Modern Protection of Three-Phase and Spare Transformer Banks

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Agenda

- Introduction
- Three-single-phase-and-spare (TSPS) configurations
- Transformer protection fundamentals
- TSPS modern protection applications
- Configurable transformer compensation matrix
- Conclusion

Introduction

- Large transformers – expensive, long lead times
- TSPS transformers – fault tolerance
- Extensive outage time for identifying and isolating failed transformer and substituting a spare
- Complex rewiring of protection system to insert spare transformer
- Spare idled for long duration

Design Objectives

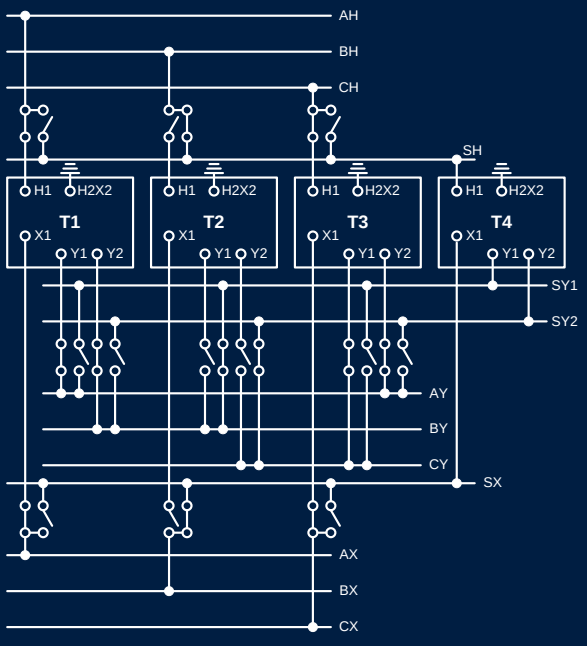
- Reduce outage duration
- Simplify substitution of spare transformer
- Promote periodic switching of spare transformer
- Apply modern microprocessor technology
  - Precise identification of faulted unit or lead bus phase
  - Automatic and quick reconfiguration of protection zones

Two TSPS Transformer Applications Considered

- Transmission autotransformer
- Generator-step-up (GSU) transformer

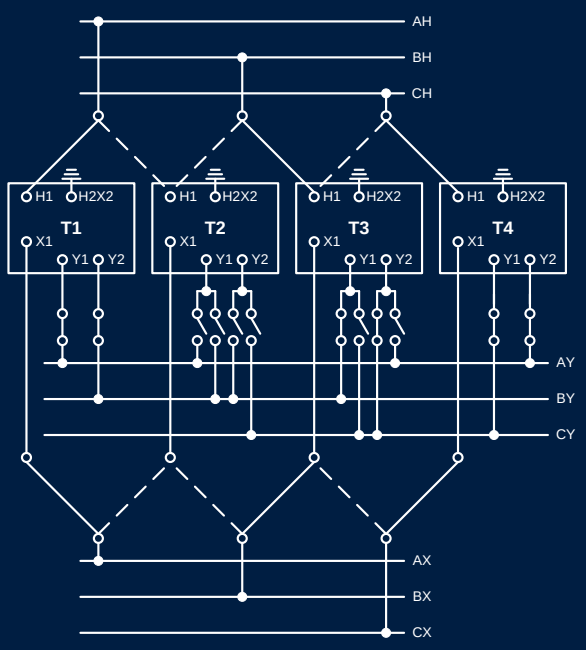
TSPS Configuration 1
Dedicated Spare

- Dedicated spare transformer substituted for any normally in-service transformers
- Switches and buswork links for reconfiguration



TSPS Configuration 2
No Dedicated Spare

- Single-phase transformer cannot be substituted for all three phases
- Lead bus of any phase can only be switched between two single-phase units



