



Reliability and Resiliency of High Voltage Transmission and Distribution in support of Space Mission

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Content



Importance of
Ground support

Importance of
reliable and resilient
power supply

Technologies used to
enhance and improve
power supply

Importance of Ground support



Launch Infrastructure/Facilities

- Launch pads & supporting infrastructure
- Payload processing & vehicle integration facilities
- Supporting ground infrastructure systems
- Ground Support Equipment (GSE)

Ground Operations Facilities/Infrastructure

- Mission Operations facilities & data centers
- Radome and antenna sites

Weapons Systems Infrastructure

- Global Strike Command
- Intercontinental ballistic missile (ICBM)
- Missile Defense

Test Infrastructure/Facilities

- Vacuum chambers (e.g. thermal testing)
- Test stands
- Supporting infrastructure systems

Power Distribution Infrastructure

- High power distribution
- Power generation & back-up
- Uninterruptible power systems (UPS)

Mobile Ground Systems

- Ground terminals & supporting ground systems
- Supporting the warfighter (air/ground)
- Transporter systems
- Mobile Launcher systems

Nuclear Infrastructure/Facilities

- Fuel conversion/processing
- Research (e.g., Magnetic laboratories)
- Testing/Laboratories

Large Ground-based Telescope Infrastructure/Facilities

- Antenna array systems (radio, radar)
- Optical reflecting telescopes, Infrared telescopes

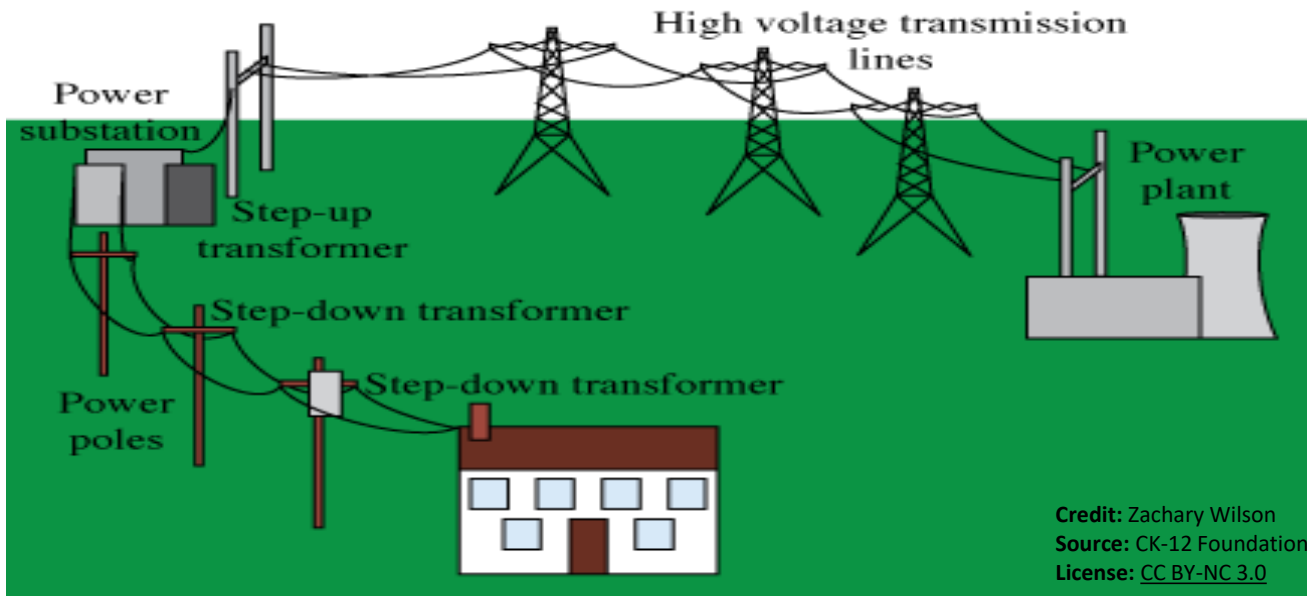
Manufacturing/Production Facilities

- Satellite manufacturing
- Rocket assembly

Data Center

- Containerized data center
- Fixed site data center

Electrical Power Infrastructure



- Aerospace customer typical area of operation/responsibility
 - HV Transmission (38 kv to 100 kv Typical; distances >5 miles)
 - Distribution Substation (HV to 12kv; consists of transformers and switchgear)
 - MV Distribution (12 kv; distances of <5 miles)
 - LV Distribution (<1kv, consists of distribution transformers and switchboard)
- Voltages and Frequencies will vary based on country.



