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Applications of Automated Protective Relay Testing

Josh LaBlanc

First, automated protective relay testing….

What is it?

Where can it be applied?

- Preventative Maintenance Testing
  - The applications are endless and depends on your companies testing program
- Relay Commissioning
  - End-to-End Testing
  - Transformer Testing
  - Bus Differential Testing
- NERC CIP
  - Data Verification

What are the benefits?

- If designed correctly can reduce human error.
- Can complete repetitive, boring tasks in a very short amount of time allowing the end user to focus more of their time in the areas that need attention.
- Can be used in maintenance testing to provide consistency in testing results formatting.
- Can use automation as a peer check on the overall protection system.
- Can perform relay data verification. (Very useful in the CIP realm)

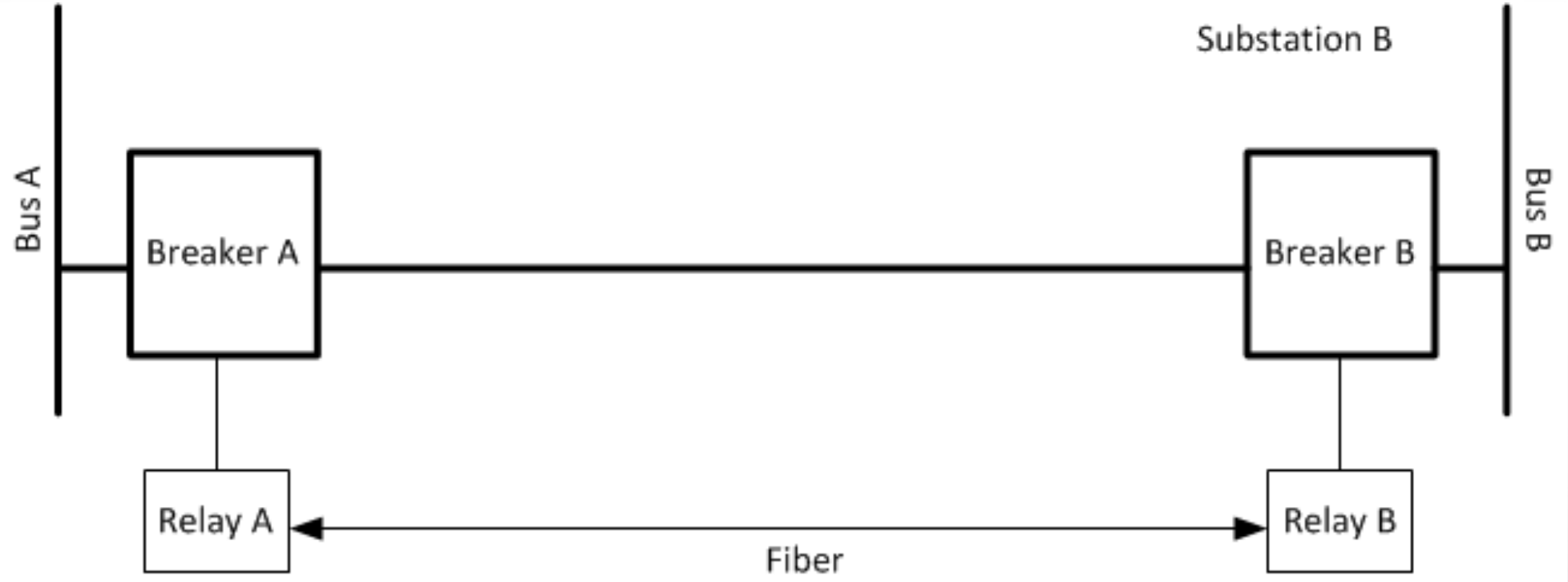
Human Error

- Nobody makes mistakes, right?

- Common Relay Maintenance Testing Mistakes
  - Forgetting to remove of a protection system device from service as part of testing isolation.
  - Forgetting to test an element that needs testing.
  - Testing something and forgetting to mark the results.
  - Flipped or backwards wiring connections when performing A/D converter tests.

