Electrical Reliability Studies for Infrastructure Evaluation and Planning

Presented By:

Sid A. Gaudet IV, P.E.
Senior Electrical Engineer

AGENDA

- M S Benbow and Associates
- What is Reliability?
- What is Needed to perform a Reliability Study?
- How is Reliability Calculated?
- Using Software to Perform Calculations
- Reliability Improvement

WHAT IS RELIABILITY?

<u>Reliability</u> – precise meaning depends on the specific application

Electrical Reliability is a measure of the ability of a power distribution system to deliver sufficient electrical power to a system within accepted standards and in the amount desired

WHAT IS RELIABILITY ANALYSIS?

- Reliability Analysis – The determination of two main calculated indexes based on a system's topography, component selection, material condition, age, etc.

System Interruption Frequency (incidents / unit time)

System Expected Interruption Duration (time / incident)

IEEE 493 – IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems

RELIABILITY ANALYSIS TERMS

- Availability - The average fraction of time that a component or system is in service and satisfactorily performing its intended function
- Failure Rate – The mean number of failures of a component per unit exposure time (typically failures/year)
- MTBF – Mean Time Between Failures – The mean exposure time between consecutive failures of a component
- MTTR – Mean Time To Repair – The mean time to repair or replace a failed component

RELIABILITY ANALYSIS TERMS

- Cut-Set – A set of components that, if removed from the system, results in loss of continuity to the load point being investigated
- 1st Order Cut-Set – A Cut-Set containing only a single component
  - Example – A power transformer that is a single source of power for a distribution system
- 2nd Order Cut-Set – A Cut-Set containing two components
  - Example – A transformer feeding a MTM system, and the tie breaker failing to close upon interruption

CONSIDERATIONS FOR CUT-SETS

- N^{th} Order Cut-Sets includes N devices
- The probability of higher order cut-sets are much lower than lower order cut-sets
- Typically, the analysis only considers the minimum order cut-sets plus one higher order.
  - For Example, if you have 1^{st} order cut-sets, then we only consider 1^{st} and 2^{nd} order in the evaluation

WHAT INFORMATION IS NEEDED?

- Information needed depends on the type of equipment and the type of failure modes being considered
- The failure modes analyzed depend on the loss impact of the specific failure, and whether or not the system has a backup that will engage immediately upon failure
- An example would be an ATS with a redundant supply, or a breaker with redundant protection relays

FAILURE MODES

- Distribution Component Failures are calculated differently based on the type of outage they cause
  - Permanent Forced Outage – A component failure requires repair or replacement
  - Transient Forced Outage – Component failure does not result in component damage. The component can be immediately restored to service (for example an overcurrent trip)

  Note: Forced outage is defined as an outage/failure that cannot be deferred

FAILURE MODES

- Protection Component Failures have several different failure modes, each having different functions in a reliability study
  - Continuous Functions:
    - Operation due to short circuit or overload event
    - Switching device opening/closing without proper command
  - Response Functions:
    - Switching device fails to open/close on command
    - Protection system trips for a fault outside the protection zone

    Note that these failures are only manifested when response is required, so they is treated differently than a forced outage

FAILURE MODES

Reliability of systems and components is based not only on the design itself, but also on how the components are operated and maintained.

Common Failure Modes:

- Insufficient device ratings
- Insulation breakdown
- Corrosion (environmental impact)
- Compromised grounding
- Lack of surge protection
- Nuisance trips
- Harmonic content

Risks to Reliability:

- Lack of maintenance
- Improper coordination
- Outdated power studies
- Obsolescence
- Lack of spares
- Single points of failure
- Beyond useful life

FAILURE MODES

Equipment Useful Life

Equipment Type	Expected Useful Life Period (years)[1]
Transformers	25 to 30
Circuit Breakers	15 to 20[2]
Switchboards/Switchgear	30 to 40
MCC / Motor Starters	20 to 30
Panelboards	30
Motors	18 to 25
Generators	5 to 20
UPS	10
Luminaire	20
Capacitors (Power Factor Correction)	17
VFDs	20
Cable/Wire	30 to 40

[1]Life expectancy info collected from ABB, CDA, CDM, IEEE Gold Book, and Siemens.

[2]By year 10, 50% of circuit breakers don't function properly per specs. By year 20, 90% don't function properly.

