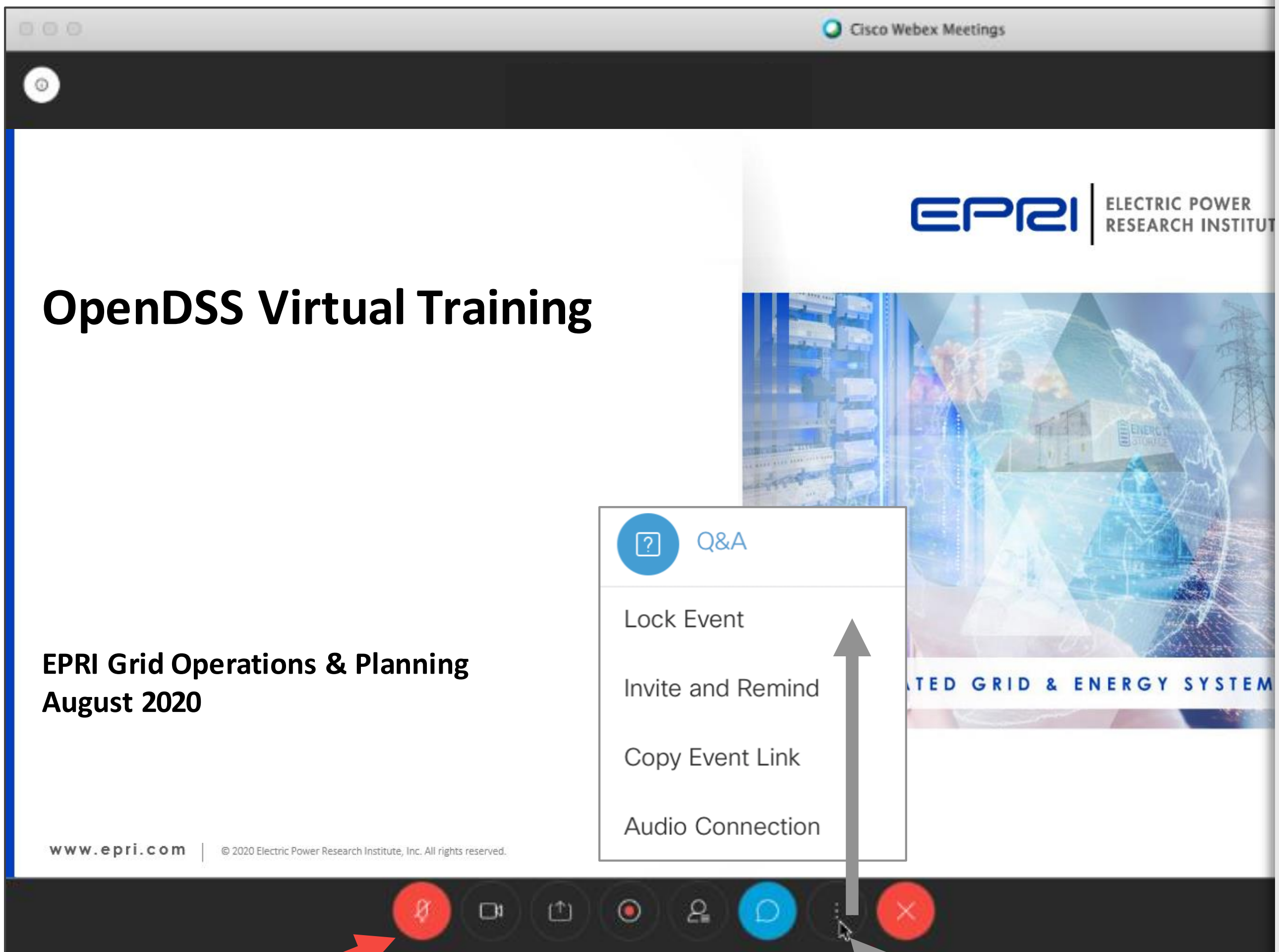

Red Means Muted

Polling, Q&A

Meeting Logistics

- **Audio Options:**
  1. Connect via computer audio
  2. Call local dial number and use participant code
- **You are Muted on Entry**
  - **Use Q&A to ask panelist questions**
- **Q&A window**
  - Panelist will either answer in the Q&A, or
  - Panelist will voice the question
- **We are Recording**
- **Polling window**
  - Polling questions will be active throughout

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OpenDSS Training Workshop

Distribution System Basics

Roger C. Dugan
EPRI Knoxville, TN

August 24, 2020

Instructor

- **Roger C. Dugan, *Life Fellow, IEEE***
- **Roger is a Sr. Technical Executive with EPRI in Knoxville, Tennessee USA. He has over 45 years of combined experience in distribution engineering with EPRI, Electrotek Concepts, and Cooper Power Systems. He holds the BSEE degree from Ohio University and the Master of Engineering in Electric Power Engineering degree from Rensselaer Polytechnic Institute, Troy, NY. Roger has worked on many diverse aspects of power engineering over his career because of his interests in applying computer methods to power system simulation. Beginning with a student internship with Columbus and Southern Ohio Electric Co, his work has been focused on Distribution Engineering. He was elected a Fellow of the IEEE for his contributions in harmonics and transients analysis. Recently, he has been very active in distributed generation, particularly as it applies to utility distribution systems and distribution system analysis. He was the 2005 recipient of the IEEE Excellence in Distribution Engineering Award. He is coauthor of Electrical Power Systems Quality published by McGraw-Hill, now in its 3rd edition. He serves on the IEEE PES Distribution System Analysis Subcommittee and is active in the Distribution Test Feeders WG.**