Why does it matter for Space?

- Often ground power is not viewed as being as critical as space power.
 - *We have heard people say, “Ground power isn’t that important because, unlike power in space, we can easily fix it when it breaks.”*
 - *All power is important. These are time critical facilities that must be available and be reliable when needed.*
 - *Persistent power problems in any aspect of space can negatively affect mission.*
- **Available** - the capability of an electrical system to provide quality power, often measured as an uptime rate over a defined period.
- **Reliable** - ability of an electrical system to consistently supply power to customers, even when there are unexpected events
- **Resilient** - the ability of a power grid to withstand and recover from power outages



How to improve power system availability, reliability and resiliency?

- Proper testing and Commissioning
- Anomaly Analysis
- Using Instrumentation
 - *Current Transformers (CT)*
 - *Potential Transformers (PT)*
- Using ANSI Standard Protective Elements
 - *50 – Instantaneous Overcurrent*
 - *51 – AC Time Overcurrent*
 - *52 – AC Circuit Breaker*
 - *87 – Differential*
- Instrumentation provides low voltage signal that can be used to determine magnitude and phase of voltage, current, power, reactive power and frequency.



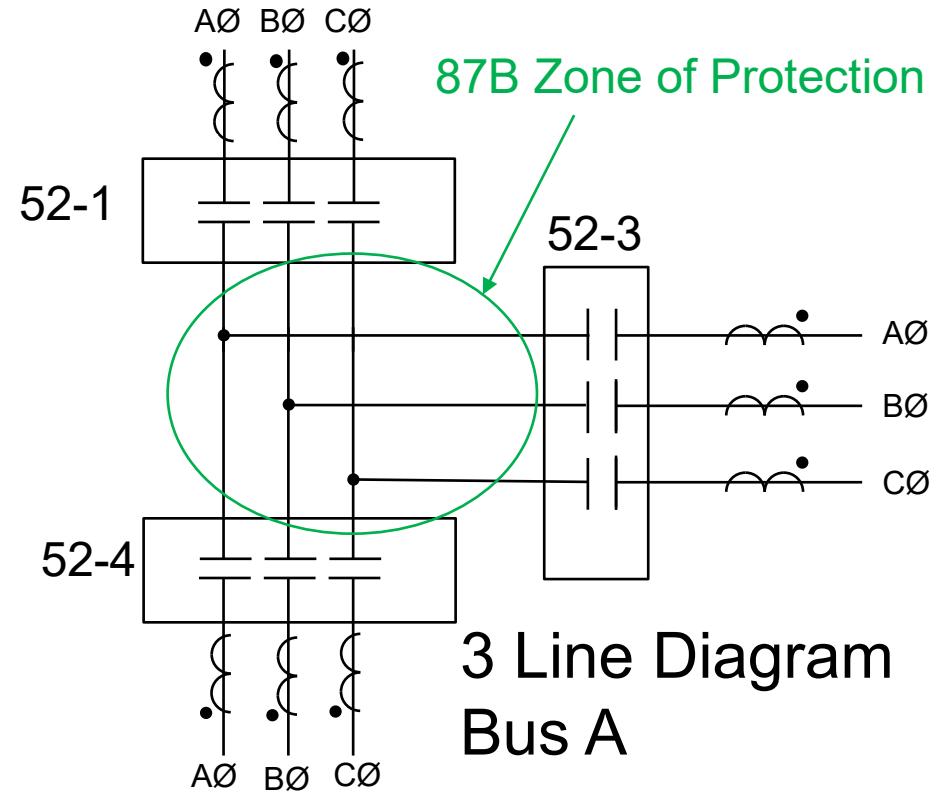
Introduction to SCADA

- SCADA plays a vital role in automating power system operations.
- Integration of advanced control algorithms and decision-making logic enables autonomous actions such as fault detection, isolation, and restoration (FDIR), load shedding, and voltage regulation.
- Some advantages
 - *enhanced monitoring and control,*
 - *improved efficiency*
 - *faster response to faults.*
- Provides Metering, Configuration Management, Anomaly/Event Data, Trips, Breaker Status, Logic Status, High Speed Oscillography.



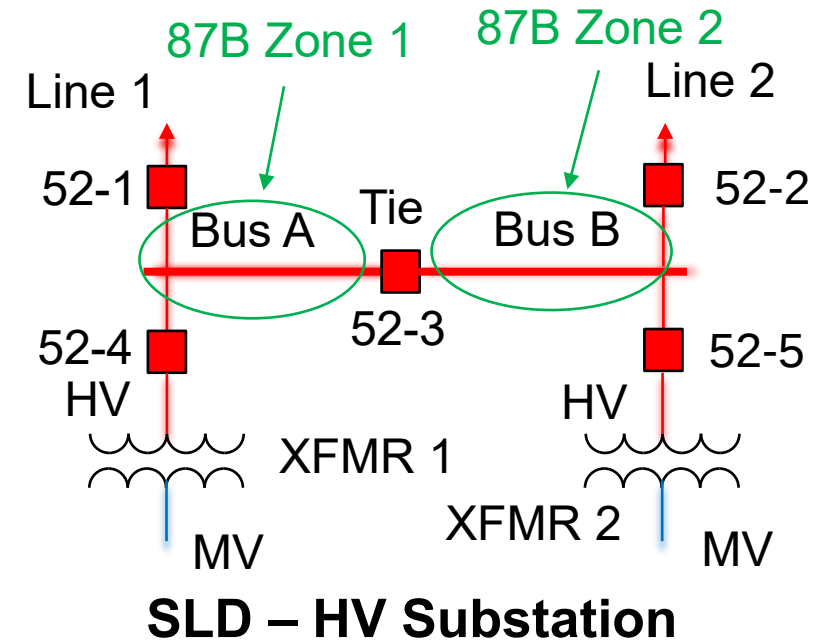
Example #1 – 87B – Bus Differential Mis operation

- Differential protection is fast, zone specific and reliable
- Works for LL, LG Faults
- 87B for zone has 9 CT's
- AØ, BØ and CØ zones have 3 CT's each
- Any 87B trip will open all phases for Bus.