Human Error

- Examples
  - PM testing Line Current Differential relays….



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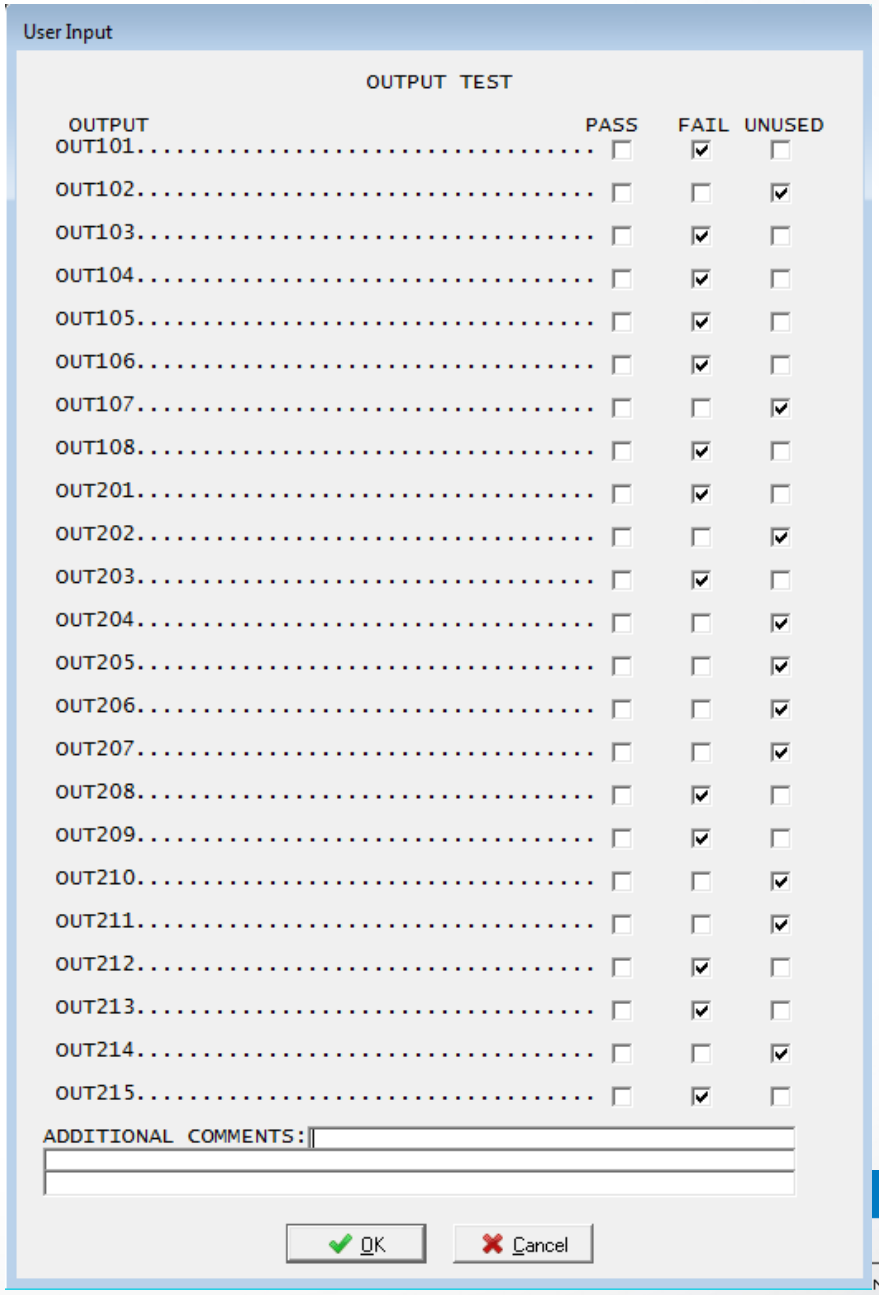
Human Error

- Examples
  - Common elements that get missed during testing…
    - Relay Outputs
    - Relay Inputs
    - Auxiliary Relays
  - How can these errors be minimized?

