TECHNICAL REPORT
PES-TR75

Methods for Detecting and Analyzing an Open Phase Condition of a Power Circuit to a Nuclear Plant Station Service or Startup Transformer

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PREPARED BY THE

Working Group K11

Power System Relaying and Control Committee

Methods for Analyzing and Detecting an Open Phase Condition of a Power Circuit to a Nuclear Plant Station Service or Startup Transformer

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The report is divided into the following sections:

1. Introduction
2. Detection methods and location of protection
3. Security and dependability concerns
4. Transformer data
5. Conclusions

Appendix A. Bibliography

Appendix B. Symmetrical Component model of Phase Open Line

Appendix C. Optical CT

Appendix D. Rogowski Coils

Appendix E. Open Phase Detection Methods Using Microprocessor Relays

Appendix F. Power Transformer Open Phase Detection by Current Transformer Open Circuiting

Appendix G. Power Transformer Open Phase Detection using specially designed window-type current sensors

Assignment

The report presents approaches used to detect open phase conditions that occur in the three phase, high voltage power supply to primary windings of grid connected station auxiliary transformers that provide energy to nuclear power plants.

The report addresses:

1. The effect of an open phase condition on transformer types (shell/core) and winding configurations
2. Schemes that can detect open phase conditions
3. Location of the detection schemes
4. Discussion of open phase consequences

Summary

In 2012, the Nuclear Regulatory Commission issued NRC Information Notice 2012-03. This notice was a call to action to the owners and operators of nuclear generating stations to review their procedures and protection schemes as to their ability to detect the loss of a phase of an offsite power circuit.

UNITED STATES

NUCLEAR REGULATORY COMMISSION

OFFICE OF NUCLEAR REACTOR REGULATION

OFFICE OF FEDERAL AND STATE MATERIALS AND ENVIRONMENTAL MANAGEMENT PROGRAMS

OFFICE OF NEW REACTORS

WASHINGTON, DC 20555-0001

March 1, 2012

NRC INFORMATION NOTICE 2012-03:

DESIGN VULNERABILITY IN ELECTRIC POWER SYSTEM

Nuclear Stations Listed in the Report

- Byron Station, Unit 2 (January 30, 2012)
- Beaver Valley Power Station, Unit 1 (November 27, 2007)
- James A. FitzPatrick Nuclear Power Plant and Nine Mile Point, Unit 1 (December 19, 2005)

Byron Station

Unit 2 experienced an automatic reactor trip from full power because of an undervoltage condition on two 6.9-kV electrical buses that power reactor coolant pumps (RCPs) B and C. A broken insulator stack for the phase C conductor on the 345-kV power circuit that supplies both station auxiliary transformers (SATs) caused the undervoltage condition. This insulator failure caused the phase C conductor to break off from the power line disconnect switch, resulting in a phase C open circuit.

Byron Station

After the reactor trip, the two 6.9-kV buses that power RCPs A and D, which were aligned to the unit auxiliary transformers (UATs), automatically transferred to the SATs, as designed. Because phase C was open circuited, the flow of current on phases A and B increased and caused all four RCPs to trip on phase overcurrent. With no RCPs functioning, control room operators performed a

natural-circulation cooldown ← Not good in the nuke world.