OpenDSS Virtual Training 2020

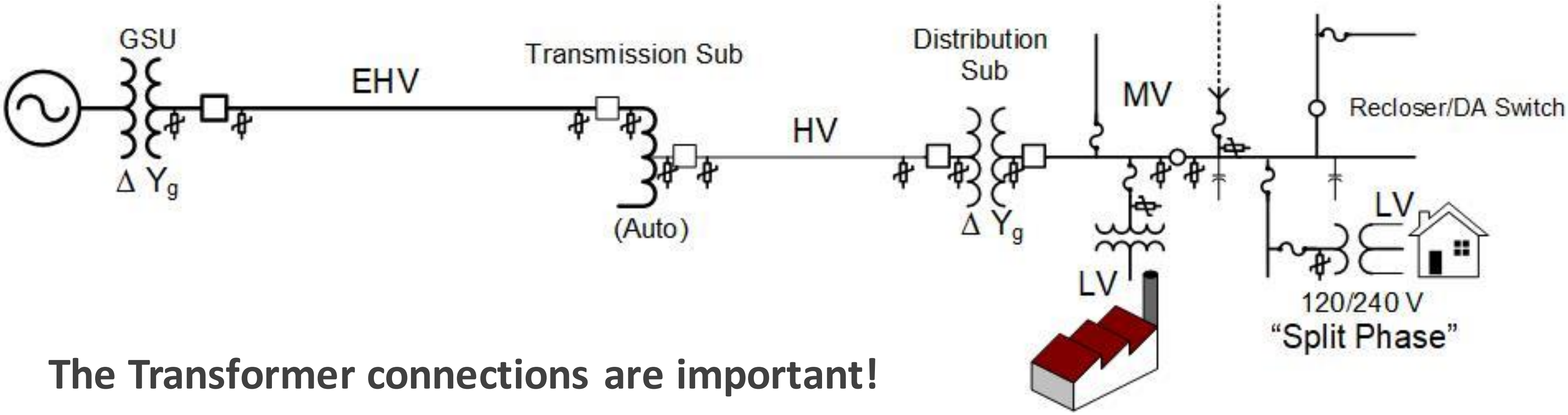
Date	Time (NY time)	Session Topic
August 24	11:30 am – 12:00 pm	Distribution System Basics
	12:00 pm – 12:30 pm	Intro to OpenDSS
	12:30 pm – 1:00 pm	OpenDSS Basics and Scripting
August 25	11:30 am – 12:00 pm	Intro to OpenDSS-G
	12:00 pm – 12:30 pm	APIs, COM interface, etc.
August 26	11:30 am – 12:30 pm	PVSystem, InvControl, Storage, Storagecontroller
August 27	11:30 am – 12:30 pm	Advanced Topics
	12:30 pm – 1:00 pm	Applying OpenDSS in R&D

Today’s Agenda

- Distribution System Basics
  - Primarily for Students who are new to Distribution
- Introduction to OpenDSS
- OpenDSS Basics and Scripting

Introduction to Distribution System Basics

One-Line Diagram of Power Delivery System from Generator to Load

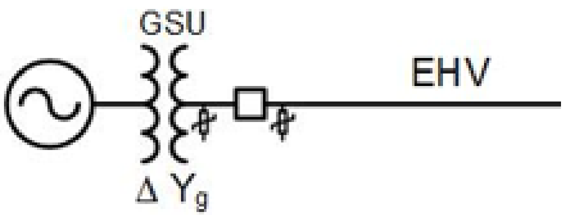


The Transformer connections are important!

Also, note locations of breakers and arresters.

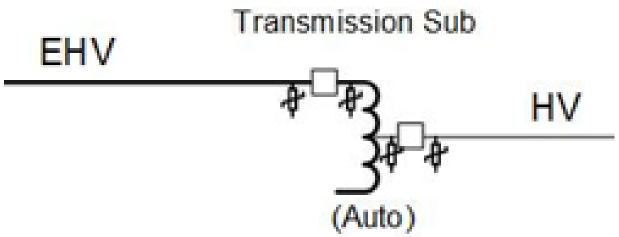
There is a good reason for everything!

