University of Cape Town

Department of Electrical Engineering (EEE3100S - 2022)

LABORATORY PRACTICAL: IEC61850 PROTECTION & AUTOMATION LAB

The aim of this practical is to introduce students to micro-processor relays including their configuration for protection and automation within a substation.

A one-line diagram of the substation is shown in Figure 1 below. The panel uses a simplified model of a substation with low power rating equipment. The substation consists of a 230V ac source modelling an incoming supply from the grid connected to bus 1 along Feeder 1 (Incoming Feeder). A 230/36V 500VA step down transformer is connected along feeder 2. The transformer is used to step down the high voltage to supply the load.

It is to be noted that for simplification, the 3 phase connections are not shown here. The substation network diagram is shown as single feeders, but they are designed in 3-phase. Assume that residential loads are connected to buses 1 and 2.

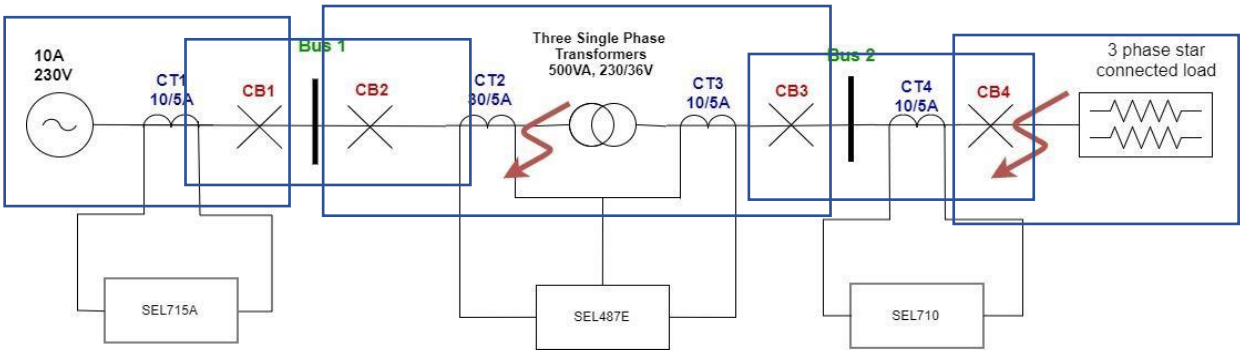

Figure 1: Substation One line Diagram with relays

The panel uses SEL relays, push-buttons to apply the faults, light indicators to illustrate the open and close positions of the circuit breakers, contactors to model the circuit breakers and Current Transformers to lower the current levels.

Question 1

a. How many zones of protection are there in the substation?

5 Zones

b. How should the system operate if an internal fault develops in the transformer?

Circuit breakers CB2 and CB3 Must trip to isolate the zone

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c. How should the system operate if a fault occurs on the load side?

CB4 Must trip.

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Procedure

- Reset all the targets on the relays using the "*TARGET RESET*" Pushbutton.
- The HMI and the relays have already been connected to the SEL2725 ethernet switch using RJ45 ethernet cables.

HMI Configurations and communication with relay

- Change the ethernet adapter IPv4 properties of the HMI to match its IP address in the ethernet network you set up.