Industry main players

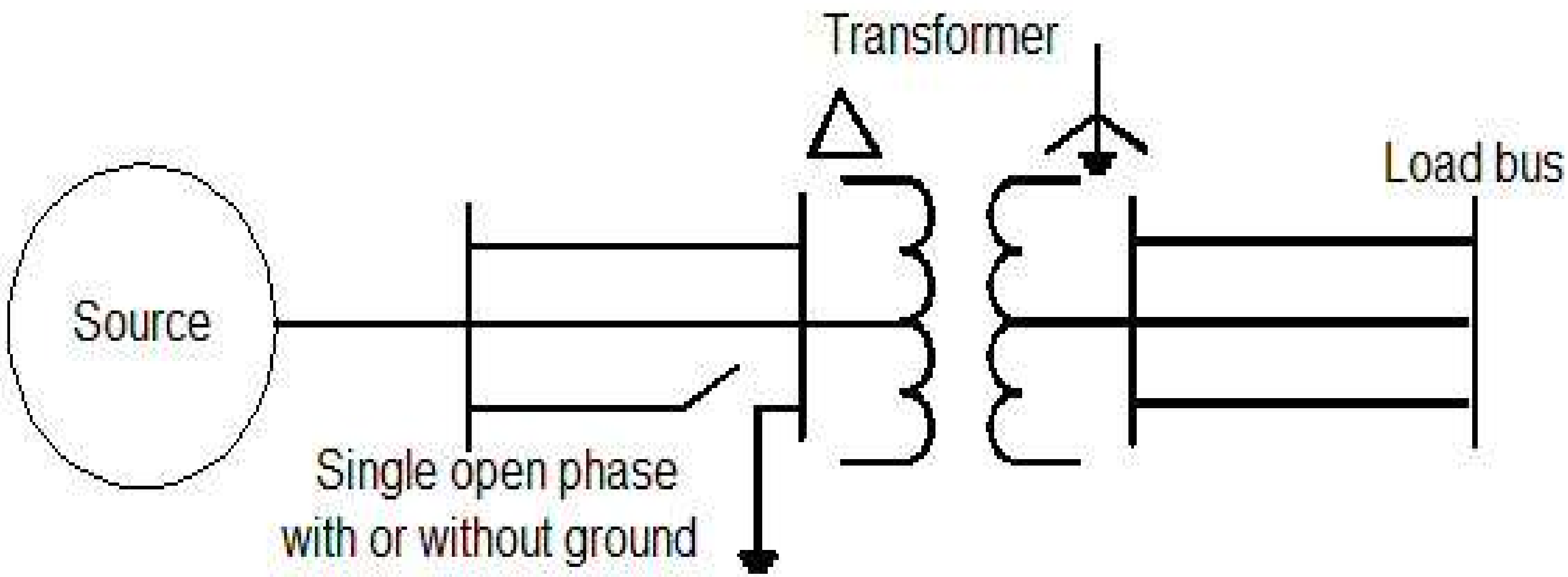
NRC Nuclear Regulatory Commission

NEI Nuclear Energy Institute

EPRI Electric Power Research Institute

IEEE PSRCC Power System Relaying and Control Committee

Individual utilities



Open phase with ground location

Detection methods

<u>Current Based Detection Schemes</u>:

Current Differential (Viable: No)

Phase Current Unbalance (Viable: Maybe)

Phase Comparison (Viable: No)

Sequence Quantities (Viable: No)

Hybrid Scheme (Viable: Maybe)

Sequence Voltage and Current Comparison (Viable: Maybe)

Detection methods

<u>Voltage Based Open Phase Detection Methods</u>:

Undervoltage (Viable: No)

Overvoltage (Viable: No)

Degraded Voltage (Viable: No)

Negative Sequence (Viable: No)

Sequence Voltage and Current Comparison (Viable: Maybe)

Detection methods

- Impedance Based Detection (Viable: No)
- Harmonic Frequency Based Detection (Viable: No)
- Communication aided schemes (Viable: Maybe)