GSU Transformers are Nearly Always Delta/Wye



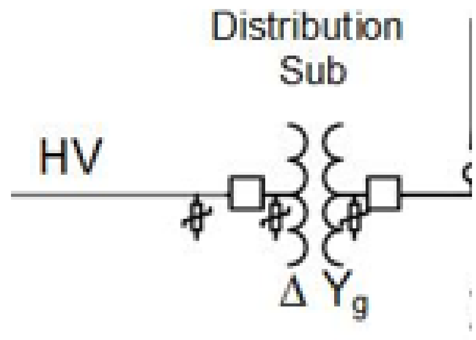
- Delta blocks 3rd harmonic current
  - Produced by generator from imperfect generator voltage
  - Keeps load-produced zero-sequence harmonics out of generator
  - Allows for sensitive ground fault generator protection
- Wye-grounded/Delta (as seen from transmission side) provides a very strong ground source
  - Keeps unfaulted phase overvoltages < arrester discharge level for single-line-to-ground faults
  - Allows use of lower BIL for equipment and saves much $$$
    - BIL = Basic Impulse Insulation Level

Many Transmission Substation Transformers are Autotransformers



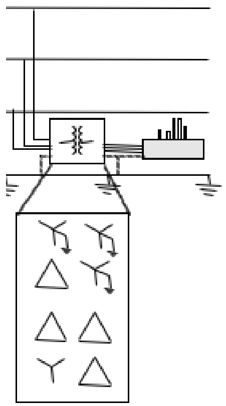
- More economical; less copper and steel than conventional two-winding transformer
- Effectively a grounded-YY connection (No phase shift)
  - Always has a grounded neutral
- Many have a Delta-connected “Tertiary” winding
  - Adds a “ground source”
  - Keeps transient overvoltages down
  - Helps control some harmonics

Most Distribution Substation Transformers are Delta/Wye



- Provides a well-grounded source for distribution MV system
- Short circuits zero-sequence harmonics coming from loads
- Has a 30-degree phase shift from HV to MV
  - By ANSI standards: MV **lags** HV by 30 degrees (Dyn1)
  - In Europe, MV **leads** by 30 degrees (Dyn11 or Dyn5)
- Some distribution sub transformers are Wye/Wye/Delta (Ynynd1)
  - Typically used where transmission system is, or was, weak and needs stronger ground source to help limit overvoltages and protect arresters during ground faults
  - Delta winding is often "buried" and not loaded

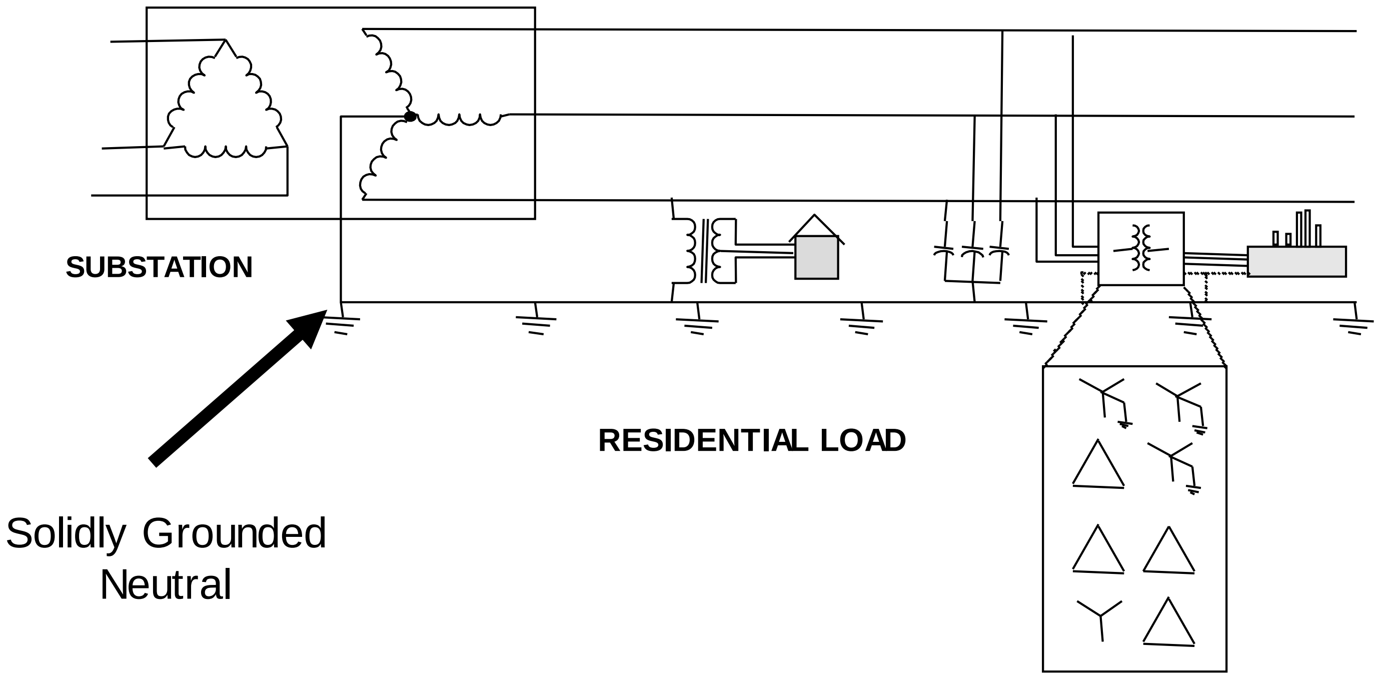
Transformers Serving Commercial 3-phase Loads