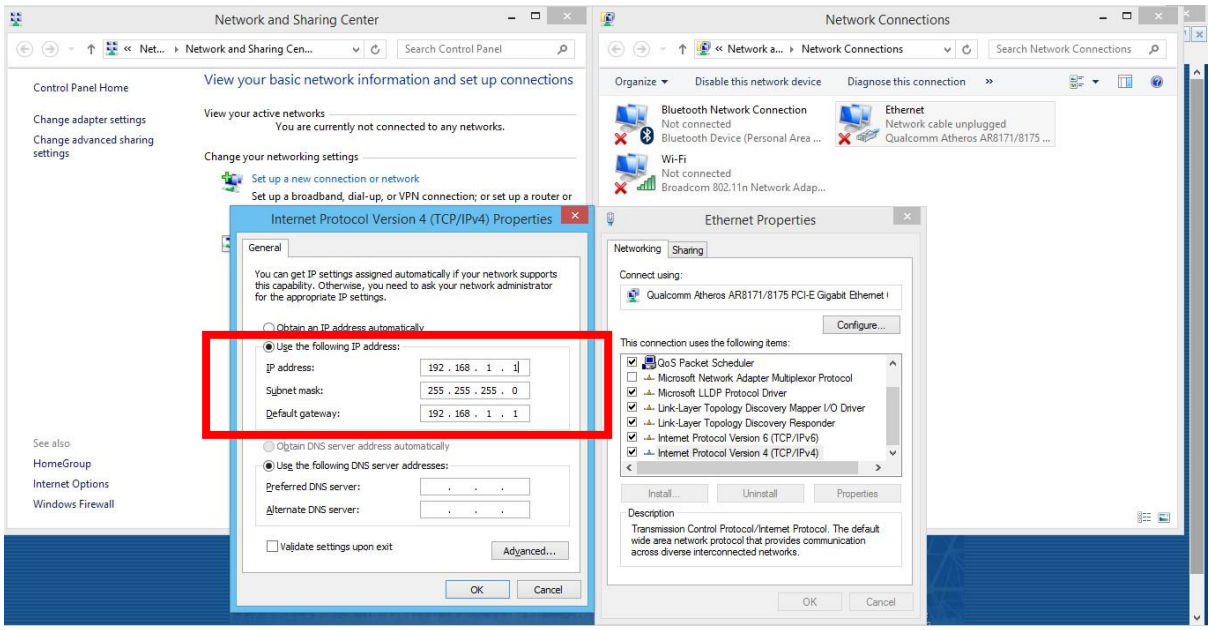

Figure 2: Steps to change the IPv4 properties of HMI for communication with relay

- Using SEL AcSELerator QuickSet, set up the communication parameters for the relay to read and write data.
- A connection should be established between the HMI and the relay. The TXD and RXD should be lit when transferring and receiving data.

Determining fault current levels

Relay pickup settings are calculated using the fault currents. In this section, we will determine the currents flowing in Feeders 1-3 using the SEL relays under no fault, internal fault and external fault conditions. We will use some of these values to configure the relay settings.

Note:- To apply the internal and external faults, press the fault pushbuttons **making sure that the push-button is in the closed position for less than 5s**.

Question 2

Why should the push-button only be pressed for a short time interval?

The fault current is at its highest during the subtransient period (the short time interval). If pressed longer, the relay will look at it as an ongoing fault.

- The relay pickup values have been pre-configured to a high value so that the relay does not pick up any fault condition.
- Inhibit all the circuit breakers including the 5 A circuit breaker.
- Using the 3-phase supply from the Power Engineering Lab, apply power to the substation.
- At this point, the green LEDs should be on and the red LEDs should be off indicating a no-fault condition. There should be no trip conditions asserted on the relays. (*TARGET RESET the relays if any trip condition asserts).*

Question 3

a. Connect to the SEL751A relay and open its HMI. Go to "Phasors" to see the 3-phase currents including their magnitude and angle. Find the current (including angle) in feeder 1 under no fault, internal fault, and external fault conditions.

Feeder 1 current (Measure using SEL751A)			
Phase	***No fault***	***Internal fault***	***External fault***
A	$0.20\ A \angle 0.00°$	$2.20\ A \angle 0.00°$	$0.30\ A \angle 0.00°$
B	$0.20\ A \angle -118.80°$	$2.00\ A \angle -171.60°$	$0.20\ A \angle -140.10°$
C	$0.20\ A \angle 117.10°$	$0.30\ A \angle 131.00°$	$0.20\ A \angle 119.80°$

a. Connect to the SEL487E relay and open its HMI. Go to "Phasors" to measure the current in Feeder 2 under no fault condition, internal fault and external fault condition. Note that 'S' is the primary terminal and 'T' is the secondary terminal of the relay.

Feeder 2 primary currents (Measure using SEL487E)			
Phase	***No fault***	***Internal fault***	***External fault***
IAS	$0.175\ A \angle 154.61°$	$2.209\ A \angle 19.87°$	$0.244\ A \angle 4.02°$
IBS	$0.154\ A \angle 40.08°$	$1.871\ A \angle -148.61°$	$0.194\ A \angle -128.10°$
ICS	$0.162\ A \angle -84.69°$	$0.310\ A \angle 148.08°$	$0.155\ A \angle 123.78°$

Feeder 2 secondary currents (Measure using SEL487E)			
Phase	***No fault***	***Internal fault***	***External fault***
IAT	$0.318\ A \angle -0.15°$	$0.181\ A \angle -162.13°$	$0.905\ A \angle -164.27°$
IBT	$0.306\ A \angle -118.41°$	$0.476\ A \angle 100.75°$	$0.332\ A \angle 81.87°$
ICT	$0.315\ A \angle 118.60°$	$0.360\ A \angle 20.15°$	$0.303\ A \angle -31.38°$

b. On the SEL487E, go to "Differential metering" to find the values of the operate currents (IOPx, x = A,B or C) and restraint currents (IRTx, where x = A,B or C) from the SEL487E under no fault condition, internal fault and external fault condition.

