Transformer Protection Principles

1. Introduction

Transformers are a critical and expensive component of the power system. Due to the long lead time for repair of and replacement of transformers, a major goal of transformer protection is limiting the damage to a faulted transformer. Some protection functions, such as overexcitation protection and temperature-based protection may aid this goal by identifying operating conditions that may cause transformer failure. The comprehensive transformer protection provided by multiple function protective relays is appropriate for critical transformers of all applications.

2. Transformer Protection Overview

The type of protection for the transformers varies depending on the application and the importance of the transformer. Transformers are protected primarily against faults and overloads. The type of protection used should minimize the time of disconnection for faults within the transformer and to reduce the risk of catastrophic failure to simplify eventual repair. Any extended operation of the transformer under abnormal condition such as faults or overloads compromises the life of the transformer, which means adequate protection should be provided for quicker isolation of the transformer under such conditions.

3. Transformer Failures

Failures in transformers can be classified into

- winding failures due to short circuits (turn-turn faults, phase-phase faults, phase-ground, open winding)
- core faults (core insulation failure, shorted laminations)
- terminal failures (open leads, loose connections, short circuits)
- on-load tap changer failures (mechanical, electrical, short circuit, overheating)

Conditions	Protection Philosophy
Internal	
Winding Phase-Phase, Phase-Ground faults	Differential (87T), overcurrent (51, 51N) Restricted ground fault protection (87RGF)
Winding inter-turn faults	Differential (87T), Buchholz relay,
Core insulation failure, shorted laminations	Differential (87T), Buchholz relay, sudden pressure relay
Tank faults	Differential (87T), Buchholz relay and tank-ground protection
Overfluxing	Volts/Hz (24)
External	
Overloads	Thermal (49)
Overvoltage	Overvoltage (59)
Overfluxing	Volts/Hz (24)
External system short circuits	Time overcurrent (51, 51G), Instantaneous overcurrent (50, 50G)

- abnormal operating conditions (overfluxing, overloading, overvoltage)
- external faults

4. Innovative GE Multilin Solutions to Transformer Protection Applications

4.1 Differential Characteristic

The major operating challenge to transformer differential protection is maintaining security during CT saturation for external faults while maintaining sensitivity to detect low magnitude internal faults. CT saturation reduces the secondary output current from the CT, and causes a false differential current to appear to the relay. GE Multilin differential relays meet this challenge in the following ways:

- the restraint current is based on the maximum measured winding current, as opposed to the traditional magnitude sum of the currents. This ensures ideal restraint for the actual fault condition, balancing sensitivity and security.
- the differential element uses a dual slope-dual breakpoint characteristic. The differential element can be set to account for both DC and AC saturation of the CTs, ensuring security, while maintaining sensitivity.
  Available in the T60, T35.

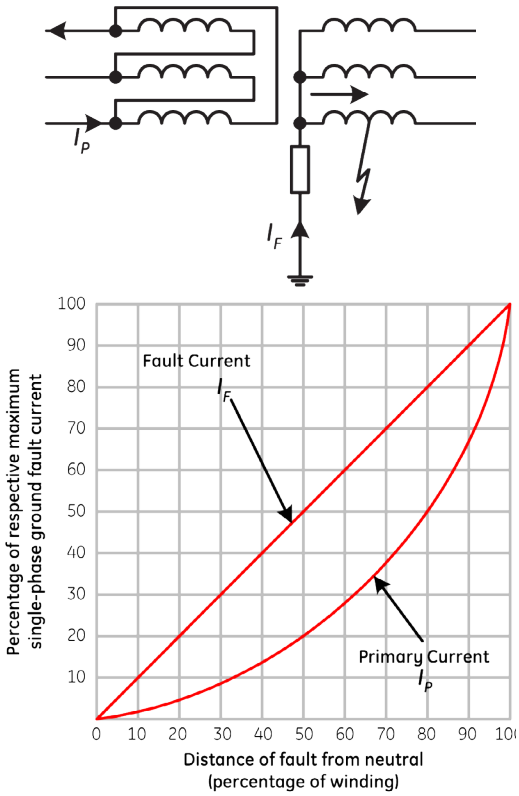
4.2 Inrush Inhibit during Transformer Energization:

The transformer energization resembles the condition of an internal fault. If no inhibiting mechanism is provided, the differential element will trip. The magnetizing inrush current has significant 2nd harmonic content. The level of 2nd harmonic current can be used to differentiate between inrush and a fault condition. The UR T60 and T35 GE Multilin transformer relays use two different 2nd harmonic modes to inhibit the differential element for inrush.