- These transformers may have many different winding connections
- Grounded-YY is most common in US today
  - Avoids most ferroresonance in cable-fed situations
- Many legacy Delta/grounded-Y transformers still in service
- Ungrounded-Y/Delta with center-tapped leg is commonly used for small commercial buildings
  - Serves 120-V office loads and 3-phase 240-V motor
  - Have to leave the neutral ungrounded to prevent failure upon ground faults on the distribution feeder
- The Open-Y/Open-Delta connection is used in rural areas

The Typical North American Distribution System is a 4-wire multi-grounded neutral system

Many elements are connected to the neutral

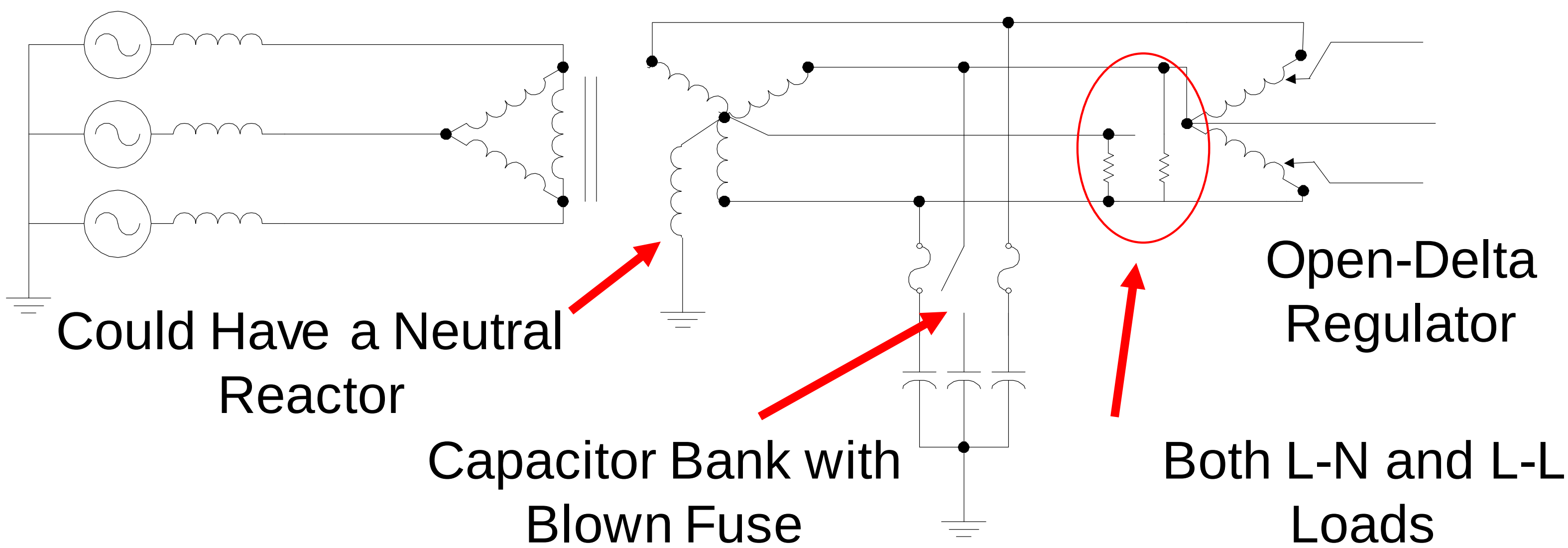


Unigrounded/Delta 3-wire also common on the West Coast

The North American Distribution System is Often Very Unbalanced

Transmission System analysis is often performed assuming balanced 3-phase systems (Positive-Sequence model)

But this takes more than a positive-sequence model:

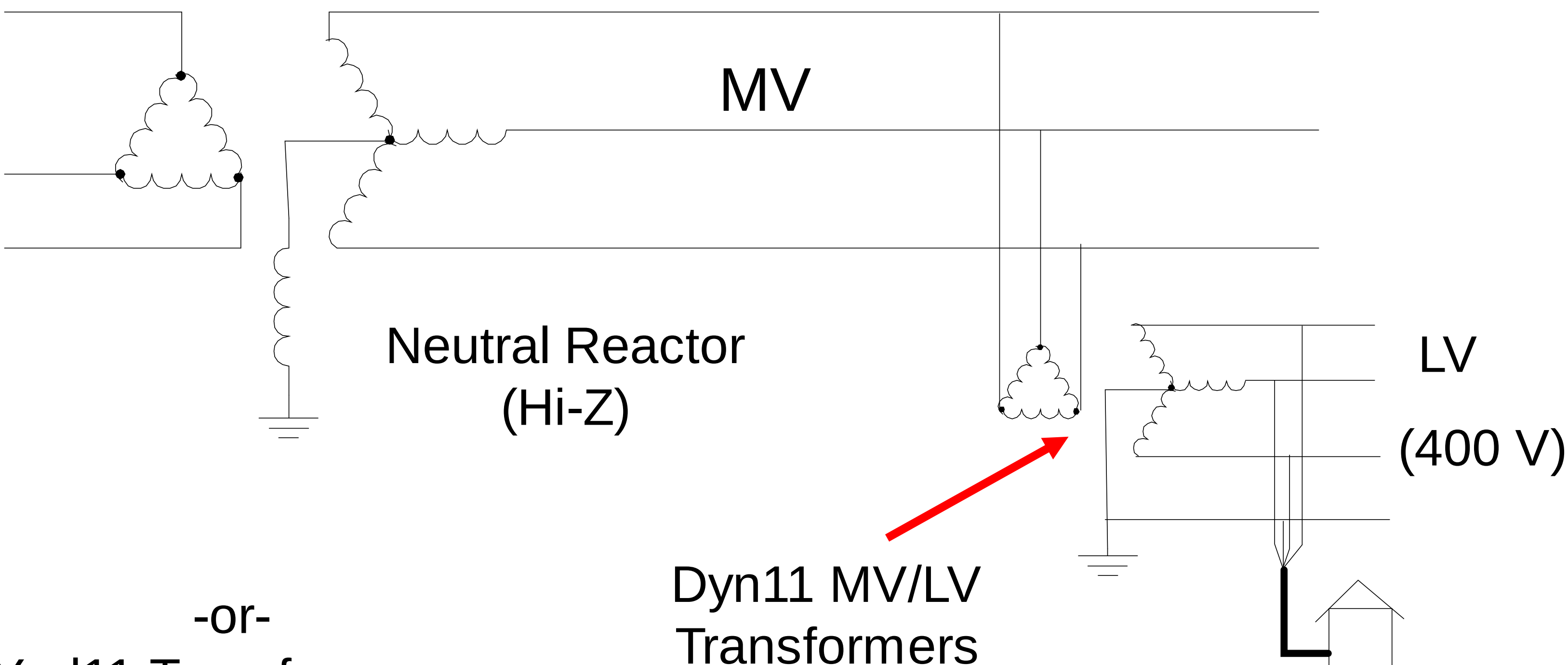


OpenDSS was designed to handle this model … and more!

The Typical European Style System

– 3-wire unigrounded primary (MV)

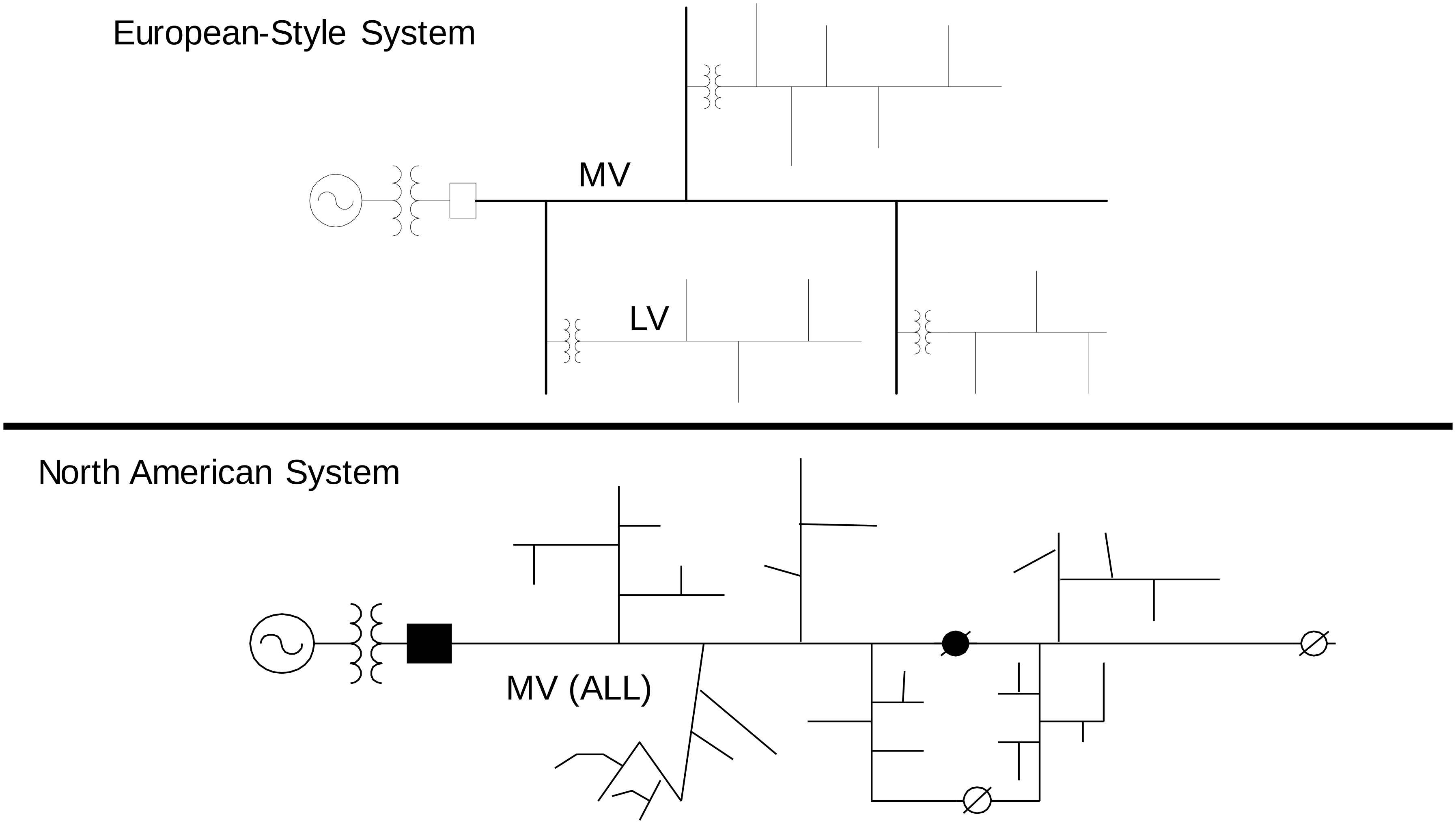
Three-phase throughout, including secondary (LV)