Operate current (IOPx)			
Phase	***No fault***	***Internal fault***	***External fault***
A	0.10A	1.71A	0.09A
B	0.09A	1.45A	0.12A
C	0.09A	0.22A	0.09A

Restraint current (IRTx)			
Phase	***No fault***	***Internal fault***	***External fault***
A	0.18A	1.76A	0.31A
B	0.16A	1.53A	0.20A
C	0.17A	0.29A	0.16A

c. Connect to the SEL710 relay and open its HMI. Go to "Phasors" to see the 3-phase currents including their magnitude and angle. Find the current (including angle) in feeder 3 under no fault, internal fault and external fault conditions.

Feeder 3 current			
Phase	***No fault***	***Internal fault***	***External fault***
A	$0.3\ A \angle 0°$	$0.2\ A \angle 0°$	$0.9\ A \angle 0°$
B	$0.3\ A \angle -117.0°$	$0.5\ A \angle -97.2°$	$0.3\ A \angle -120.7°$
C	$0.3\ A \angle 122.7°$	$0.3\ A \angle -176.2°$	$0.3\ A \angle 128.8°$

d. What should the SEL751A relay pickup value be set to if the relay is to be used for instantaneous overcurrent protection?

It should be set to 0.20A

e. What should the SEL710 relay pickup value be set to if the relay is to be used for instantaneous overcurrent protection?

It should be set to 0.3A

f. Sketch a plot of the relay under the 3 conditions. Note that the 087P setting is set to **1.00 pu**. The SLP1 setting is set to **10 %** and the SLP2 setting is set to **50 %**.

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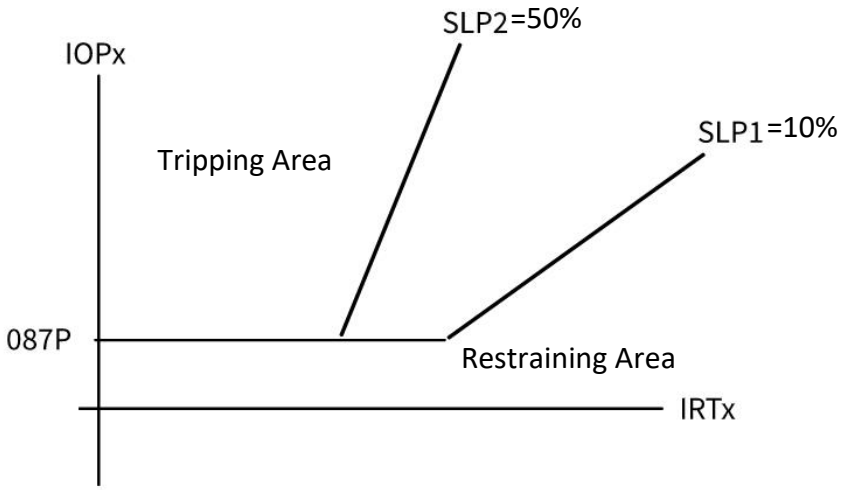
SLP2=50%
IOPx
SLP1=10%
Tripping Area
087P
Restraining Area
IRTx

g. The DIOPR and DIRTR settings on the SEL487E relay are incorrectly configured. What should these values be set to so that the relay detects the internal and external fault?

DIOPR = 0.09A and DIRTR = 0.16A

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Configure relay pickup settings and load settings to relay

1. Connect to the SEL487E relay and open the incorrect settings named "SEL487E_incorrect". Your tutor will assist you to find the directory for the incorrect settings.
2. Go to *Group 1 > Set 1 > Differential Element Configuration and Data*. Set the DIOPR and DIRTR settings on the relay using the values from (g).
3. Now, connect to the SEL710 relay and open the incorrect settings named "SEL710_incorrect".
4. Go to *Group 1 > Set 1 > Overcurrent Elements > Phase Overcurrent*. Use your answer in (e) to set the pickup current for the instantaneous overcurrent trip pickup (50P1P) in the SEL710 relay. Also, set the 087P setting to **1.00 pu**.