Traditional 2nd harmonic blocking – The traditional 2nd harmonic restraint responds to the ratio of the magnitudes of the 2nd harmonic and the fundamental frequency currents.

Adaptive 2nd harmonic blocking– The adaptive 2nd harmonic blocking responds to both magnitudes and phase angles of the 2nd harmonic and the fundamental frequency currents. The differential element correctly distinguishes between faults and transformer energization, when the 2nd harmonic current is less than the entered 2nd harmonic setting. While levels of 2nd harmonic during inrush often do not go below 20%, many transformers are susceptible of generating lower 2nd harmonic current during energization. Setting the 2nd harmonic restraint below 20% may result in incorrect inhibit of the differential element during some internal fault events. The adaptive 2nd harmonic blocking allows settings in the traditional 20% range, while maintaining the security of the differential element against inrush.

Available in the T60, T35.



Ground fault current for impedance grounded neutral transformer for faults at different % of the winding.

An alternative method for inrush inhibit is also available, where either current, voltage, or breaker status is used to indicate a de-energized transformer. The threshold can be lowered during energization of the transformer as indicated either by breaker contact, current or voltage sensing, and will last for a settable time delay. This allows settings of less than 20% for inrush inhibit during transformer energization.

Available in the 745.

4.3 Sensitive Ground Fault Protection to limit Transformer Damage

Differential and overcurrent protection do not provide adequate protection for wye-connected windings with grounded neutrals. Faults close to the neutral produces lesser fault current as shown by the current distribution curve. The restricted ground fault function can be used to provide differential protection for such ground faults, down to faults at 5% of the transformer winding. Restricted ground fault protection can be a low impedance differential function or a high impedance differential function. The low impedance function has the advantage to being able to precisely set the sensitivity to meet the application requirement. This sensitive protection limits the damage to the transformer to allow quicker repair. The restricted ground fault element uses adaptive restraint based on symmetrical components to provide security during external phase faults with significant CT error. This permits the function to maximize sensitivity without any time delay.

Available in the 745, T60.

4.4 Overflux Protection

Transformer overfluxing can be a result of

- Overvoltage
- Low system frequency

A transformer is designed to operate at or below a maximum magnetic flux density in the transformer core. Above this design limit the eddy currents in the core and nearby conductive components cause overheating which within a very short time may cause severe damage. The magnetic flux in the core is proportional to the voltage applied to the winding divided by the impedance of the winding. The flux in the core increases with either increasing voltage or decreasing frequency. During startup or shutdown of generator-connected transformers, or following a load rejection, the transformer may experience an excessive ratio of volts to hertz, that is, become overexcited. When a transformer core is overexcited, the core is operating in a non-linear magnetic region, and creates harmonic components in the exciting current. A significant amount of current at the 5th harmonic is characteristic of overexcitation.

Available in the 745, T60, and T35.

4.5 Winding hot-spot temperature protection

The transformer winding hot-spot temperature is another quantity that should be used for protection of transformers. Protection based on winding hot-spot temperature can potentially prevent short circuits and catastrophic transformer failure, as excessive winding hot-spot temperatures cause degradation and eventual failure of the winding insulation. The ambient temperature, transformer loading, and transformer design determine the winding temperature. Temperature based protection functions alarm or trip when certain temperature conditions are met.