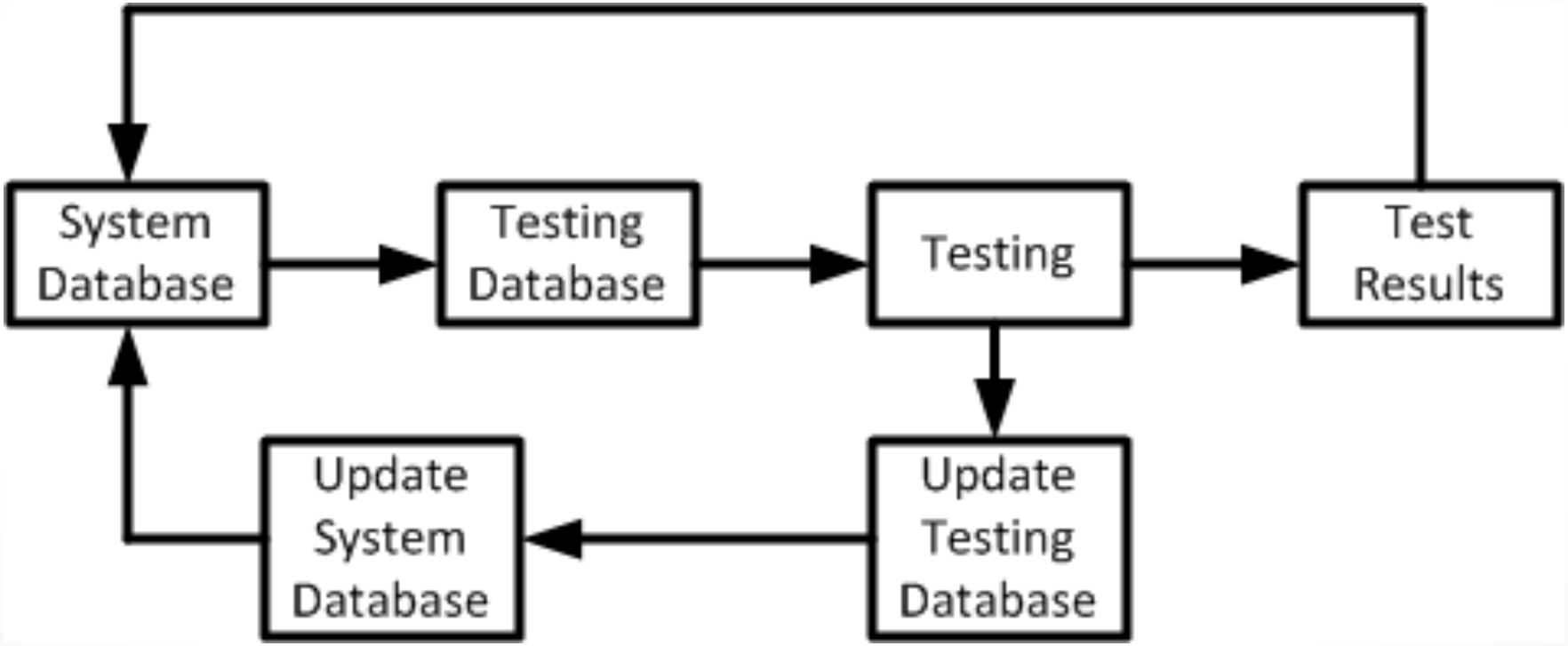
Human Error

- Outputs



Human Error

- Auxiliary Devices



Human Error

- Examples
  - What if the testing circuit is incorrectly wired?
    - Using a few simple calculations we know what the relay's response to common circuit errors are going to be.
      - Comparing Phase Rotation
      - Comparing System Magnitudes
      - Etc.
    - If these calculations indicate incorrectly wired circuits, the end user can be informed before the testing routine are sent to print allowing them to make adjustments to wiring before printing.