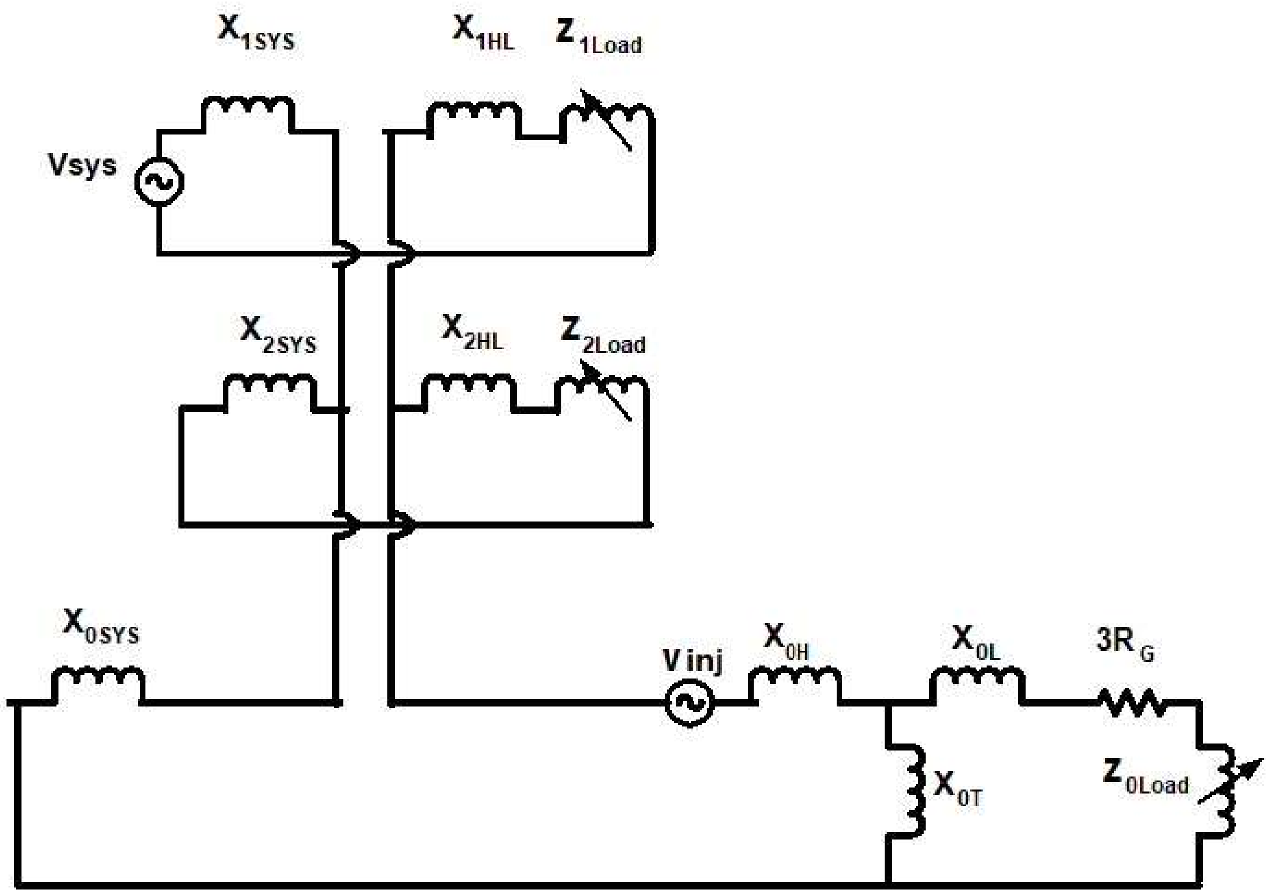
Instrument Transformers

- Current transformers
- Optical CTs (Viable: Yes)
- Rogowski Coils (Viable: Maybe)
- Traditional iron core current transformers

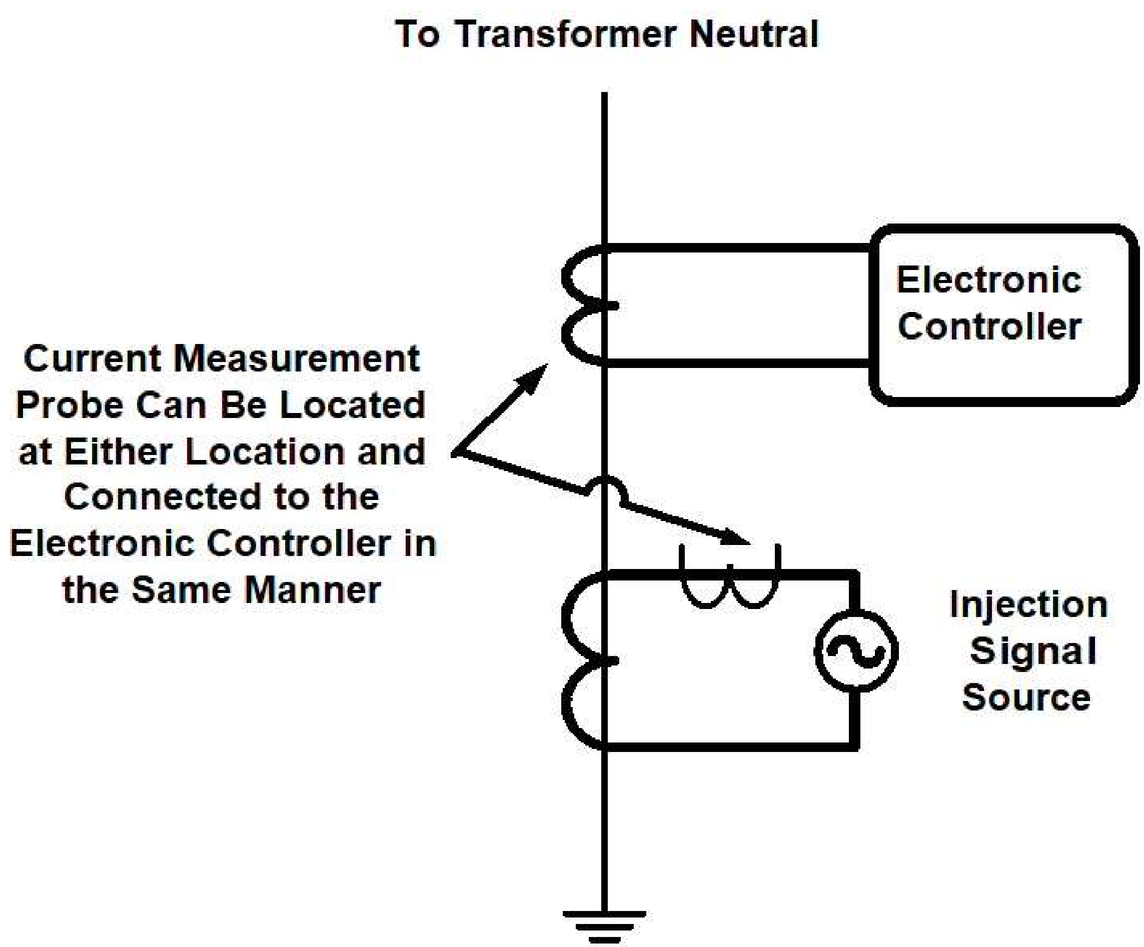
Open Phase Detection Based on Active Neutral Signal Injection Combined with Passive Neutral Overcurrent Detection