Dyn11 MV/LV Transformers Serving LV

-or-
Ynd11 Transformer +
Zig-Zag for grounding)

Comparisons of Systems

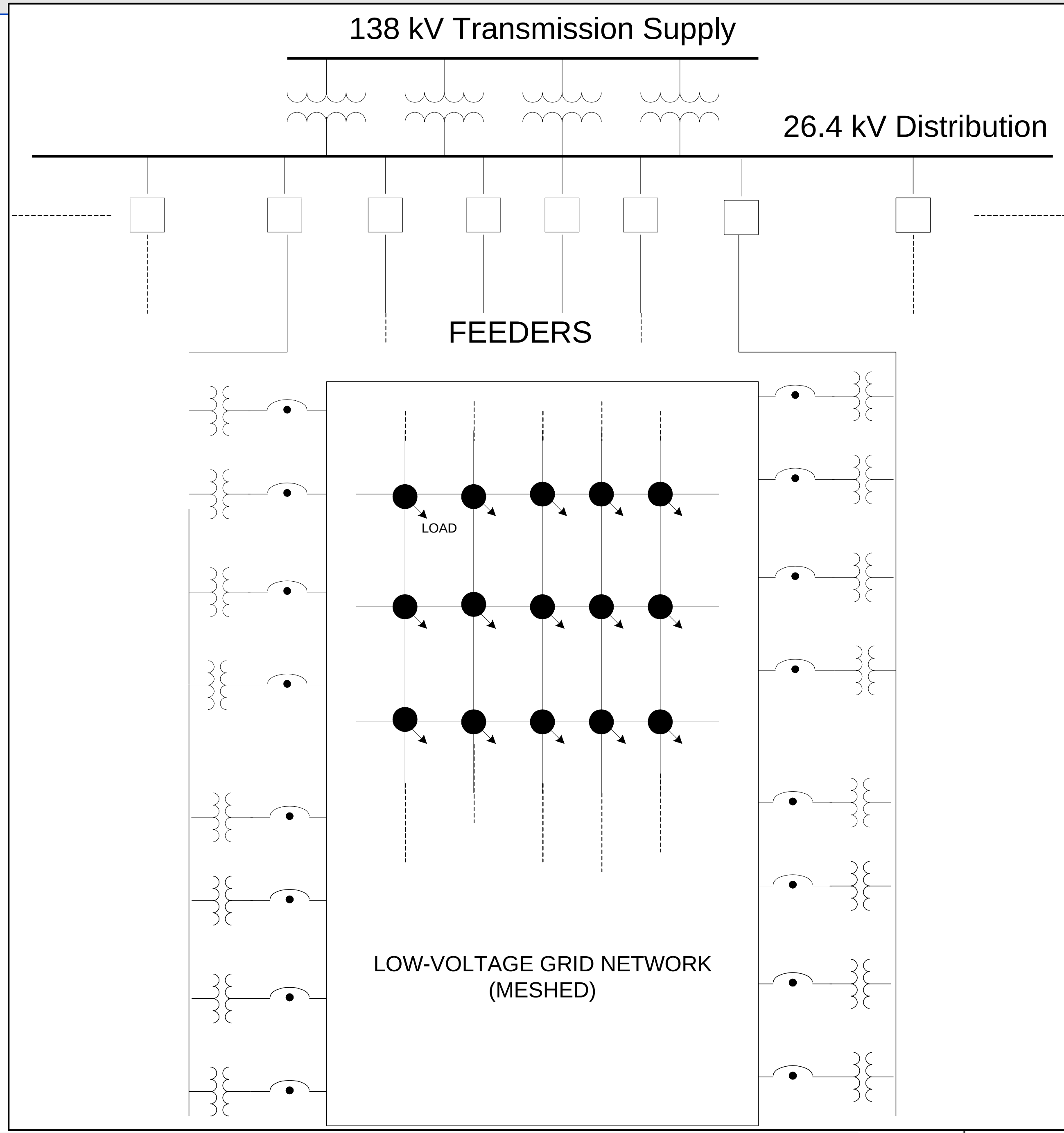


Comparison of Distribution Systems

- North American System
  - Primary (MV) system is extensive, complex
  - Secondary (LV) is short
  - 4-5 houses per distribution transformer
    - 120/240 V single-phase (“split phase”) service
  - 1 Industrial customer per distribution transformer
    - Or multiple transformers per customer
  - Extended by adding transformer + wire

- European Style System
  - MV System has simpler structure
  - LV System (400 V) is extensive
  - Perhaps 100 residences on MV/LV transformer
    - 230/400 V 3-phase
  - Extended by adding wire
    - Fewer transformers