COMPONENT INFORMATION

- Historical data is used to determine the average failure rates of different types of electrical equipment
- Many facilities have maintained records of failures that can be used in the analysis. When this information is unknown, IEEE 493 provides data from historical studies.
- Sometimes the consideration of environment can impact the numbers, and can be included in the calculation if desired
- When considering outage time, scheduled maintenance should also be included when determining the calculated availability of the system

COMPONENT INFORMATION

- Component Information needed for the analysis:
  - Frequency of failure (or MTBF)
  - Expected duration of the outage (or MTTR)
    - Repair or replacement time
    - Switching time for redundant systems
    - Component reset time for transient forced outage
  - Frequency of maintenance
  - Expected duration of maintenance outage

CALCULATING RELIABILITY

- The following are key variables used in calculating reliability in components and systems:

  d = MTBF (hours or years) ==> hours/8760 = years

  r = MTTR (hours or years) ==> hours/8760 = years

  λ = failure rate [1 / d] (failures / year)

  R = reliability [$e^{-(\lambda)}$]

  A = availability [d / (d + r)] (units do not matter)

  μ = repair rate [1 / r] (hours or years)

  P = probability of failure [1-R]

  *Note that MTBF and MTTR are based on historical data

CALCULATING RELIABILITY

- Example for a single component failure

  Given:

  d = MTBF = 10 years

  r = MTTR = 48 hours = 48/8760 years (0.00548 years)

  λ = failure rate = 1 / 10 years = 0.1 failures per year

  R = reliability [$e^{-(0.1)}$] = 0.9048 or 90.48 percent

  A = availability [10 / (10 + 0.00548)] = 0.99945 or 99.945%

  μ = repair rate [1 / 0.00548] = 182.48 failures per year of repair time

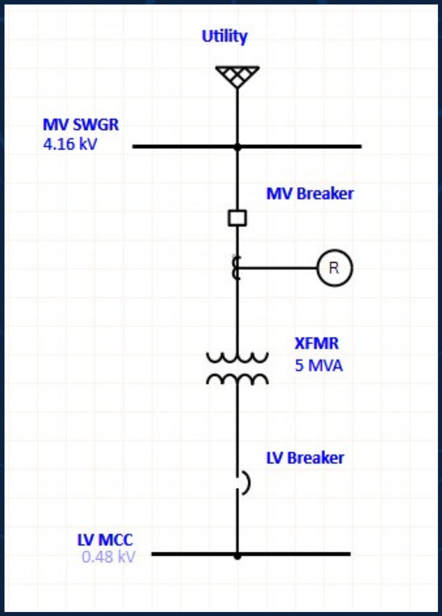
  *Note that repair rate is more useful for multiple order failures

  P = probability of failure [1-.9048] = 0.0952 or 9.52%

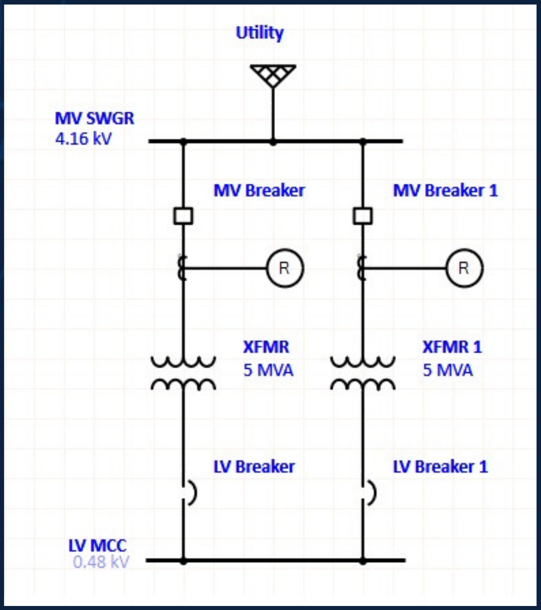
CALCULATING RELIABILITY

- Reliability is analyzed differently for multiple components whether in series or parallel

Series System:



Parallel System:



CALCULATING RELIABILITY

- Series System Analysis for the LV MCC

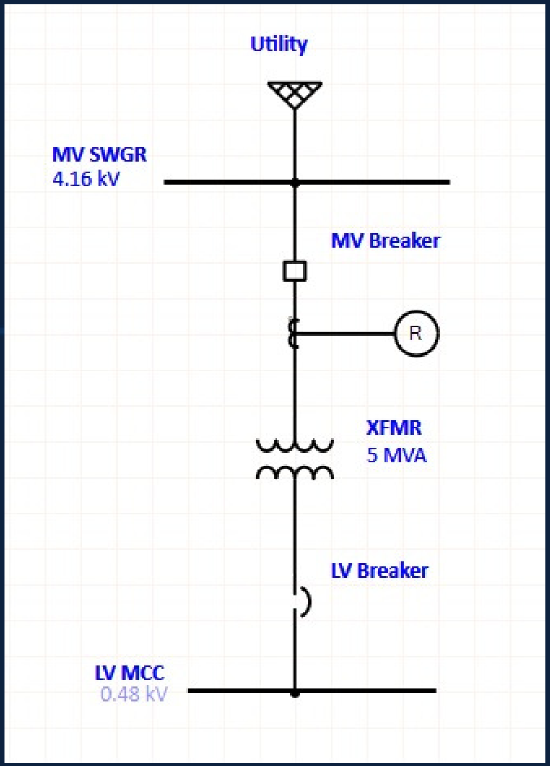
For the cut-set method, only 1 order is analyzed since any single element can cause a failure.

1st order failures:

MV SWGR
MV Breaker
LV Breaker
LV MCC
XFMR

Calculate reliability and availability for each component, then use the following formulas for the overall system calculations

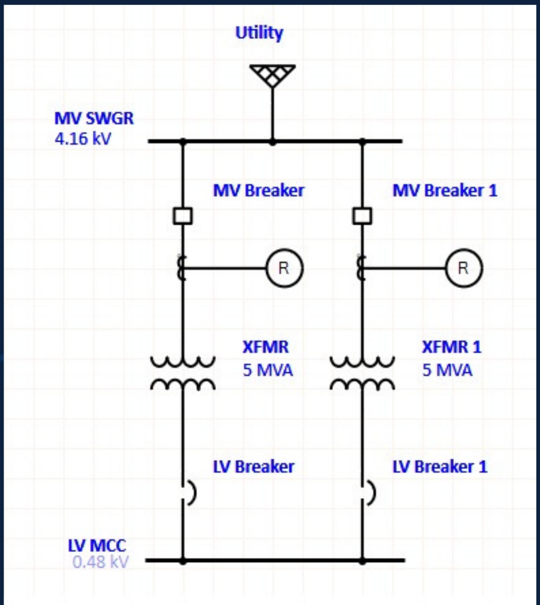
$$R_s = R_1 \times R_2 \times R_3 \times R_4$$
$$A_s = A_1 \times A_2 \times A_3 \times A_4$$



CALCULATING RELIABILITY

- Parallel System Analysis for the LV MCC

For the cut-set method, 2 orders are considered, the lowest order (n) that can cause failure, and the n+1 order failure. The system on the right has 1st and 2nd order failures.



1st order failures:	2nd order failures:
MV SWGR	MV Breaker + MV Breaker
LV MCC	MV Breaker + XFMR
	MV Breaker + LV Breaker
	LV Breaker + XFMR
	LV Breaker + LV Breaker
	XFMR + XFMR

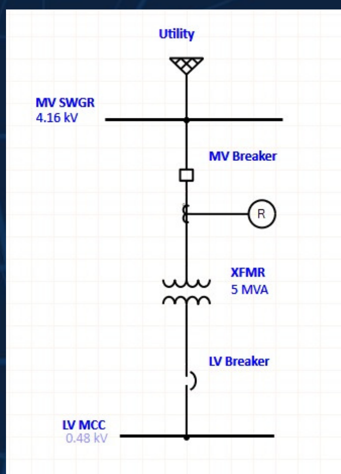
Reliability and Availability calculations depend on whether a parallel system is repairable or unrepairable. In a basic sense, the formula for combined reliability and availability for parallel systems S1 and S2 are as follows:

$R_p = [1 - (1 - R_{S1})(1 - R_{S2})]$
$A_p = [1 - (1 - A_{S1})(1 - A_{S2})]$

CALCULATING RELIABILITY

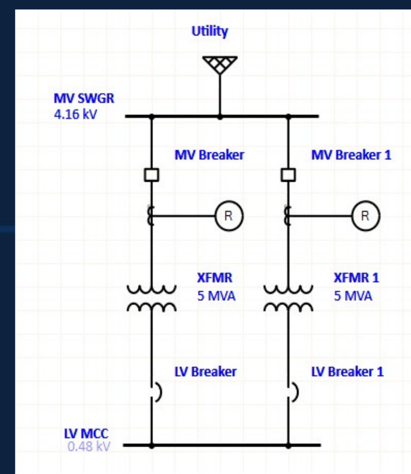
- Example Calculation Series Vs. Parallel

If we consider the MV breakers, XFMRs and LV Breakers for the 2 systems, how does the reliability and availability compare?



Let's assume the following:

MV Breaker	$R_1 = 0.98$
	$A_1 = 0.992$
XFMR	$R_2 = 0.97$
	$A_2 = 0.988$
LV Breaker	$R_3 = 0.99$
	$A_3 = 0.994$



Series System:

$R_s = R_1 \times R_2 \times R_3 = 0.941$
$A_s = A_1 \times A_2 \times A_3 = 0.974$

Parallel System:

$R_p = [1 - (1 - R_{S1})(1 - R_{S2})] = 0.9965$
$A_p = [1 - (1 - A_{S1})(1 - A_{S2})] = 0.9993$

CALCULATING RELIABILITY

- Example Calculation Series Vs. Parallel

What do these numbers really mean in the end?

- We can determine the cost of downtime using the availability numbers.
- We can use the availability number to determine how much production loss is expected on average.
- Let's assume that the maximum production of a facility in dollars associated with the LV MCC in this example is $10M per year. The availability numbers will determine how much production income there will be, and how much in losses is expected:

Series System:

$A_s = A_1 \times A_2 \times A_3 = 0.974$

0.974 x $10M = $9.74M

Results in $260k in losses per year

Parallel System:

$A_p = [1 - (1 - A_{S1})(1 - A_{S2})] = 0.9993$

0.9993 x $10M = $9.993M

Results in $70,000 in losses per year

CALCULATING RELIABILITY

Reliability calculations become complex as all of the combinations of parallel and series configurations and operating modes etc. are integrated.

What factors make a reliability calculation difficult?

- Reliability is only accurate if analyzed at each production unit of a facility separately, making it a very iterative process.
- Each system can be made up of 10s to 100s of components in a combination of series and parallel configurations. The calculations can be very daunting.
- The availability is not only based on failures, but also on planned maintenance downtime.
- Failure identification must account for the nature of their effects (permanent or transient forced outage). Each has its own corresponding repair time.
- Some systems could have dozens of cut-sets to consider as failures.
- Sometimes production units can operate at reduced capacity for certain failures but not others.

CALCULATING RELIABILITY

What tools do we have to help with the reliability calculations?

- The IEEE Gold Book provides multiple methods to calculate reliability. As previously mentioned, the calculations can be very tedious and difficult to complete in an efficient manner.
- IEEE Gold Book Calculator Tool (SRATS) – A tool created using the Gold Book formulas based in Excel. It can be useful but not always the easiest to use and has many limitations as well. Also can be time consuming to fill out
- Electrical modeling software may be one of the easiest ways to produce results efficiently, and makes it easier to compare system configurations using scenarios.