- Specifically designed to detect open phase conditions where an open phase under no-load or lightly-loaded conditions is undetectable by traditional voltage or current measurements
- Viable: Yes

Sequence network connections for a single open phase on the primary of a wye-grounded transformer



Realization of the active neutral injection method



Anti-islanding technology Feasibility of Active Schemes

Island detection devices, also known as anti-islanding devices, were investigated for possible use in determining an open phase.

Viable: No

Open Phase Detection Methods Using Analog-to-Digital Converter Behavior

- A/D converters exhibit errors, these errors are significantly amplified when the input signal is no longer available and substituted by noise.
- This A/D converter behavior can be used to detect ungrounded open phase events as the excitation current signal is no longer available to be processed by the A/D converter, and the output signal becomes amplified random noise due to the A/D least significant bit toggle.
- Viable: Maybe

Power Transformer Open Phase Detection by Current Transformer Open Circuiting

- Method that uses the open circuit voltage developed across the secondary of a CT that has its secondary momentarily open circuited intentionally (when no measurable current is present).
- If no primary current flows through the CT, then no voltage will be developed across the secondary when the secondary is momentarily opened. The absence of secondary voltage is the indicator that the primary has no current flow.
- Viable: Maybe

Power Transformer Open Phase Detection using specially designed window-type current sensors

- Uses specifically-designed, “window-type” current sensors on the high voltage bushings of the power transformer.
- Viable: Yes

Security and Dependability concerns

The open phase scenarios that need to be considered include:

- Reactor at full power, normal plant operation
- Reactor shutdown, normal shutdown conditions
- Reactor startup, prior to load bus transfers
- Post reactor SCRAM, the interval of time between normal plant operations and cold shutdown conditions.
- Design Basis Event, Loss of Cooling Accident

Transformer data

- Core-Type wye-primary transformers
- Delta-primary transformers
- Shell-type transformers

Conclusions

Scheme	Viable?
Current differential	No
Phase current unbalance	Maybe
Phase comparison	No
Sequence quantities	No
Hybrid scheme	Maybe
Sequence Voltage and current comparison	Maybe
Undervoltage	No

Conclusions

Scheme	Viable?
Overvoltage	No
Degraded voltage	No
Negative Sequence differential voltage	No
Impedance	No
Frequency	No
Voltage and Current comparison	Maybe
Communication aided	Maybe

Conclusions

Scheme	Viable?
Optical CT	Yes
Rogowski coils	Maybe
Active Neutral Signal injection	Yes
Anti-islanding	No
Open Phase Detection Methods Using Microprocessor Relays	Maybe
CT open circuiting	Maybe
Specially designed window-type CT	Yes

Report Availability

- https://www.pes-psrc.org/kb/published/reports/K11_8.70_OpenPhaseDetectionNuclear.pdf

- https://resourcecenter.ieee-pes.org/technical-publications/technical-reports/PES_TP_TR75_PSRC_012020.html

Thanks for watching!

Questions?