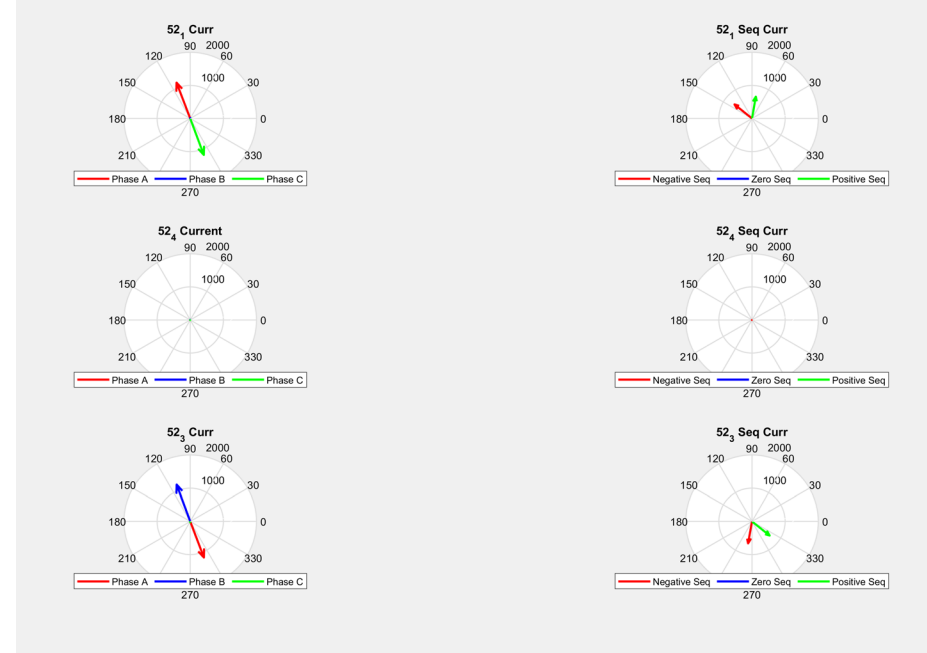


Example 1 – 87B Bus Differential Mis operation

- Protection Mis Operation types
 - *False Trip*
 - *No Trip*
- This example is for a false trip. Actual Fault was about 10 miles from substation and the Line differential relay tripped on LL fault.
- Bus Differential is based all current entering Bus A is equal to all current leaving Bus A.
- Closed Tie is example of reliable operation and design.



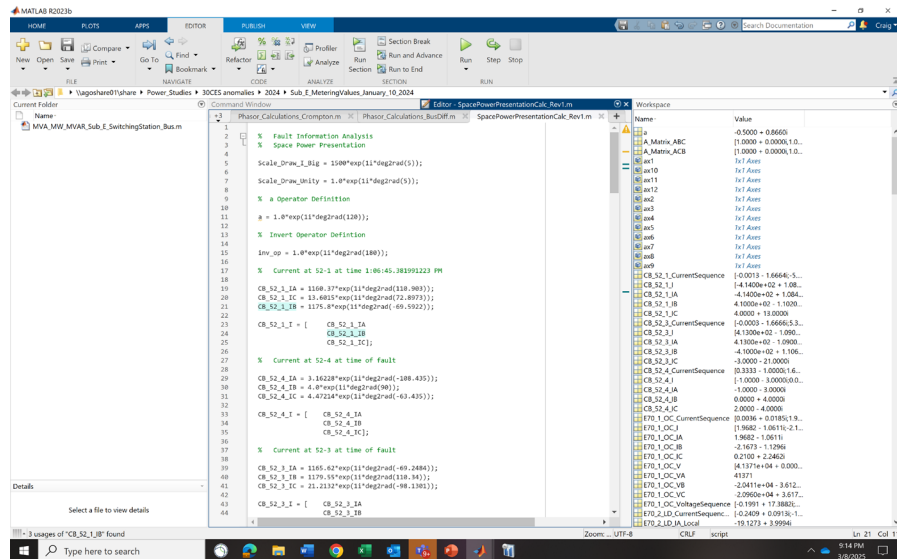
Example #1 – 87B – Bus Differential Mis operation



- AØ net is zero, BØ net is non-zero and CØ net is non-zero
- Sequence Currents net is non-zero
- No zero sequence current – not a ground fault
- Magnitude of positive and negative sequence currents is equal – line to line fault
- Swapping BØ and CØ at 52-1 results in all phase currents net zero and all sequence currents net zero

Introduction to MATLAB

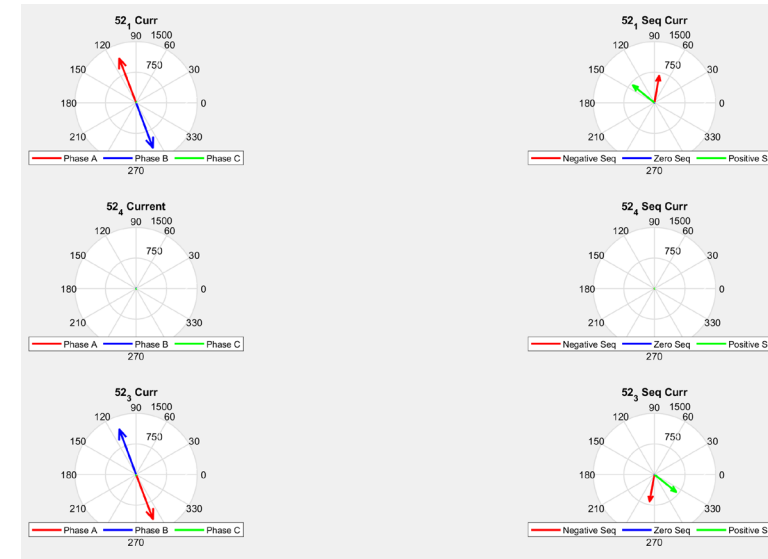
- MATLAB is used to carry out system analysis in form of:
 - *Phasor Diagrams*
 - *Sequential Components*
 - *Transformer Connection Compensation*
 - *Simulation*