Automation and Communication using GOOSE messages

1. The SEL487E is pre-configured to send a GOOSE message to the SEL751A whenever the SEL487E relay issues a trip condition.
2. When the load experiences a fault, the feeder protection relay (SEL751A) should be informed of the fault. The SEL710 has also been pre-configured to send a GOOSE message to communicate the load fault to the SEL751A.

Applying faults and making observations

1. Press the internal fault push-button, again making sure it is pressed for less than 5s. Note all observations made.

The LEDs of SEL-487E that turn red are :Trip, A PH DIFF, B PH DIFF.

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LEDS that turn green: Trip BREAKER S01, Trip Breaker T01

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2. Allow some time for the fault current to disappear. TARGET RESET ALL THE RELAYS. You may have to do this multiple time.
3. Press the external fault push-button, again making sure that it is pressed for less than 5s. Note all observations made.

The LEDs of SEL-487E that turn red are : EXTERNAL FAULT

COMMS ALARM turns yellow

SEL710 shows TRIP LED in red.

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Question 4

a. What happens to the LEDs in the transformer differential protection zone during the internal fault? Explain what happens to the circuit breakers.

The LEDs in the zone go green to red. This symbolizes the circuit breakers CB3 and CB2 being open.

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b. What happens to the LEDs in the load protection zone during the external fault? Explain what happens to the circuit breakers.

Only the last two LEDs change, the green one turns off and the red one is on to show a trip in the circuit breaker CB4

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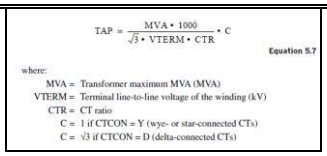
Appendix A

SEL751A & SEL710 Settings

Configurable Settings	
CTRP	Current Transformer Ratio on Phase
CTRN	Current Transformer Ratio on Neutral
VNOM	Nominal Voltage
DELTA-Y	Current Transformer connection (Delta or Star)
50P1P	Instantaneous Phase Level 1 Overcurrent Pickup
50P1D	Instantaneous Phase Level 1 Overcurrent Pickup Delay
50P1TC	Instantaneous Phase Torque Control Equation The torque control equation defines the conditions when the overcurrent element asserts. The relay uses a cosine filtering mechanism to filter the dc offset and harmonics due to severe CT saturation. The 5A rating relay can support up to 40A phase current with the assertion of the bipolar peak detector of the relay.
TR	The *TRIP* relay word bit is associated with the *TR* control equation. Hence, when the SEL751A issues a trip condition, the *TRIP* relay word bit is asserted (becomes a binary value of 1). The relay word bit can then be mapped to GOOSE messages so that other IEDs are aware of the trip condition.
OUT102	Output contact 102
OUT103	The output contacts are used to trip or close the breakers and turn on or off the indicators used on the protection panel. The output contact used on the SEL751A relay is the OUT103 (on Slot A) which provides a Normally Open and a Normally Closed Contact. These 2 contacts operate together when OUT103 asserts. The Fail Safe operation setting is explained in the SEL751A Instruction Manual. When the SEL751A issues a TRIP condition or the level 1 phase instantaneous pickup asserts (50P1P), the NO contact closes and the NC contact opens.
ER	Event Report
LER	Length of Event Report
Communication Parameters	
IP	Internet Protocol Address
Subnet Mask	Usually set 255.255.255.1
Gateway	Usually set 192.168.1.1
IEC61850 PROTOCOL	Should always be set to 'Y' to enable the IEC61850 protocol.
IEC61850 GOOSE	Should always be set to 'Y' to enable the IEC61850 GOOSE messages to be exchanged.

