

≈ 70V Peak
VT/NI Switching Threshold

60 Hz Conditions

Switching Threshold Voltage V Peak

60 Hz Voltage Available

Voltage Blocking Area

45 Vpeak
Primary-to-Secondary Isolation

VT/NI INSTALLATION

- Primary
- Fuse
- Distribution Transformer
- Arrester
- Primary Neutral
- VT/NI
- Primary Ground
- Secondary Neutral
- Secondary Ground
- 6 Ft. Minimum

Note: Remove bond between secondary neutral and transformer tank.

Remove neutral ground strap from tank

Must be insulated (Reference NESC Section 97-D2)

(Some states require a greater minimum spacing)
Typical Installation
1996

- Major review by Wis. PSC
- Acceptable stray voltage criteria reviewed
- Some groups wanted an isolating device with a 300 V threshold to block transients
- Utilities and phone companies objected – safety?
- Compromise: A variable threshold isolator
- VT/NI Introduced in late 1996
Wis. Stray Voltage Criteria

- 2 ma limit between cow contact points*
- 1 ma allocated to on-farm sources
- 1 ma allocated to off-farm sources
- Off-farm limit must be met independent of on-farm contribution

* Limit based on 500 Ohm cow (2 ma = 1 volt)
Wis. Stray Voltage Criteria

- If utility cannot meet 1 ma criteria:
  - A neutral isolator can be installed for 90 days to address the problem
  - A PCS waiver is required for more than 90 days

- If a utility meets 1 ma criteria:
  - Farmer can request an isolator at his expense and leave it installed, but only if farm wiring meets code
VT/NI Ratings

- AC Fault Current
  - 3200A @ 1 cycle
  - 2400A @ 3 cycles
  - 1900A @ 10 cycles
  - 1700A @ 30 cycles

- Lightning Current
  - 30kA crest (8x20 waveform)
VT/NI Ratings

- Distribution Voltage – 15kV, 25kV, 35kV
- Response Time: 1-2 microseconds
- Failure Mode: Shorted
- Switching Threshold Voltage: See Graphs
- Typical AC impedance when “V” below switching threshold, > 2 Megohm
VT/NI Switching Threshold

Transient Conditions

Switching Threshold Level $V_{peak}$

Voltage Blocking Area
Switch Open

Time to Trigger in Microseconds

0 100 200 300 400 500 1000
Switching Threshold-Original NI

Voltage Blocking Area
Switch Open

36 Vpeak for 60 Hz or Transients
Jan. 1, 2009 Design Change

- New thyristor with higher di/dt rating
- New inductor (higher μH value to reduce di/dt seen by thyristor)
  - Above changes made to improve immunity to lightning caused failures
- New visual identification to highlight change
Internal Change

Prior Design

Revised Design

Thyristor

Inductor
External Visual Change

Prior Design

Revised Design
Field Testing Procedure

- Isolate one terminal from circuit
- Measure resistance between terminals
- If $R >> 5,000$ Ohms, unit O.K. ($R$ typically several hundred thousand ohms or higher)
Summary

- Neutral Isolators first introduced in 1983
- For power utilities for farm application only
- Intended to be installed until utility can correct the problem by other means
  - Often left installed upon user request
- Never intended or sold for other uses (e.g. shocks by swimming pools, hot tubs, etc.)
References

- PCS of Wis.
  - Findings of fact, conclusion of law, and order, July 16, 1996
- DEI brochure on Variable Threshold Neutral Isolator
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