Transformer Protection Fundamentals

- Transformer differential protection requires ampere-turn balance (ATB) equations for magnetic circuit
- Single-phase transformers have closed magnetic circuit
- ATB equations can be written on a per-phase basis
- Zero-sequence compensation (delta compensation) is not required, hence it enables faulted-tank identification

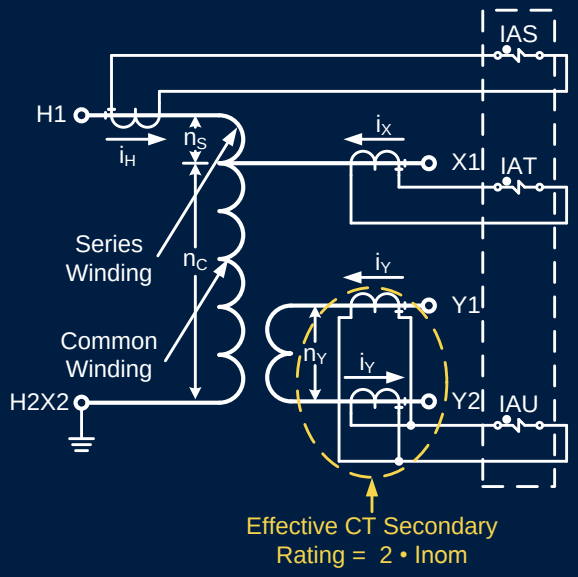
ATB Differential Protection

ATB Equation for Single-Phase Transformer

$$AT = (n_s + n_c) \bullet i_H + n_c \bullet i_X + n_Y \bullet i_Y = 0$$

Tap Equation

$$TAPn = \frac{MVA_{T1\Phi} \bullet 1000}{KVn_{WINDING} \bullet CTRn}$$



Partial-Winding Fault Protection

- Turn-to-turn and turn-to-ground faults
- Phase differential (less sensitive)
- Sensitivity of protection (critical)
- Partial winding fault protection schemes
  - Fault pressure relay (63 w/50P)
  - Restricted earth fault (REF)
  - Negative-sequence differential (87Q)

Modified REF Scheme

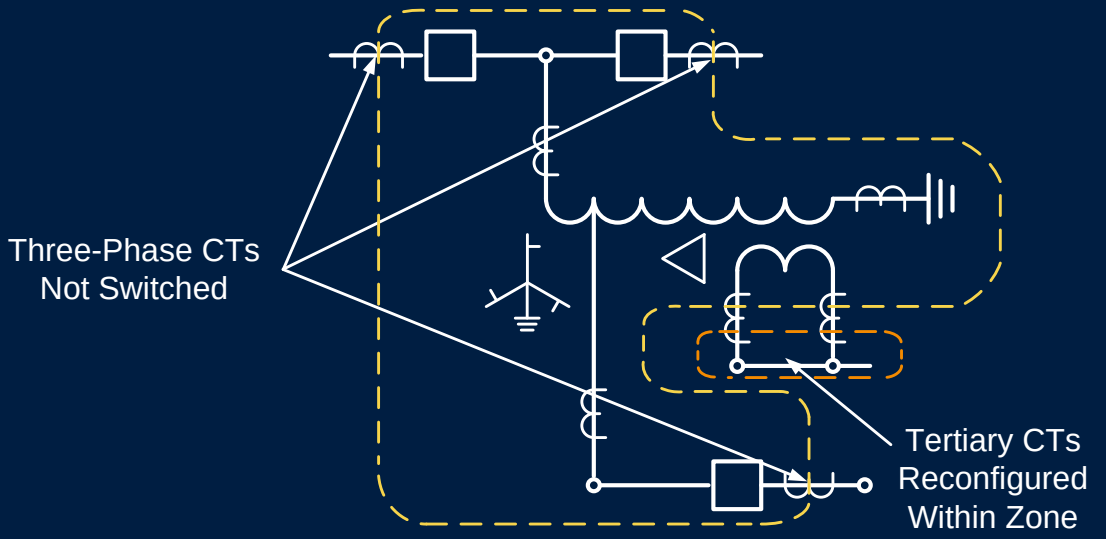
- Scheme is implemented in lead bus, low-impedance differential relays
- Lead bus relays include three unused differential elements
- Ground differential is created around each in-service tank
- Zone switching logic easily accommodates spare substitution
- Scheme uses Kirchoff's current law and not ATB differential, so is immune to effects of magnetic circuit

