Performance Measures

- Communication network level

Failures

- Failures of communication
  - » Impact of single point failure
  - » Risks and rewards of adding more components

Industrial Process Performance Expectations

- Need quantifiable measures of performance
  - » Based on proper outcome of the process
- Engineering design has measurable performance expectations based on physics.
- Especially systems or components where failures effect human safety
- Does a failure in communication device leave no option for safe failure mode
- Updating equipment in process environment not trivial

Fault Tree Analysis

- Look at the steps in the process
  - » For example, tripping a circuit breaker upon detection of a fault
- Look at the components involved
  - » And the communication paths
- Look at failure modes of that equipment
  - » And probability of failure
  - » Can go a step further and look at effects of failures

Six Line Substation Example

- With RTU for now

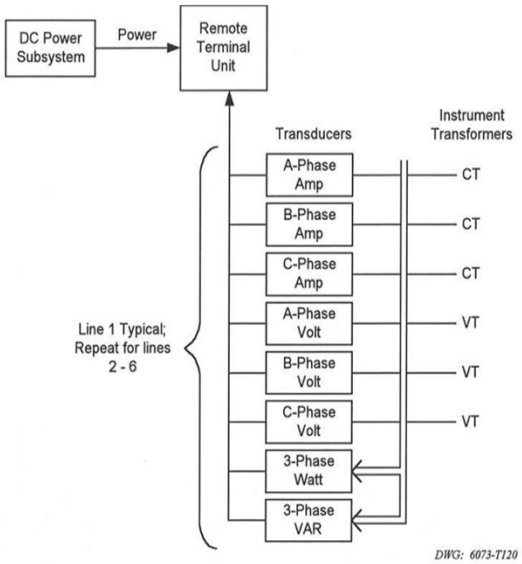

Figure from: G.W. Scheer, "Answering Substation Automation Questions Through Fault Tree Analysis," *4th Annual Substation Automation Conference, 1998*

Supervisory Control & Critical Infrastructures

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Fault Tree for Not Acquiring Data from Line 1

- Equipment on left common to comparison cases
- This case has a RTU

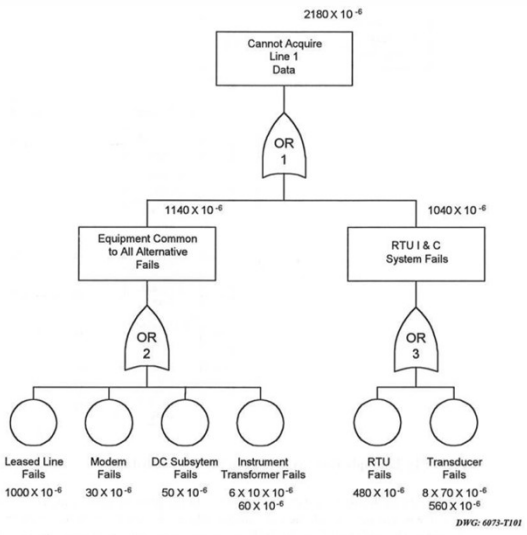

Figure 2: Fault Tree for RTU System in Six-Line Substation

Figure from: G.W. Scheer, "Answering Substation Automation Questions Through Fault Tree Analysis," *4th Annual Substation Automation Conference, 1998*

Supervisory Control & Critical Infrastructures

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Fault Tree for Cannot Operator Breaker 1 or Acquire Data from Line 1

- Equipment on left common to comparison cases
- Added the circuit breaker
- A in triangle is identifying equivalent circuit

Figure from: G.W. Scheer, "Answering Substation Automation Questions Through Fault Tree Analysis," *4th Annual Substation Automation Conference, 1998*