CALCULATING RELIABILITY

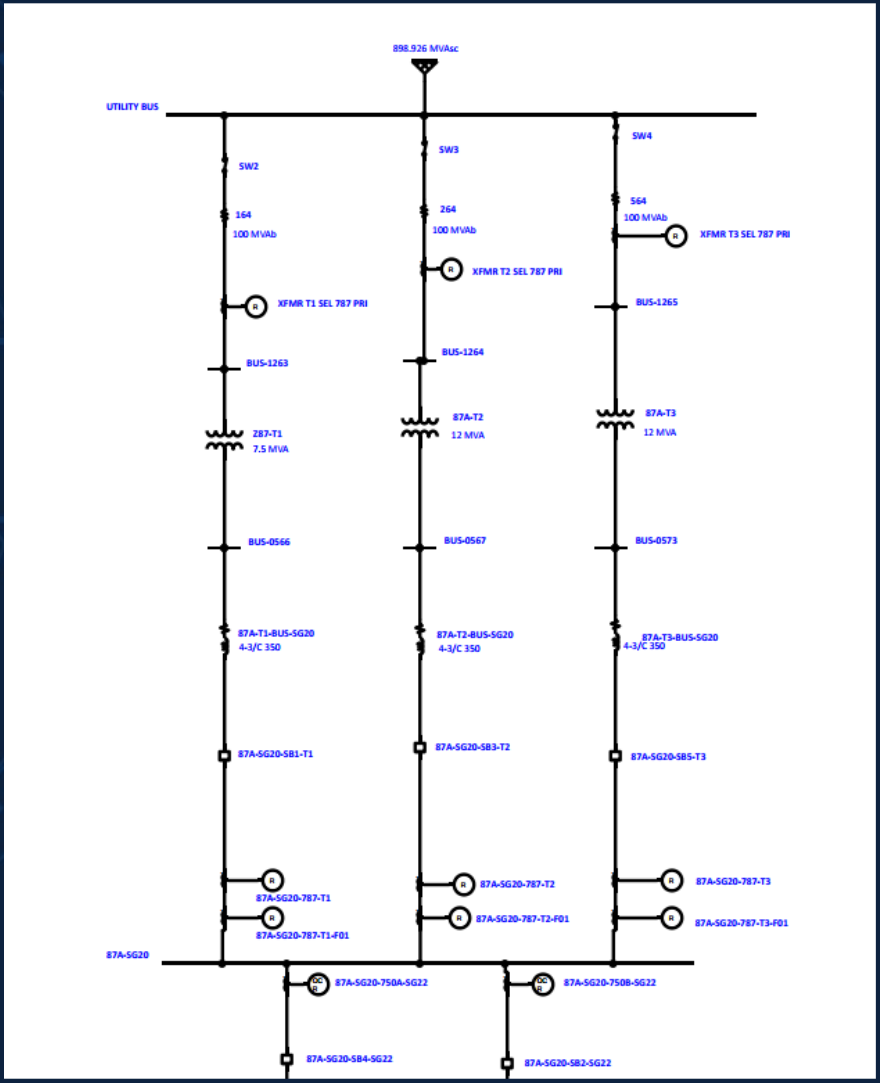
Benefits of using modeling software:

- Using software such as ETAP to build a model that is evergreen can provide many advantages for system planning and analysis
- Most facilities should have an electronic model used to perform short circuit, load flow, arc flash analysis and coordination studies.
- Software such as ETAP can add reliability data to the library to help determine the overall cost of an outage based on the calculated availability values

USING SOFTWARE TO CALCULATE RELIABILITY

ETAP Software

- Modeled components will each have reliability data included via the library.
- Common values can be used for common components to help reduce the amount of inputs required.
- Load data will be assigned to each bus and will drive the losses in production for any unit.
- ETAP will automatically determine the cut-sets based on the series and parallel configurations.



USING SOFTWARE TO CALCULATE RELIABILITY

ETAP Software

- Sample ECOST Report shown here.
- Each bus will have a total loss amount based on the summation of each component.
- Each individual component is presented with expected losses based on % availability and the total load associated with the bus.
- This helps not only identify the total loss, but also the highest risk components at each unit.

System/Bus/Load Point		Contributing Element		ECOST
ID	Type	ID	Type	$ / yr
87A-SPB3B	Bus	....	....	9489.17
		SW4	PD	603.32
		SW3	PD	603.32
		SW2	PD	603.32
		87A-SPB3B-SW4-SPB3A	PD	603.32
		87A-SPB3B	Bus	447.88
		87A-SG22	Bus	373.23
		87A-SG20	Bus	373.23
		87A-SG22-52-B-SG20	PD	327.23
		87A-SG22-52-A-SG20	PD	327.23
		87A-SPB3B-VB1-TX26	PD	327.23
87A-SPB4A	Bus	....	....	138797.40
		SW4	PD	8750.50
		SW3	PD	8750.50
		SW2	PD	8750.50
		87A-SPB4A-SW6-MPBE2	PD	8750.50
		87A-SPB4A	Bus	6495.98
		87A-SG22	Bus	5413.26
		87A-SG20	Bus	5413.26
		87A-SG22-52-B-SG20	PD	4746.10
		87A-SG22-52-A-SG20	PD	4746.10
		87A-SPB4A-VB1-TX9	PD	4746.10
87A-SPB5B	Bus	....	....	
87A-SPB6A	Bus	....	....	9386.32
		87A-SG22-CBL-SPB6A	Cable	1032.87
		SW4	PD	603.32
		SW3	PD	603.32
		SW2	PD	603.32
		87A-SPB6A-SW4-SG22	PD	495.66
		87A-SPB6A	Bus	373.23
		87A-SG22	Bus	373.23
		87A-SG20	Bus	373.23
		87A-SG22-52-B-SG20	PD	327.23
		87A-SG22-52-A-SG20	PD	327.23