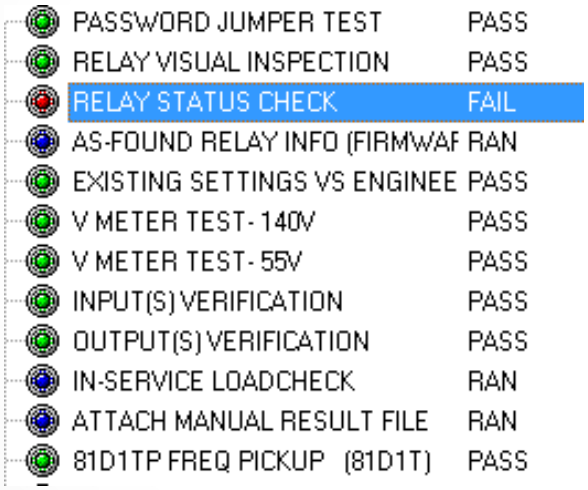
Time is Valuable

- How can time be saved?
  - Green Light, Red Light….
    - Load Checks
    - Input Testing
    - Output Testing
    - Relay Status Checks
    - Relay Setting Compares
    - A/D Converter Testing
  - Automated testing routines can grab information from relays automatically, thus the end user doesn't need to spend time writing it down.
    - **Automation is quicker, people are smarter!**

Time is Valuable

- Green Light, Red Light Principle

This has a failure in it!




```
81UF                                        Date: 09/15/2016   Time: 08:09:33
MAHTOWA SUB                                 Time Source: Internal

Serial Num = 2007256379      FID = SEL-751A-R101-V0-Z002001-D20070806
CID = 761D                   PART NUM = 751A01A1A1A71850000

SELF TESTS (W=Warn)
  FPGA  GPSB  HMI   RAM   ROM   CR_RAM  NON_VOL  CLOCK  +3.3V  +5.0V  +2.5V
  OK    OK    OK    OK    OK    OK      OK       OK     3.30   5.02   2.53

  +3.75V  -1.25V  -5.0V  BATT
  3.80    -1.29W  -5.06  3.47

Option Cards
  CARD_C  CARD_D  CARD_E  CURRENT
  OK      OK      OK      OK

Offsets
   IA    IB    IC    IN    VA    VB    VC
  OK    OK    OK    OK    OK    OK    OK

  Relay Enabled

=>>
```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Time is Valuable

- Green Light, Red Light Principle

This does not!

PASSWORD JUMPER TEST	PASS
RELAY VISUAL INSPECTION	PASS
AS-FOUND RELAY INFO (FIRMWARE/BFID/SN/PN)	RAN
RELAY STATUS CHECK	PASS
EXISTING SETTINGS VS ENGINEER SETTINGS	PASS
METER TEST- 2.5A, 140V	PASS
METER TEST- 12A, 55V	PASS
INPUT(S) VERIFICATION	PASS
OUTPUT(S) VERIFICATION	PASS
IN-SERVICE LOADCHECK	RAN

```
ARROWHEAD 131L 21S                Date: 10/03/16    Time: 16:43:26.138
ARROWHEAD 131L 21S

FID=SEL-311A-R105-V0-Z003002-D20020703       CID=73D4

SELF TESTS

W=Warn    F=Fail

        IA       IB       IC       IP       VA       VB       VC       MOF
OS      0       -1        0        1       -0       -0       -0        0

        +5V_PS  +5V_REG -5V_REG +12V_PS -12V_PS +15V_PS -15V_PS
PS       5.03     5.02   -4.95    12.11  -12.13   14.99  -15.06

        TEMP     RAM      ROM      A/D      CR_RAM   EEPROM   IO_BRD
         38.5    OK       OK       OK       OK       OK       NA

 Relay Enabled

=>>
```