The image shows the MATLAB R2023b environment. The main window displays a script titled 'Fault Information Analysis'. The script defines variables for fault location, fault type, and fault current. It then calculates the fault current using the formula $I_f = \frac{V_{LL}}{\sqrt{3} \cdot Z_{f+g}}$. The results are displayed in the Command Window.

```
1 % Fault Information Analysis
2 % Space Power Presentation
3 %
4 % Scale Draw Unit = 1500*exp(11*deg2rad(5));
5 %
6 % a operator Definition
7 %
8 % a = 1.0*exp(11*deg2rad(120));
9 %
10 % Invert Operator Definition
11 %
12 % Inv_op = 1.0*exp(11*deg2rad(180));
13 %
14 % Current at 52-3 at time 1:06:45.383992223 PM
15 %
16 % CR_52_3_1A = 1160.37*exp(11*deg2rad(138.989));
17 % CR_52_3_1B = 1160.37*exp(11*deg2rad(138.989));
18 % CR_52_3_1C = 1160.37*exp(11*deg2rad(138.989));
19 % CR_52_3_1R = 1175.4*exp(11*deg2rad(49.5922));
20 %
21 % CR_52_3_1I = [ CR_52_3_1A
22 % CR_52_3_1B
23 % CR_52_3_1C ];
24 %
25 % Current at 52-4 at time of fault
26 %
27 % CR_52_4_1A = 3.16228*exp(11*deg2rad(-188.435));
28 % CR_52_4_1B = 4.0*exp(11*deg2rad(90));
29 % CR_52_4_1C = 4.0*exp(11*deg2rad(90));
30 % CR_52_4_1R = 4.0*exp(11*deg2rad(90));
31 % CR_52_4_1I = [ CR_52_4_1A
32 % CR_52_4_1B
33 % CR_52_4_1C ];
34 %
35 % Current at 52-5 at time of fault
36 %
37 % CR_52_5_1A = 1165.62*exp(11*deg2rad(-69.2886));
38 % CR_52_5_1B = 1179.5*exp(11*deg2rad(138.989));
39 % CR_52_5_1C = 1179.5*exp(11*deg2rad(138.989));
40 % CR_52_5_1R = 1179.5*exp(11*deg2rad(138.989));
41 % CR_52_5_1I = [ CR_52_5_1A
42 % CR_52_5_1B
43 % CR_52_5_1C ];
44 %
```

MATLAB programing



Phasor diagrams

Summary



- A reliable ground support is necessary to enable any space-based capabilities i.e. to receive, transmit, process, launch etc.
- To support the launch missions, payload processing facilities, ground stations and data center a reliable and resilient power source is required.
- The system resiliency and reliability can be enhanced and improved using microprocessor based protective relays, SCADA (Supervisory Control and Data Acquisition) combined with mathematical modelling of power systems.



Thank you



Definitions and Acronyms

- SCADA - Supervisory Control and Data Acquisition
- MATLAB – is a proprietary multi-paradigm programming language and numeric computing environment developed by MathWorks
- SLD – single line diagram
- False Trip – a type of protection failure wherein tripping results in response to an event outside of the zone of protection.
- No Trip – a type of protection failure wherein no tripping occurs in response to an event inside the zone of protection. Often results in significant damage.