Urban Low-Voltage Network Systems



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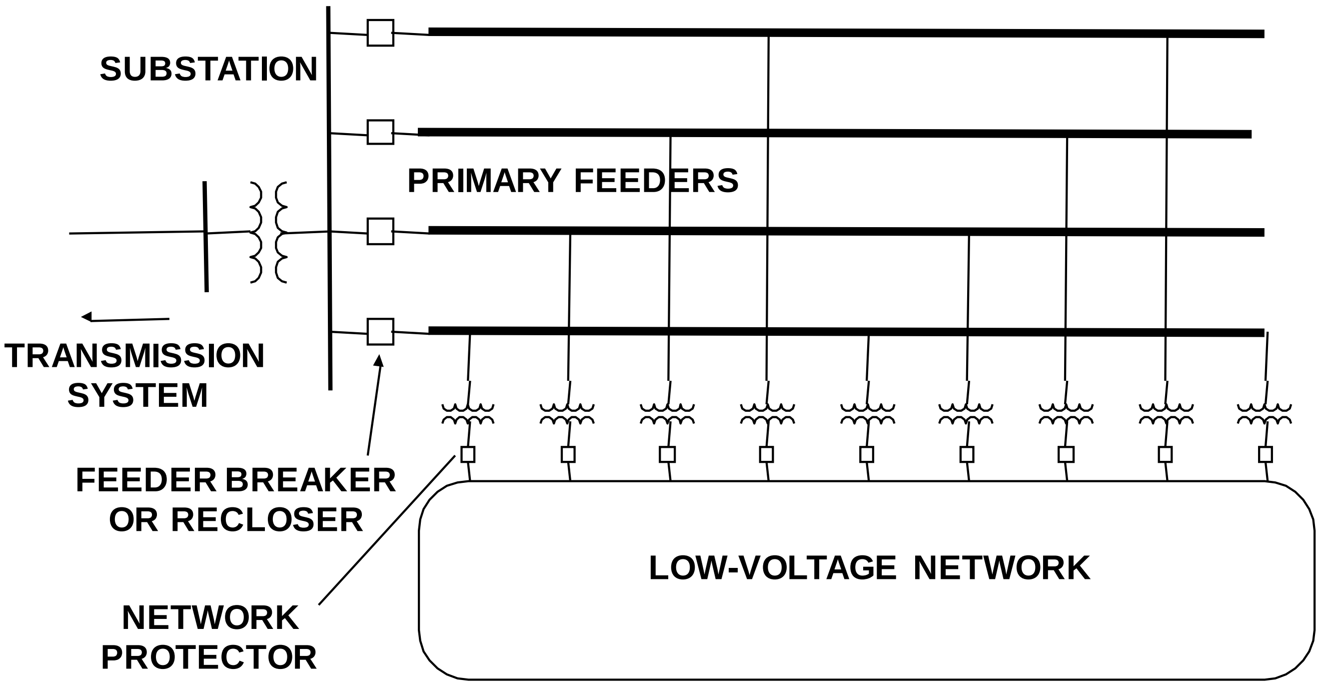
Urban LV Network Systems – Another View



Urban LV Network Systems

- Used in downtown areas (e.g., Manhattan) requiring extraordinary reliability
- In a number of major cities
  - New York
  - Seattle
  - Chicago
- Reliability is on the order of 100 times better than radial
- Much more costly to build
- Uses devices not found on other distribution systems
  - Network transformer and network protectors
- Most distribution systems in the world are radial

Why are most distribution systems radial?