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Time is Valuable

- Load Checks
  - When verifying legitimacy of a load check, the engineering brain is making a lot of logical decisions.
  - Why not use logic in automation to filter only the load check results that need detailed investigation.
  - 90% of load checks can be verified to be satisfactory by simple automation logic.
  - The remaining 10% are flagged and verified by an engineer
    - **Automation is quicker, people are smarter!**

Time is Valuable

- Load Check Filtering, 3-Phase Applications
  - Compare phase rotation on both current and voltage.
  - Compare phase angle displacement is close to 120°.
  - Compare metered voltage magnitudes to the nominal value.
  - Compare metered current magnitudes to verify they are roughly balanced.
  - Verify the circuit power factor is above an acceptable level.

Time is Valuable

- Relay Settings Check Example (3-Phase Routine)
  - Is this a failure?

```
              3 PHASE VOLTAGE/CURRENT LOAD CHECK

       SUBSTATION:BLANCHARD 115/14 KV SUB
         PANEL:45L              RELAYS:21-1;21-2;21-3

              VOLTAGE   PH ANGLE    CURRENT   PH ANGLE
    A PHASE:  66.5       0           .244       265
    B PHASE:  67.2       119         .263       16
    C PHASE:  67.5       240         .279       144

              VNOM:67              RESULT:FAIL

    ------------------------------------------------
```

- Not necessarily

Time is Valuable

- Load Check Filtering, Single Phase
  - Compare metered voltage magnitudes to the nominal value.
  - Compare metered neutral voltage magnitudes to verify they are non-zero but substantially large.
  - Compare metered neutral current magnitudes to verify they are non-zero but substantially large.

Time is Valuable

- Load Check Filtering, Differential Schemes
  - Why not meter the differential element?
  - Should see minimal operate current and substantial restraint current!

```
          TRANSFORMER DIFFERENTIAL LOADCHECK

SUBSTATION:GRAND RAPIDS 115/23 KV SUB
PANEL:1TR              RELAYS:87T

                  % DIFF      TOLL
 A PHASE:          0.00%    < 2.5%
 B PHASE:          0.00%    < 2.5%
 C PHASE:          0.00%    < 2.5%

                RESULT:RAN

-----------------------------------------
```

Time is Valuable

- Load Check Filtering, Sync
  - Compare metered voltage magnitudes to the nominal value.
  - Compare metered phase angle displacement to verify minimal displacement between the two sources.

Time is Valuable

- Relay Settings Check Example (Sync Routine)
  - Can anyone see the relay settings problem?
    - Relay is a SEL-421
    - 115kV Nominal System
    - PTRY=1000 (Corresponds to Vpmag)
    - PTRZ=600 (Corresponds to NVS1mag)

```
MET SYN

Verndale 133L 115 KV 21P                    Date: 10/19/2015  Time: 18:54:18.139
Verndale 133L 115 KV 21P                    Serial Number: 1142900296

Breaker 1 133L

  VPmag      NVS1mag      Angle1      Slip1
    (V)         (V)         (Deg)       (Hz)
 115.53       69.36       -1.157      0.000

=>

MET BK1
```