SEL487E Settings

Configurable Settings	
NFREQ	Nominal Frequency
ECTTERM	Enable specific current terminals of the SEl487E relay
E87	Enable specific terminals in the differential element
CTRx; x = S,T,U,W or X	Current Transformer Ratio on Terminal x.
CTCONx; x = S,T,U,W or X	Current Transformer connection (Delta or Star) for Terminal x.
E87Tx; x = S,T,U,W or X	Include Terminal x in the differential element (Set to 1 to include the terminal)
ICOM	Internal CT Compensation Matrix Enabled
TAPx; S,T,U,W or X	
087P	The maximum allowed differential current is set using the 087P setting of the relay
SLP1	Slope 1 Percentage (Consult adaptive slope for SEL487E for more details)
SLP2	Slope 2 Percentage (Consult adaptive slope for SEL487E for more details)
U87P	Unrestrained Element Current Pickup
DIOPR	Incremental Operate Current Pickup
DIRTR	Incremental Restraint Current Pickup
Trip Logic	
TRXFMR	Trip condition for transformer terminals
ULTXFMR	Unlatch Trip condition for transformer terminals
TRx; S,T,U,W or X	Trip Condition for terminal x.
ULTRX; S,T,U,W or X	Unlatch trip condition for terminal x.
TDURD	Minimum trip duration
ER	Conditions for triggering event reports
FAULT	Conditions for asserting fault bit
Outputs can be configured for any purpose. OUT102 and OUT106 are connected to breakers 2 and 3.	
Event Reporting	
SRATE	Sample rate of event report
LER	Length of Event Report
PRE	Length of pre-fault

Event Reporting Analog Quantities and Digitals can be chosen as per user choice.	
Port/Communication Parameters	
IPADDR	Device IP Address/ CIDR Prefix
DEFRTR	Default Router
FTPSERV	Enable FTP Server (Should always be enable for File Transfer between HMI)
IEC61850 PROTOCOL	Should always be set to 'Y' to enable the IEC61850 protocol.
61850 GOOSE	Should always be set to 'Y' to enable the IEC61850 GOOSE messages to be exchanged.

Appendix B – Control circuit (Auxiliary circuit)