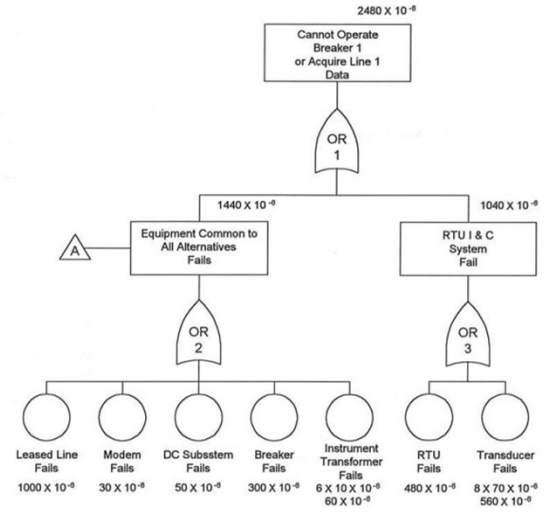
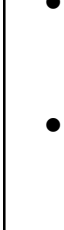


Figure 3: Fault Tree for RTU-Based I&C System in Six-Line Substation



Replace RTU with Communications Processor in Star Topology

- Communication Processor more reliable than RTU
- Lower overall unavailability score

Figure from: G.W. Scheer, "Answering Substation Automation Questions Through Fault Tree Analysis," *4th Annual Substation Automation Conference, 1998*

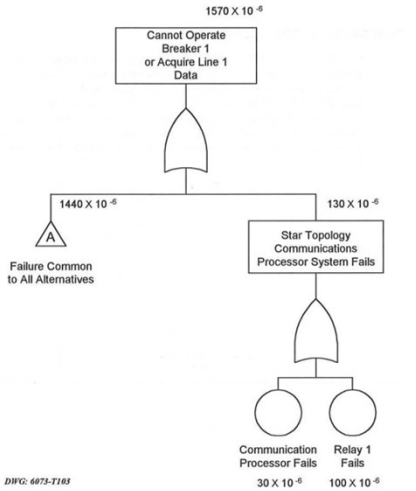


Figure 4: Fault Tree for Relay and Communications Processor Star I&C System in a Six-Line Substation

Replace RTU with PC Communicating with Relays in Multidrop Serial Network

- PC is single point of failure and is less reliable that communication processor or RTU
- Note the network failure path

Figure from: G.W. Scheer, "Answering Substation Automation Questions Through Fault Tree Analysis," *4th Annual Substation Automation Conference, 1998*

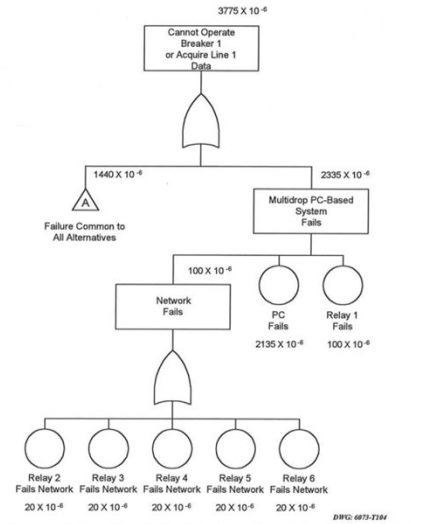


Figure 5: Fault Tree for a PC Multidrop Relay Network in a Six-Line Substation

Replace PC with Hardened Industrial PC

- PC is still single point of failure
- But now the PC is more reliable one

Figure from: G.W. Scheer, "Answering Substation Automation Questions Through Fault Tree Analysis," *4th Annual Substation Automation Conference, 1998*

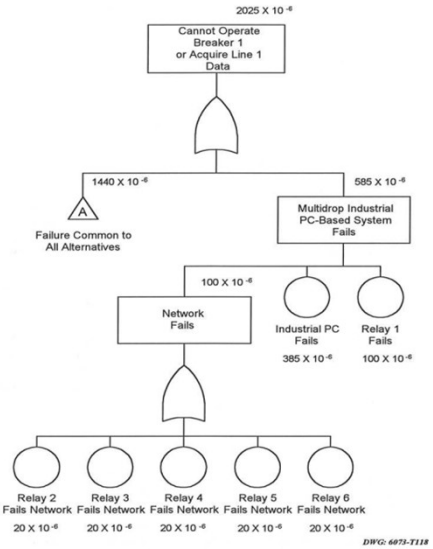


Figure 17: Fault Tree for Industrial PC Multidrop Network in a Six-Line

Can Use Fault Trees to Compare Hardware Options or Network Configurations

Table 2: Approximate Unavailabilities of Six-Line Substation Systems for Top Event *Cannot Sense or Operate Line 1*