GE Multilin relays use IEEE C57.91 compliant thermal models to calculate the winding hot-spot temperature and the loss of life of the winding insulation. The top-oil temperature may be directly measured, or calculated from the ambient temperature, load current, and transformer characteristics. In addition, the calculations may use a monthly model of ambient temperature, eliminating the need for external connections to the transformer and relay. This winding hot-spot temperature and transformer loss of life information is used in thermal overload protection to provide alarming or tripping when unacceptable degradation of the transformer winding insulation is occurring.

Available in 745, T60.

4.6 Application Capabilities

GE Multilin transformer protection relays are suitable for different transformer protection applications, including medium voltage and high voltage transformers of any size, dual secondary transformers, auto-transformers, three-winding transformers, transformers with dual-breaker terminals.

In addition, these relays are designed for both new and retrofit installations. New installations typically use wye-connected CTs, and internally compensate the measured currents for the phase shift of the protected transformer. Traditional installations may use delta-connected or wye-connected CTs that externally compensate the measured currents for the phase shift of the protected transformer. GE Multilin accommodates both methods as simple configuration settings.

Beyond these typical applications, GE Multilin transformer protection relays can be applied on more advanced applications.

4.7 Phase shift transformers

Phase shift transformers – phase shift transformers purposely introduce a variable phase shift between the primary and secondary voltage. This phase shift is not a multiple of 30 degree, but is adjustable in small increments, to allow operators to change the phase angle between parts of the power system to control power flow in the system. GE Multilin relays are successfully applied for protecting phase shifting transformers.

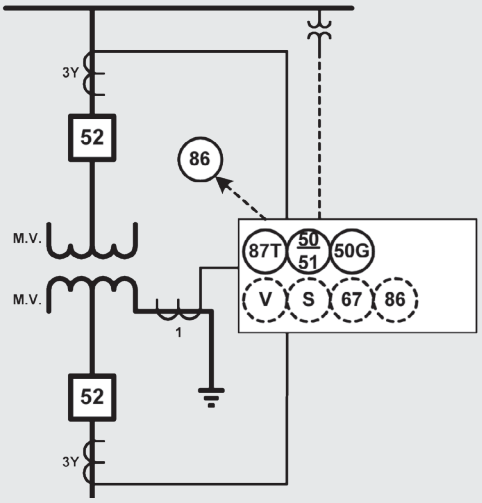
4.8 Split-phase autotransformers

Split-phase autotransformers – are single-phase auto-transformers connected in parallel to make a large three-phase bank. The differential protection from GE Multilin can be used to identify turn-turn faults in one of the auto-transformers without operating the entire bank.

5. Typical applications

This section highlights some typical application of GE Multilin transformer protection relays. This section is not intended as a comprehensive list of possible applications. For questions about the correct relay for a specific application, please contact GE Multilin.

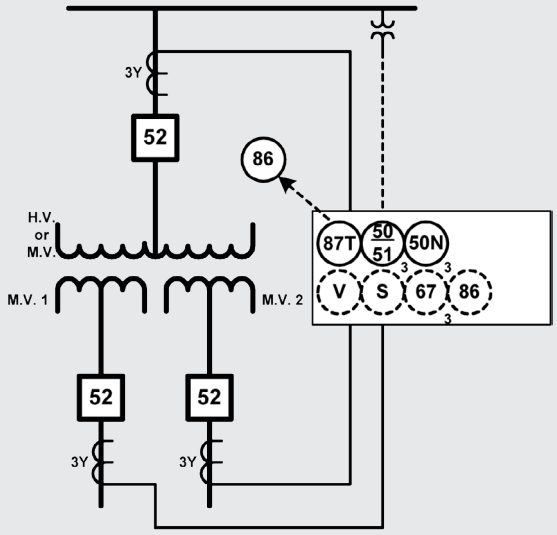
Transformers 750kVA and above, MV Windings



Typical Functions		Additional Functions	
87T	Differential	67	Directional overcurrent
86	Lockout auxiliary	V, S	Voltage and Power metering
50/51	Overcurrent and short circuit		
50G	Ground fault		