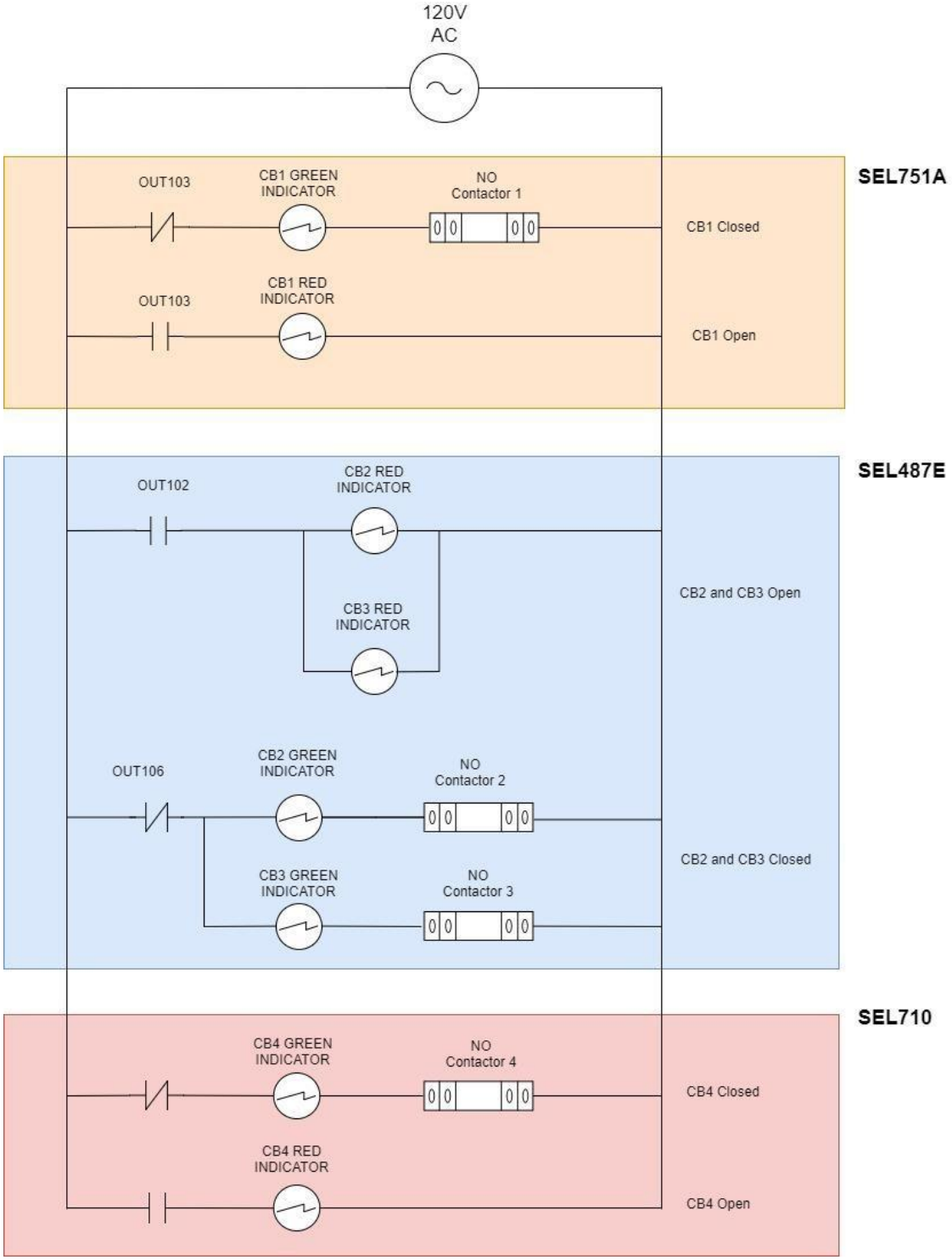


Figure B.1: DC Control circuit wiring diagram

Figure B.1 shows the control circuit including the connection between the relay contacts, contactors and light indicators.

Appendix C – Protection panel wiring diagram

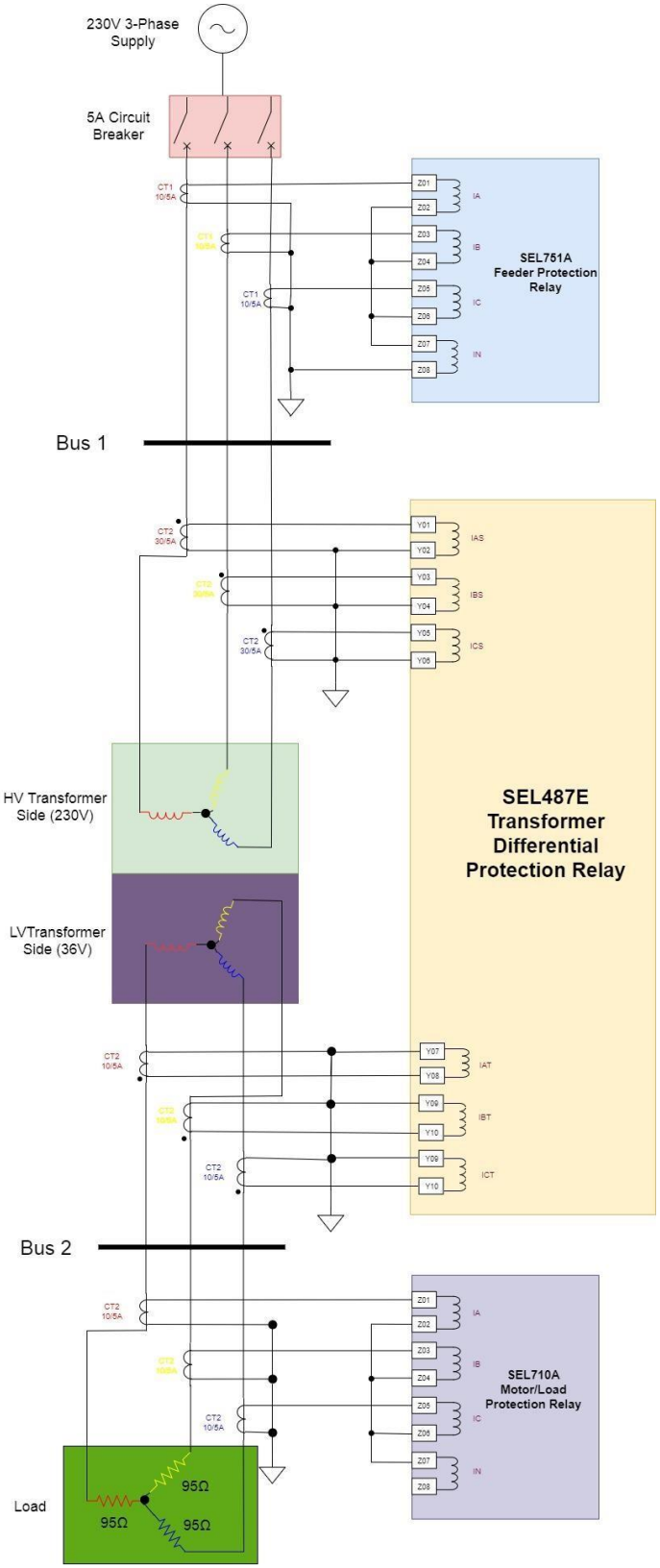


Figure C.1: Protection Panel wiring diagram