Negative-Sequence Differential Protection (87Q)

- Provides superior sensitivity
  - 87Q is not restrained by load flow
  - External fault detector enhances security
- Complements 63 w/50P and REF
- Spare substitution may result in incomplete three-phase current sets

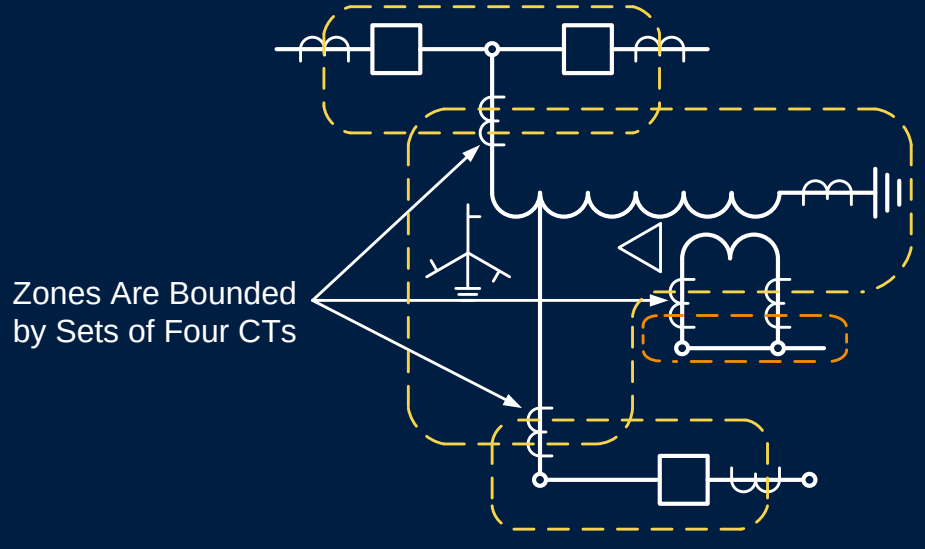
Autotransformer Protection Option 1

Main A System, Overall Differential

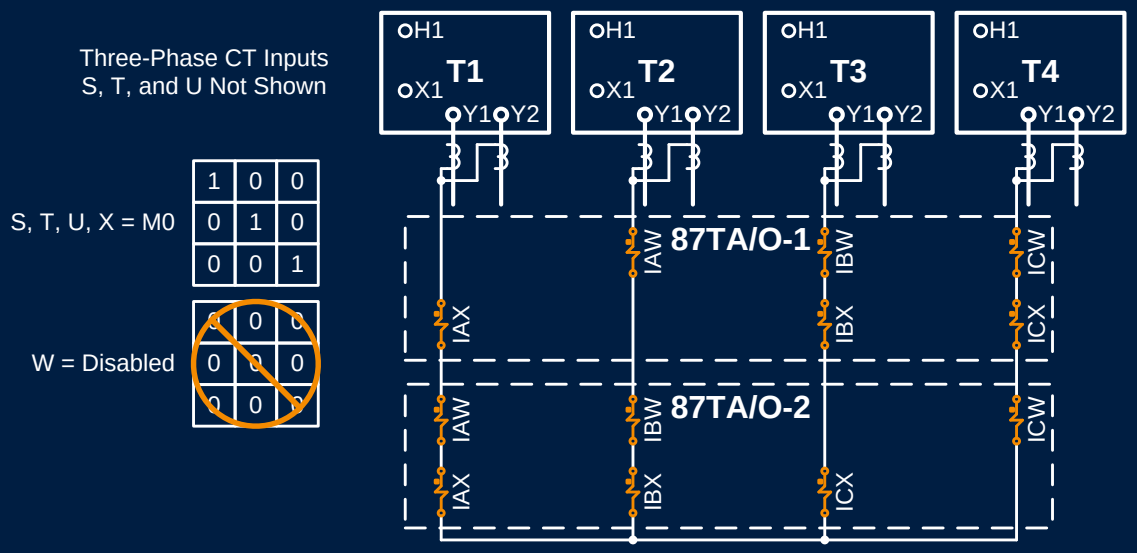