TECHNIQUES TO IMPROVE RELIABILITY

Reliability of systems and components is based not only on the design itself, but also on how the components are operated and maintained.

There are many techniques for improving reliability including configuration changes, operational changes and maintenance practices. The results of a reliability study provide a road map for which techniques to apply to which parts of the system for maximum benefit at minimum cost.

<u>Active vs. Passive solutions</u>

- An active solution will directly affect the calculations and will increase the overall availability of a component or system.
- A passive solution will not necessarily show in the calculations, but will inherently reduce the probability of failure.

TECHNIQUES TO IMPROVE RELIABILITY

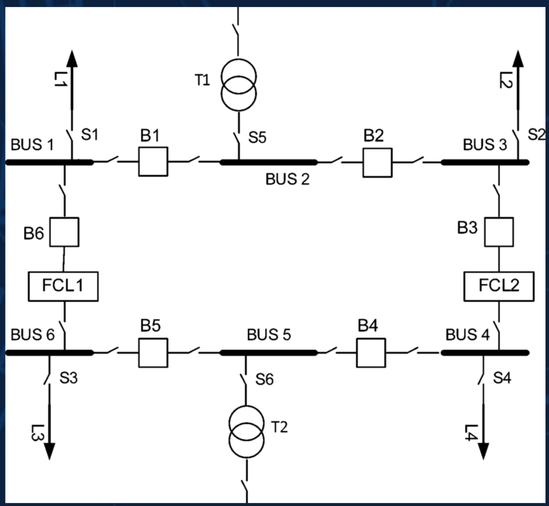
Active Solutions:

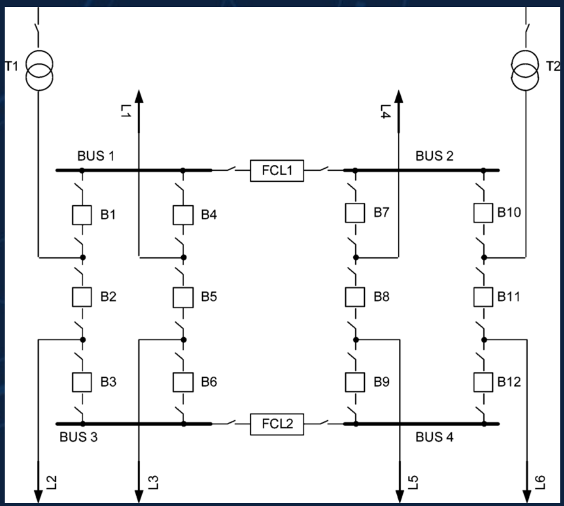
- Redundant systems
  - Parallel Feeds
  - Multiple Utility Connections
  - Generator Backups (with AutoStart)
  - UPS or Battery Systems
  - Auto Transfer Schemes
- System Stability Designs
  - Load Shed Systems (reduce impact of a loss of power)
  - VAR Compensation (ensure stability of voltage)
  - Voltage Regulation (add tap changers to XFMRs)
  - Power System Active Monitoring

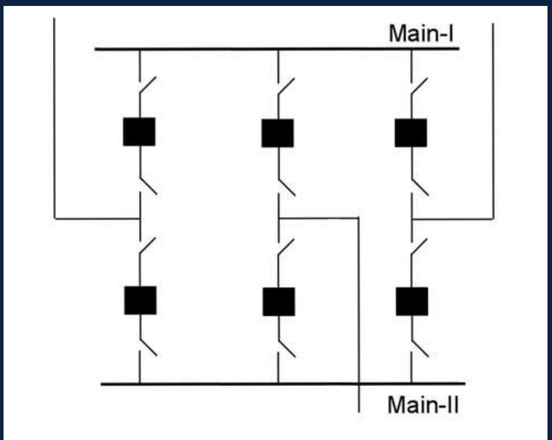
TECHNIQUES TO IMPROVE RELIABILITY

Active Solutions:

- Primary Distribution Network Design
  - Double-bus switchgear
  - Ring Bus
  - Breaker and a Half
  - Double Breaker (most expensive but highest reliability)





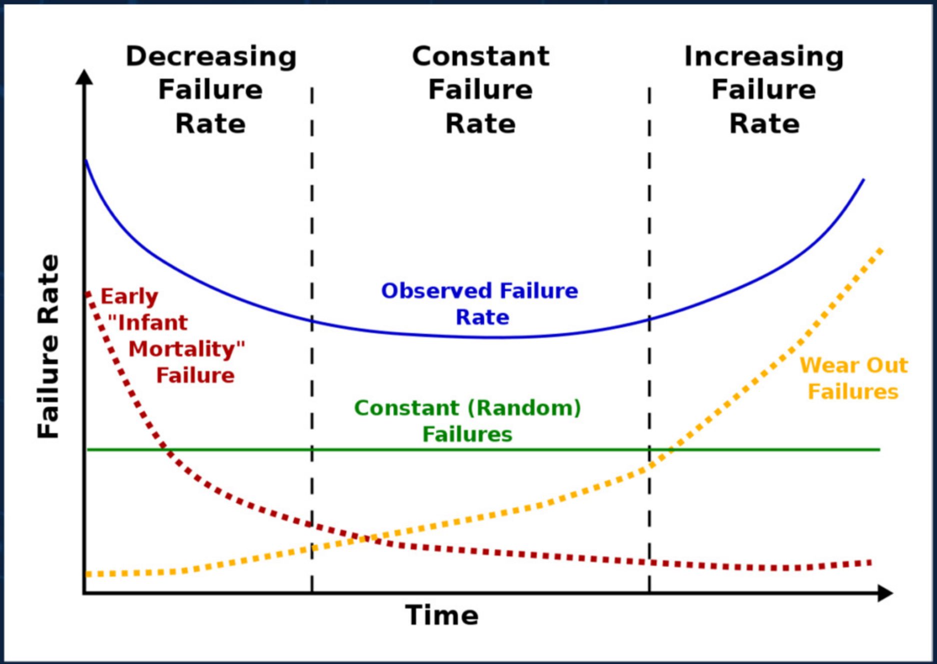


Double Bus Double Breaker Configuration

TECHNIQUES TO IMPROVE RELIABILITY

Active Solutions:

- Modernizing Equipment
  - Replacing older equipment
  - More self monitoring capabilities
  - Better communication



TECHNIQUES TO IMPROVE RELIABILITY

Passive Solutions:

- Equipment Specifications
  - Higher rated equipment (less heating)
  - Self monitoring systems
  - GIS equipment (less exposure to environment)
  - Environmental Ratings
- Equipment Maintenance and Inspection
  - UV inspections
  - Partial discharge monitoring
  - NETA MTS programs
  - Breaker testing
  - Generator exercising

TECHNIQUES TO IMPROVE RELIABILITY

Passive Solutions:

- System Design
  - HRG Systems (less faults and continued operation)
  - Zone Interlocking protection (less nuisance trips)
  - Active power monitoring and load shifting
  - Use of multifunction relays (using all elements)
- Electrical Modeling
  - Maintain system model for fault and load studies
  - Coordination studies
  - Harmonics analysis
  - Transient stability

RELIABILITY IS CRITICAL

Summary:

- Reliability should be examined periodically taking into account obsolescence, age of equipment and system changes.
- Similar to electrical studies, every change in the system will impact reliability to some extent
- Utilization of software such as ETAP gives the opportunity to keep an evergreen model and calculate reliability at a much lower cost than individual extensive studies
- Maintenance is key to ensuring proper operation of the system components.

THANKS FOR PARTICIPATING

QUESTIONS CAN BE SUBMITTED THROUGH THE Q/A SECTION IN ZOOM

For more information:
Sid Gaudet: sgaudet@msbenbow.com
Scott Uffman: suffman@msbenbow.com
Dean Ruiz: druiz@msbenbow.com