Functions	Typical Product Order Code
Typical Functions	745-W2-P5-G5-HI-T T35-N00-HCH-F8N-H6P-MXX-PXX-UXX-WXX T60-N00-HCH-F8N-H6P-MXX-PXX-UXX-WXX
+ Harsh Environment Option	745-W2-P5-G5-HI-T-H T35-N00-ACH-F8N-H6P-MXX-PXX-UXX-WXX T60-N00-ACH-F8N-H6P-MXX-PXX-UXX-WXX
+ Voltage and Power metering	745-W2-P5-G5-HI-T T35-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX
+ Directional overcurrent	T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX
Lockout Standalone Integrated	 HEA61-A-RU-220-X2 T35-N00-HPH-F8N-H6P-MXX-P4L-UXX-WXX T60-N00-HPH-F8N-H6P-MXX-P4L-UXX-WXX

Power Transformers, Dual MV Secondary Windings

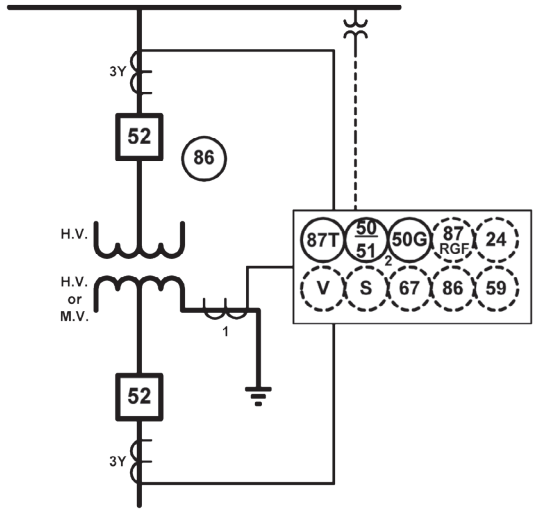


Typical Functions	
87T	Differential
86	Lockout auxiliary
50/51	Overcurrent and short circuit (three windings)
50N	Neutral ground fault (three windings)

Additional Functions	
67	Directional overcurrent
V, S	Voltage and Power metering

Functions	Typical Product Order Code
Typical Functions	**745-W3-P5-G5-HI-T** **T35-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX** **T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
+ Harsh Environment Option	**745-W3-P5-G5-HI-T-H** **T35-N00-ACH-F8L-H6P-M8N-PXX-UXX-WXX** **T60-N00-ACH-F8L-H6P-M8N-PXX-UXX-WXX**
+ Voltage and Power metering	**745-W3-P5-G5-HI-T** **T35-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX** **T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
+ Directional overcurrent	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
Lockout Standalone Integrated	 **HEA61-A-RU-220-X2** **T35-N00-HPH-F8L-H6P-M8N -P4L-UXX-WXX** **T60-N00-HPH-F8L-H6P-M8N -P4L-UXX-WXX**

Power Transformers, HV Windings

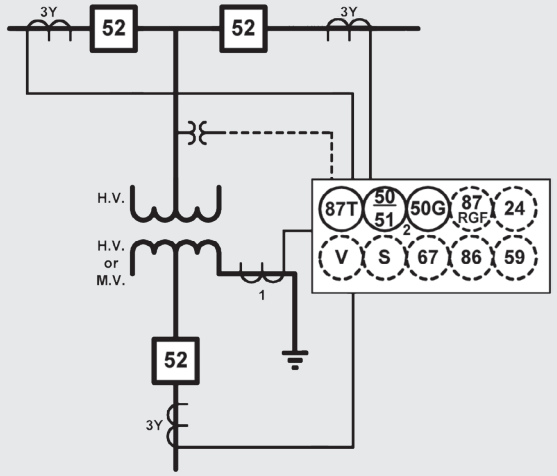


Typical Functions	
87T	Differential
86	Lockout auxiliary
50/51	Overcurrent and short circuit (both windings)
50G	Ground fault

Additional Functions	
87RGF	Restricted Ground Fault
67	Directional overcurrent
24	Volts per Hertz
59	Overvoltage
V, S	Voltage and Power metering