Autotransformer Protection Option 1

Main B System, Separated Zones



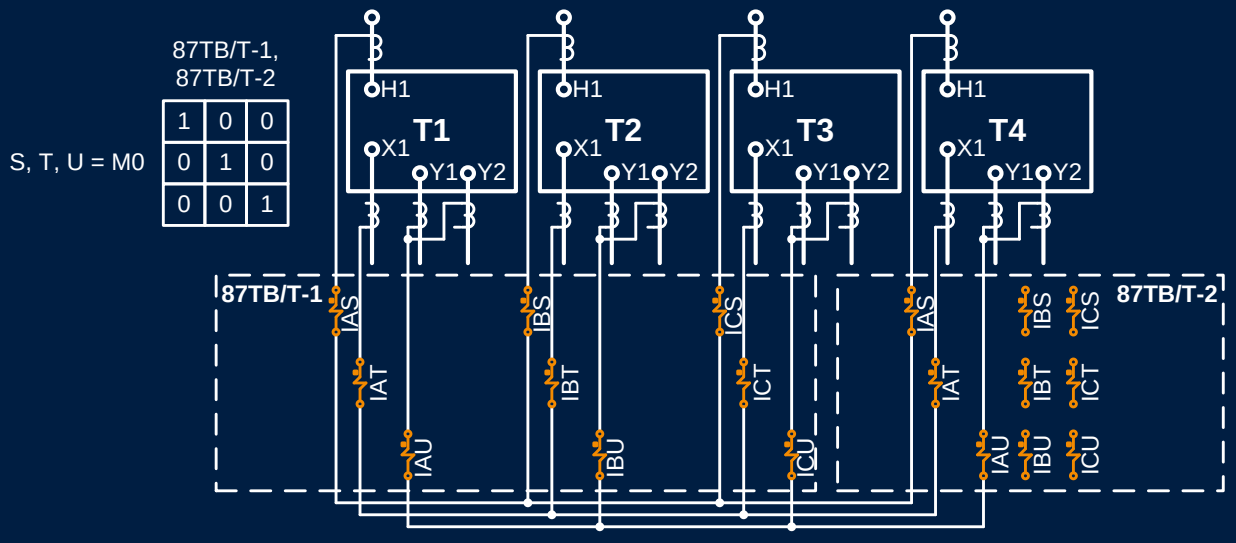
Overall Differential



Overall Differential

- 87TA/O-1 performs differential protection using ATB per phase
- 87TA/O-2 performs conventional differential (if tertiary is unloaded)
- Tertiary bus differential is via separate relay or 87P-BYT
- 87TA/O-1 and 87TA/O-2 functionally interchanged for T3 and T4 transformer out of service (TOOS)