Time is Valuable

- Relay Settings Check Example (Sync Routine)
  - Can anyone see the relay settings problem?
    - The relay sync element KS1M setting was sent to 1.
    - Per SEL-421 logic, PT ratios should be accounted for in the setting, therefore it should have been set to 1.66.
    - Automated checks prevented a breaker reclosing failure.

```
                SYNC CHECK LOAD CHECK

SUBSTATION:VERNDALE 115/34 KV SUB
  PANEL:133L          RELAYS:21P

                  MEASURED    NOMINAL
                  VOLTAGE     VOLTAGE
     REFERENCE: 115.5         110.8
        SOURCE: 69.36         110.8

          DISPLACEMENT ANGLE:  -1.

   BKR STATUS:OPEN         RESULT:FAIL

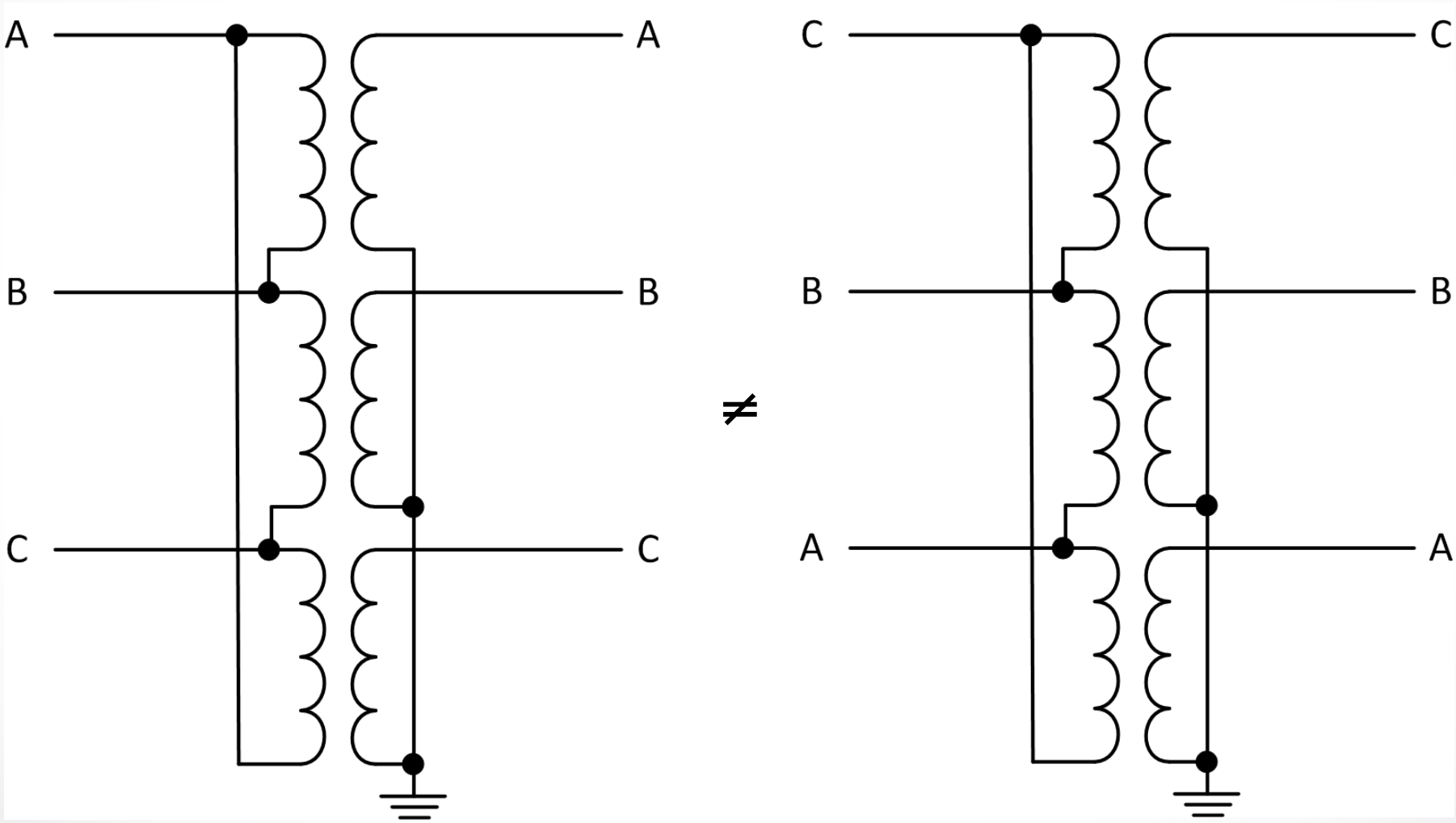
-------------------------------------------
```

Format Consistency

- Auditors love formatting consistencies!
  - Automation guarantees the testing results for each particular element are printed the same every time.
  - Testing results formats are not dependent on each individuals documentation methods.
  - Consistent formats are much easier to provide an engineering review as compared results with formatting inconsistencies.