Functions	Typical Product Order Code
Typical Functions	**T60-N00-HCH-F8N-H6P-MXX-PXX-UXX-WXX** **T35-N00-HCH-F8N-H6P-MXX-PXX-UXX-WXX** **745-W2-P5-G5-HI-T**
+ Voltage and Power metering	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX** **T35-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX** **745-W2-P5-G5-HI-T**
+ Additional Functions (87G, 67, 24, 59)	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX** **745-W2-P5-G5-HI-R-T**
Lockout Standalone Integrated	 **HEA61-A-RU-220-X2** **T35-N00-HPH-F8N-H6P-MXX-P4L-UXX-WXX** **T60-N00-HPH-F8N-H6P-MXX-P4L-UXX-WXX**

Power Transformers, HV Windings, Dual-Breaker Source

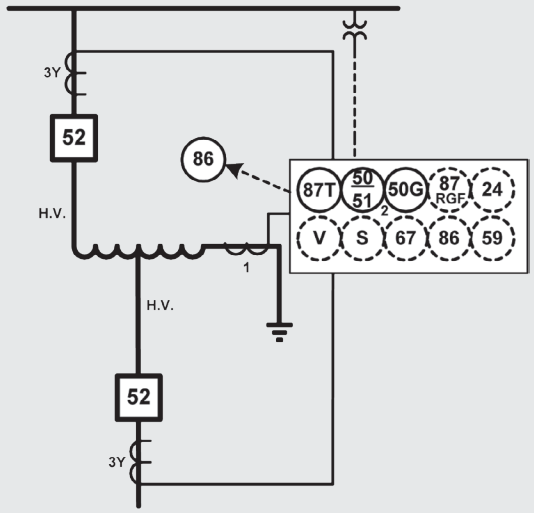


Typical Functions	
87T	Differential
86	Lockout auxiliary
50/51	Overcurrent and short circuit (two windings)
50G	Ground fault

Additional Functions	
87RGF	Restricted Ground Fault
67	Directional overcurrent
24	Volts per Hertz
59	Overvoltage
V, S	Voltage and Power metering

Functions	Typical Product Order Code
Typical Functions	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX** **T35-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
+ Voltage and Power metering	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX** **T35-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
+ Additional Functions	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
Lockout Standalone Integrated	 **HEA61-A-RU-220-X2** **T35-N00-HPH-F8L-H6P-M8N-P4L-UXX-WXX** **T60-N00-HPH-F8L-H6P-M8N-P4L-UXX-WXX**

Auto-Transformer

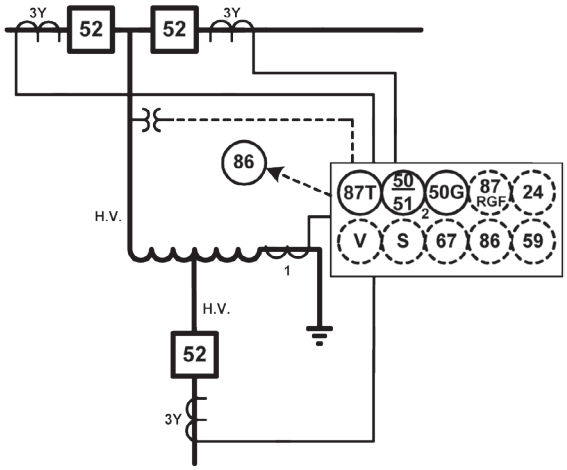


Typical Functions	
87T	Differential
86	Lockout auxiliary
50/51	Overcurrent and short circuit (both sources)
50G	Ground fault

Additional Functions	
87RGF	Restricted Ground Fault
67	Directional overcurrent
24	Volts per Hertz
59	Overvoltage
V, S	Voltage and Power metering

Functions	Typical Product Order Code
Typical Functions	**T60-N00-HCH-F8N-H6P-MXX-PXX-UXX-WXX** **T35-N00-HCH-F8N-H6P-MXX-PXX-UXX-WXX**
+ Voltage and Power metering	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX** **T35-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
+ Additional Functions	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
Lockout Standalone Integrated	 **HEA61-A-RU-220-X2** **T35-N00-HPH-F8N-H6P-MXX-P4L-UXX-WXX** **T60-N00-HPH-F8N-H6P-MXX-P4L-UXX-WXX**