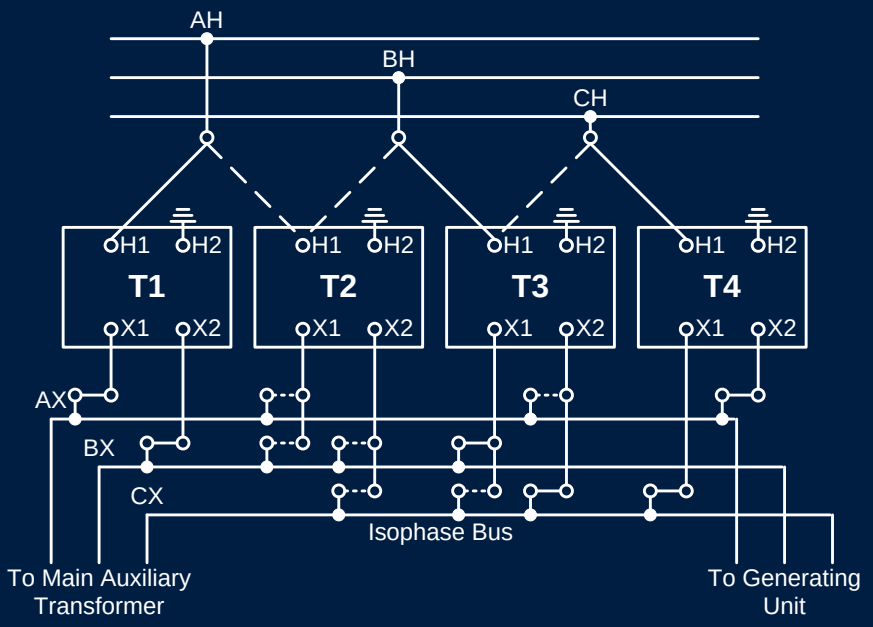
Autotransformer Differential



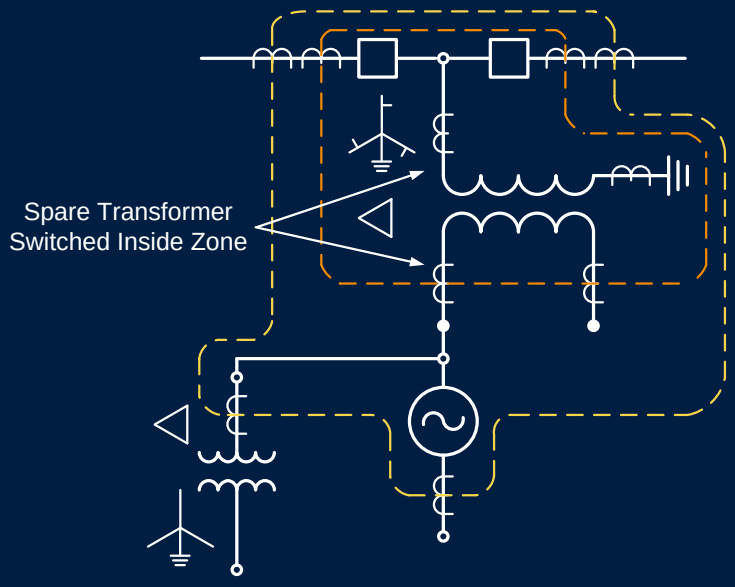
Main B Protection System

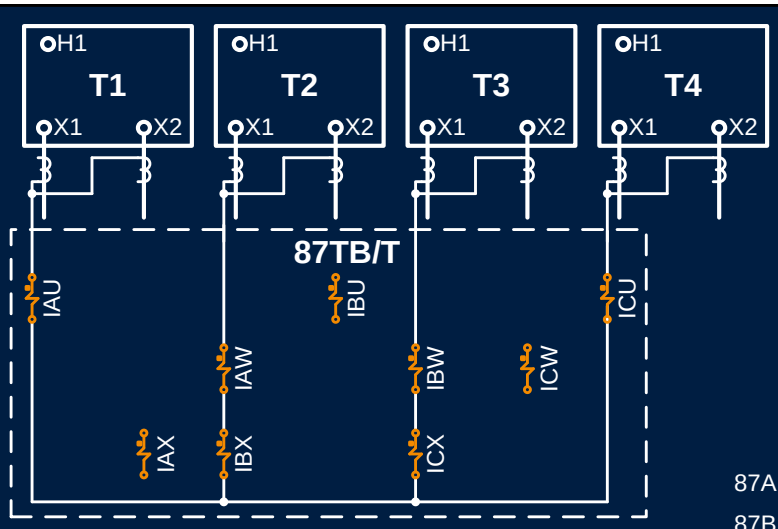
- Dedicated single-phase transformer and high- and low-side bus protection
- Differentiation of faulted zones
- High-side lead bus relay that has 6 differential elements (high-side bus differential and modified transformer REF)
- Low-side lead bus relay that has 6 differential elements (low-side bus and tertiary bus)
- Advanced zone switching in lead bus differential relays
- 63 w/50P complementing 87Q in Main A system