System	I&C Unavailability	Total Unavailability
RTU-based	1040×10^{-6}	2480×10^{-6}
Communications processor star to relays	130×10^{-6}	1570×10^{-6}
PC star to relays	2235×10^{-6}	3675×10^{-6}
Industrial computer star to relays	485×10^{-6}	1925×10^{-6}
PC multidrop to relays	2335×10^{-6}	3775×10^{-6}
Industrial PC multidrop to relays	585×10^{-6}	2025×10^{-6}
PLC multidrop to relays	520×10^{-6}	1960×10^{-6}

From: G.W. Scheer, "Answering Substation Automation Questions Through Fault Tree Analysis," 4th Annual Substation Automation Conference, 1998

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Generalize for failure of any control action or communication

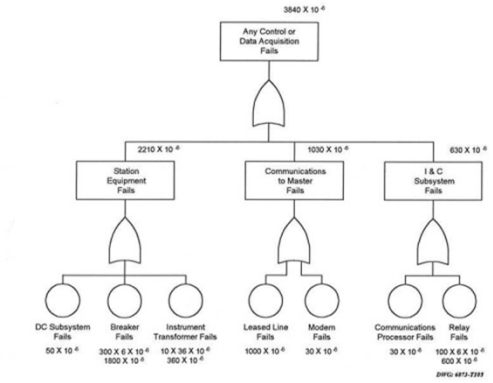

Figure 6: Fault Tree for Any Failure of Relay and Communications Processor Star I&C System in a Six-Line Substation

Figure from: G.W. Scheer, "Answering Substation Automation Questions Through Fault Tree Analysis," 4th Annual Substation Automation Conference, 1998

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Adding Redundancy

- Also have redundancy in the dc power supply
- And the power system apparatus

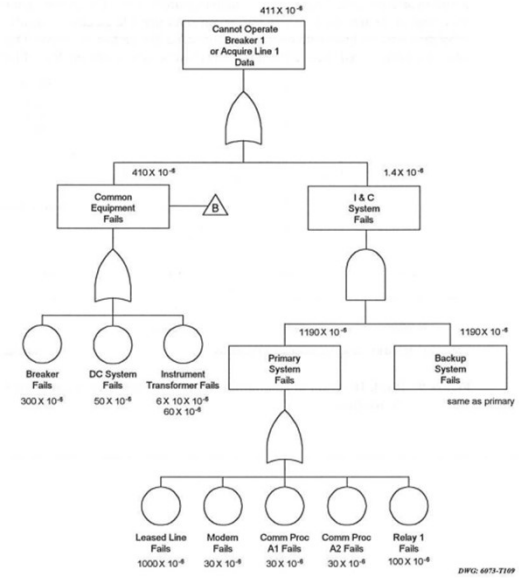

Figure 10: Fault Tree for Communications Processor I&C System for 54-Line Substation

Figure from: G.W. Scheer, "Answering Substation Automation Questions Through Fault Tree Analysis," *4th Annual Substation Automation Conference, 1998*

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Comparing Ethernet Network Device Choices and Topologies

Component	Unavailability (10^{-6})*
Communications Processor	30
Ethernet Hub	46
IED (protective relay)	55
IED Network Interface	285
Monitoring/metering IED	320
Industrial PC	385
SCADA Gateway	385
Ethernet switch	477
Ethernet router	577

*G.W. Scheer and D.J. Dolezilek, "Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks," 2nd Annual Western Power Delivery Automation Conference, April 2000

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