Auto-Transformer, Dual-Breaker Terminals

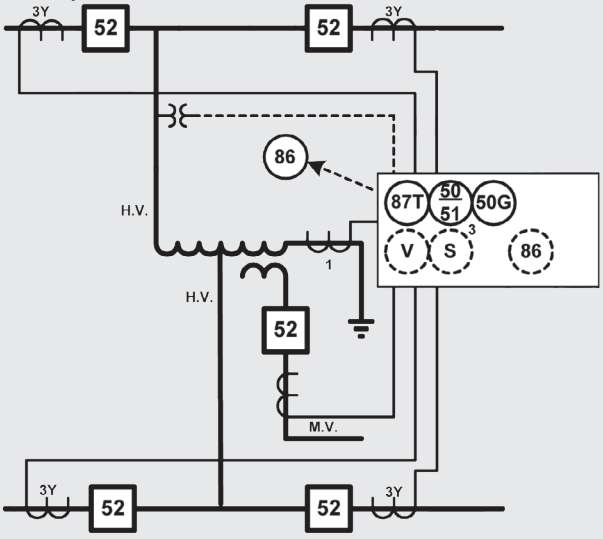


Typical Functions	
87T	Differential
86	Lockout auxiliary
50/51	Overcurrent and short circuit (two windings)
50G	Ground fault

Additional Functions	
87RGF	Restricted Ground Fault
67	Directional overcurrent
24	Volts per Hertz
59	Overvoltage
V, S	Voltage and Power metering

Functions	Typical Product Order Code
Typical Functions	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX** **T35-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
+ Voltage and Power metering	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX** **T35-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
+ Additional Functions	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
Lockout Standalone Integrated	 **HEA61-A-RU-220-X2** **T35-N00-HPH-F8L-H6P-M8N-P4L-UXX-WXX** **T60-N00-HPH-F8L-H6P-M8N-P4L-UXX-WXX**

Auto with Dual-Breaker on both sides and loaded tertiary

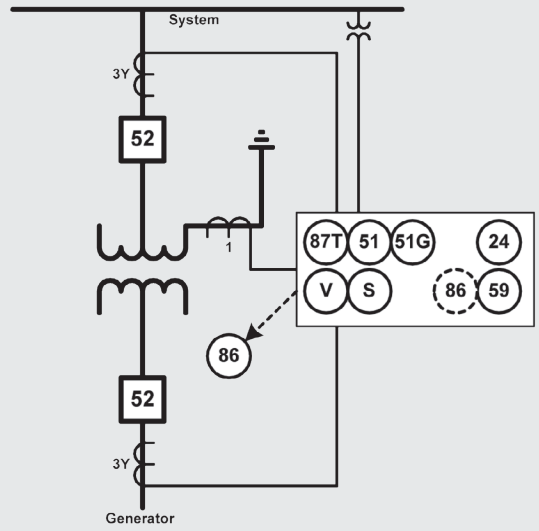


Typical Functions	
87T	Differential
86	Lockout auxiliary
50/51	Overcurrent and short circuit (three windings)
50G	Ground fault

Additional Functions	
V, S	Voltage and Power metering

Functions	Typical Product Order Code
Typical Functions	**T35-N00-HCH-F8L-H6P-M8N-PXX-U8N-W6P**
+ Voltage and Power metering	**T35-N00-HCH-F8L-H6P-M8N-PXX-UXX-W6P**
Lockout Standalone Integrated	 **HEA61-A-RU-220-X2** **T35-N00-HPH-F8L-H6P-M8N-P4L-U8N-W6P**