GSU Protection



GSU Protection Option 2





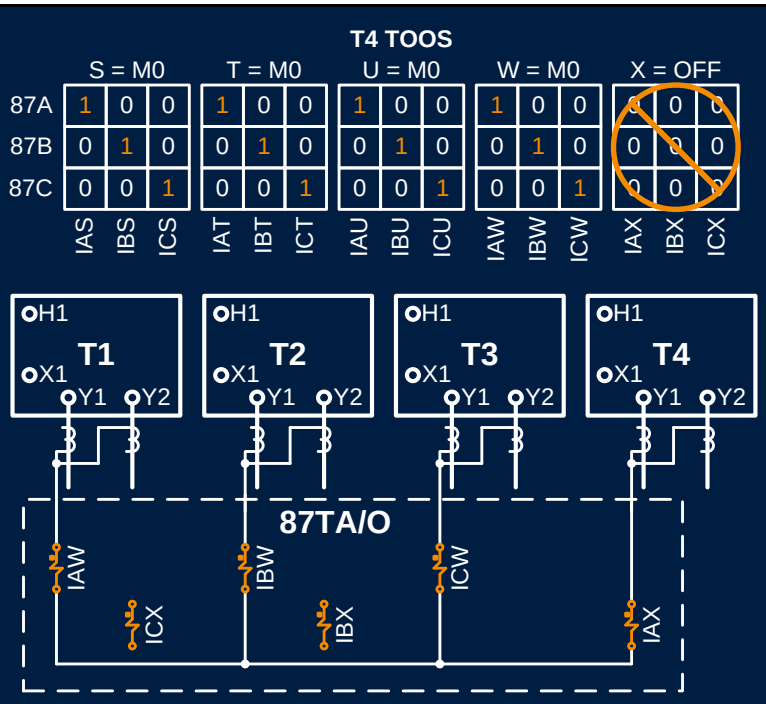
Main B System
GSU Differential

T4 TOOS

	U = M0			W = OFF			X = M0		
	T1	NC	T4	T2	T3	NC	NC	T2	T3
87A	1	0	0	0	0	0	1	0	0
87B	0	1	0	0	0	0	0	1	0
87C	0	0	1	0	0	0	0	0	1
	IAU	IBU	ICU	IAW	IBW	ICW	IAX	IBX	ICX

Configurable Compensation Matrix (M13)

- Matrix is proposed for applications involving complex compensation
- Single relay can accommodate all TSPS configurations
- Functionality is not sacrificed
- ATB is per phase and provides faulted-phase identification
- M13 is future application for special cases



Matrix M13

Conclusion

- TSPS transformers improve fault tolerance and availability
- Single-phase transformers allow ATB per phase and positive faulted-phase indication
- Proposed schemes using modern microprocessor-based relays enable quick insertion of spare on correct phase

Conclusion

Goals of Modern Protection Schemes

- Sensitive and redundant protection for all faults
- Identification of right phase and equipment
- Elimination of CT wiring reconfiguration
- Reduced outage times (from days to hours)
- Novel CT circuits (easy to wire and test)
- Automatic reconfiguration of zones via pushbuttons or switch statuses

Questions?