Commissioning Peer Check

- Delta-Wye Transformer Testing



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Commissioning Peer Check

- Things to consider when commissioning a Delta-Wye Transformer Relay
  - How are the delta windings of the transformer internally connected? DAB or DAC?
  - How are the transformer delta windings externally connected to the power system? ABC or ACB?
  - How are the CTs connected? Same polarity or opposing polarity?
  - CT ratios?
  - Transformer Turns Ratio?
- Gathering Data
  - Always formulate questions so that you are testing the system and NOT the relay!

Commissioning Peer Check

- Transformer Example Questions
  - From the transformer nameplate, how are the delta windings internally connected to one another?
  - From the system three line diagram, how are the transformer's delta windings connected to the power system?
  - From the system three line diagram, are the differential relay's current transformers connected in opposing or the same polarity?
  - From the system three line diagram, what are the ratios of the primary and secondary current transformer ratios used in the differential scheme?
  - From the transformer nameplate, what are the operating primary and secondary voltages of the transformer?

Commissioning Peer Check

- Delta-Wye Transformer Testing
  - The most important test is a through line to ground fault of the transformer.
  - With minimal operate and substantial restraint current during this test, the correct transformer voltage and compensation angle is confirmed.
  - Note that the way this test is set up, the protection system was tested and not the protective relay!
    - If relay settings are used as inputs into the test setup, you are only testing that the relay behaves according to how you have programmed it. This isn't much different than an A/D converter test during a preventative maintenance test.

Commissioning Peer Check

- Transmission Line End-to-End Testing
  - Again, tests the protection system and not the relay!
  - Fault quantities can be exported out of power system modeling software to be used as real time fault simulation when performing End-to-End testing.
  - The transmission line relay communication scheme is really being tested in a transmission line End-to-End test.
    - Care should be taken when deciding where to place faults for simulation in the modeling software.

Commissioning Peer Check

- Transmission Line End-to-End Testing
  - Automation can be used on relays to automatically save the relay SER's to results which in turn speeds up testing.
  - When using automation during testing, the user should pay attention to every device to verify the correct operation of each device during the tests.
  - The user should then review the SERs saved with each test to verify the correct relay logic operations.

CIP

- What benefit can automation have in CIP?
  - CIP is extremely information, comparison, and tracking intensive.
  - Automation can perform a large amount of the mind numbing tasks CIP requires!
    - Automated routines can compare relay information to verify no discrepancies where expected.
    - Automated routines can tell the end user the password complexity allowed from the device simply by gathering and analyzing the relay firmware string.
    - Automation can gather and print all the relay port settings using terminal programs.
    - Relay information can be automatically updated to a relay nameplate in the system database by simply using import functions.

CIP

- Data Verification Example

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  3.80    -1.29W  -5.06  3.47