Generator Step Up Transformer

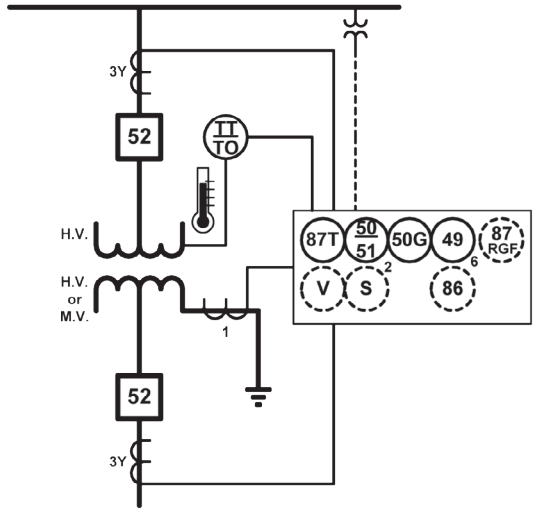


Typical Functions	
87T	Differential
86	Lockout auxiliary
51	Overcurrent and short circuit (three windings)

Additional Functions	
51G	Ground Fault
24	Volts per Hertz
59	Overvoltage
V, S	Voltage and Power metering

Functions	Typical Product Order Code
Typical Functions	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-WXX**
Lockout	
Standalone	**HEA61-A-RU-220-X2**
Integrated	**T60-N00-HPH-F8L-H6P-M8N-P4L-UXX-WXX**

Thermal Overload Protection

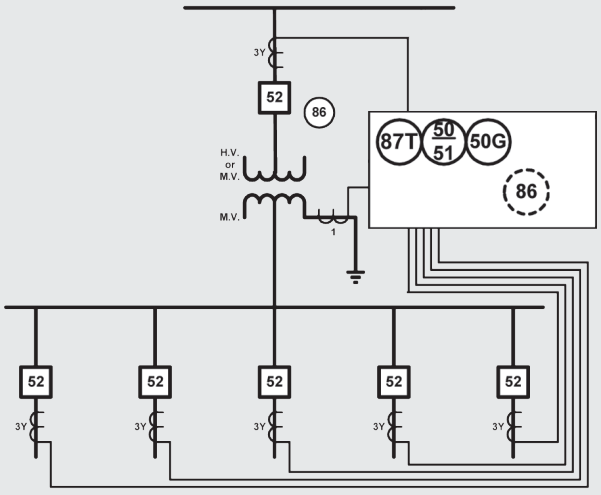


Typical Functions	
87T	Differential
86	Lockout auxiliary
50/51	Overcurrent and short circuit (two windings)
50G	Ground fault
TT/TO	Top Oil Temperature, RTD or Transducer
	Winding hot-spot temperature, loss-of-life
49	Thermal overload protection

Additional Functions	
87RGF	Restricted Ground Fault
V, S	Voltage and Power metering

Functions	Typical Product Order Code
Typical Functions	**T60-N00-HCH-F8N-H6P-MXX-PXX-UXX-W5E** **745-W2-P5-G5-HI-L-T**
+ Voltage and Power metering	**T60-N00-HCH-F8L-H6P-M8N-PXX-UXX-W5E** **745-W2-P5-G5-HI-L-T**
+ Additional Functions	**T60-N00-HCH-F8N-H6P-MXX-PXX-UXX-W5E** **745-W2-P5-G5-HI-L-R-T**
Lockout	
Standalone	**HEA61-A-RU-220-X2**
Integrated	**T60-N00-HPH-F8N-H6P-MXX-P4L-UXX-W5E**

Distribution Transformer with no load-side Circuit Breaker



Typical Functions	
87T	Differential
86	Lockout auxiliary
51	Overcurrent and short circuit (two windings)
50G	Ground fault

Functions	Typical Product Order Code
Typical Functions	**T35-N00-HCH-F8N-H6P-M8N-PXX-U8N-WXX**
Lockout	
Standalone	**HEA61-A-RU-220-X2**
Integrated	**T35-N00-HPH-F8N-H6P-M8N-P4L-U8N-WXX**

6. References

IEEE Std C37.91-2000 IEEE Guide for Protective Relay Applications to Power Transformers