Option Cards
  CARD_C  CARD_D  CARD_E  CURRENT
  OK      OK      OK      OK

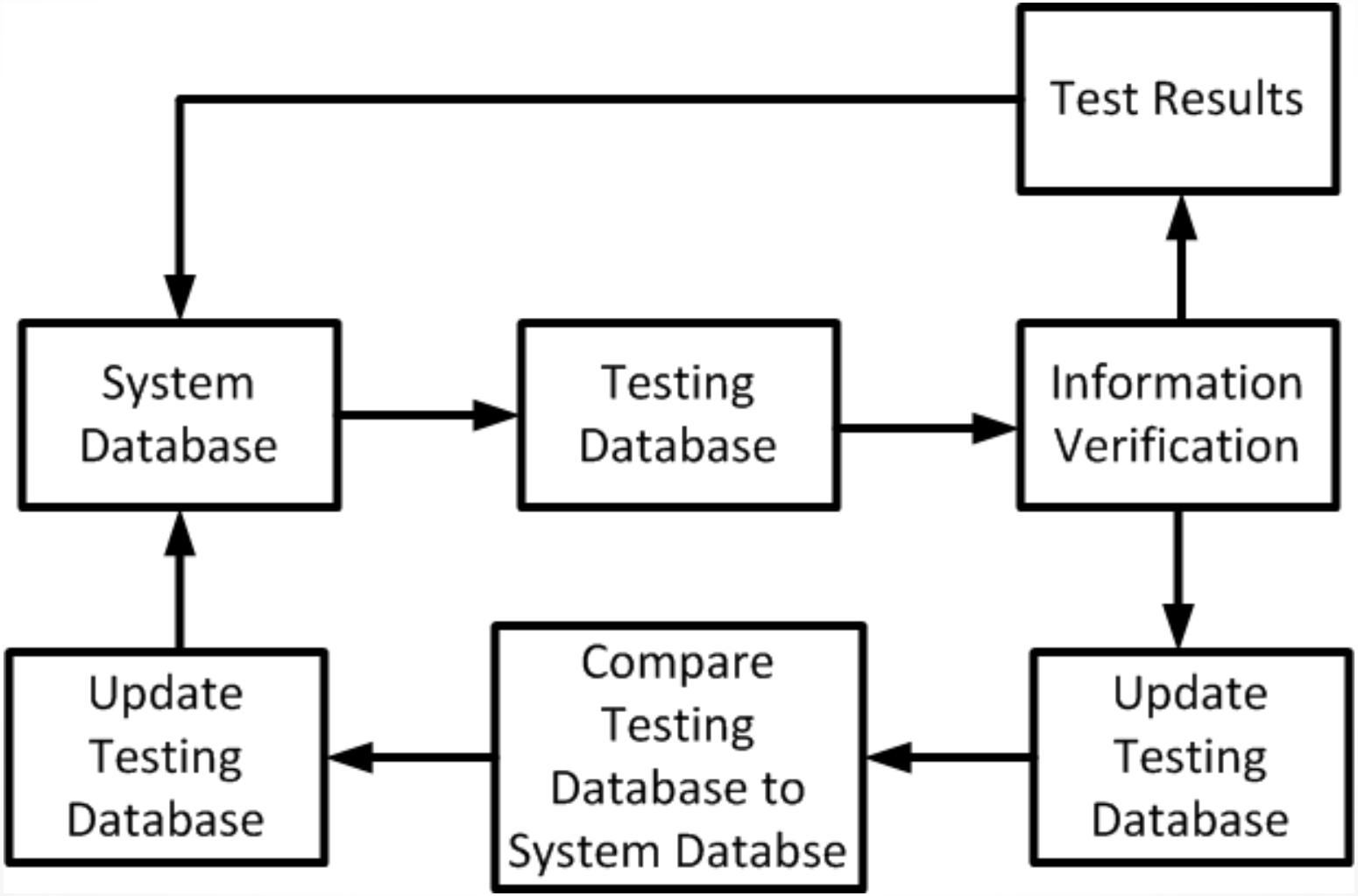
Offsets
   IA    IB    IC    IN    VA    VB    VC
  OK    OK    OK    OK    OK    OK    OK

  Relay Enabled

=>>
```

CIP

- CIP Flow Diagram



Lessons Learned and Advise

- Lessons Learned
  - Have an overall vision and stick to that vision.
  - Gather all possibilities of application of the relay before scripting the testing routine.
  - When first using a testing routine, print more to results than needed. It helps for debugging if program errors occur.
  - When creating routines, there will be bugs just get used to it and be proactive in fixing them.
  - Start with the hardest routine. Often, parts of this routine can be copied to other routines.
  - Automated testing routines can always be made better. Be accepting of constructive feedback.

Lessons Learned and Advise

- Advise
  - The programmer should have a solid familiarity of a three phase power system.
  - Ask the tester for feedback wherever possible, especially if program bugs are found. The tester is your best help!
  - Have familiarity of the entire automated process.

Questions?