Utility Fault-Clearing Practices

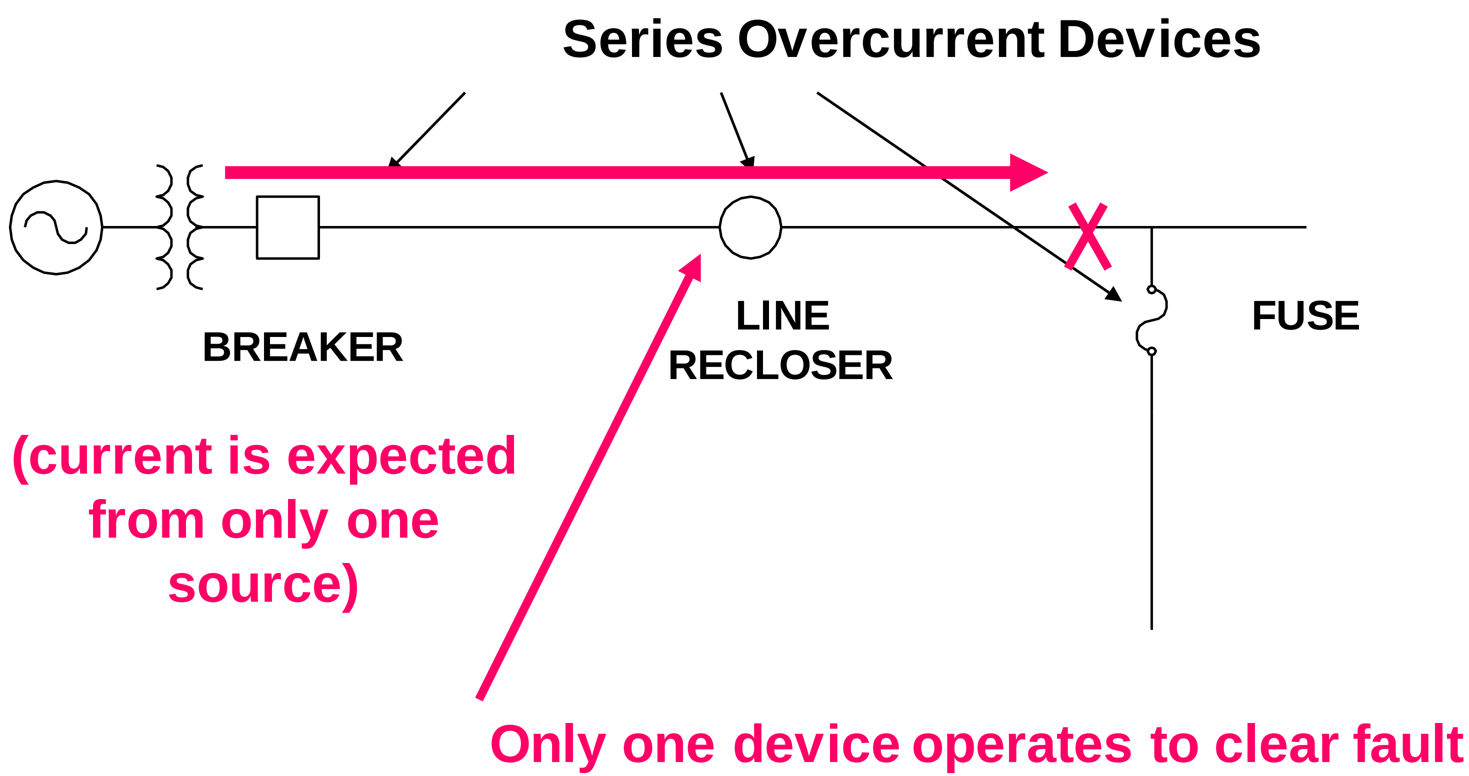
- This explains why most systems are radial

- Important to understand this for DER application on the "Integrated Grid"
  - Lower-cost protection for the inevitable short circuit

- This is where many of the operating conflicts arise !!

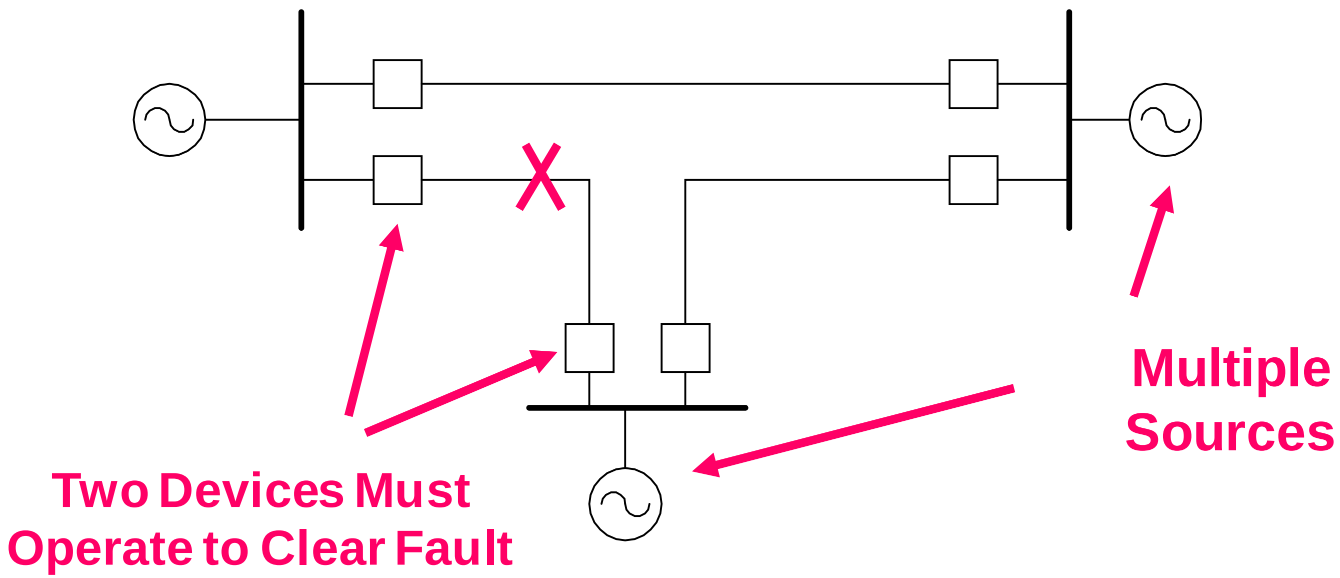
- DER response during faults can
  - Affect utility practices, fault clearing
  - Be damaged by fault clearing practices

Radial Distribution Fault Protection Requires Only One Device to Operate



Transmission Fault Protection Typically Requires Two Breakers to Operate

The Transmission System is designed to accommodate multiple generation sources



The fault can often be cleared without interrupting loads.

Radial Circuit Economics

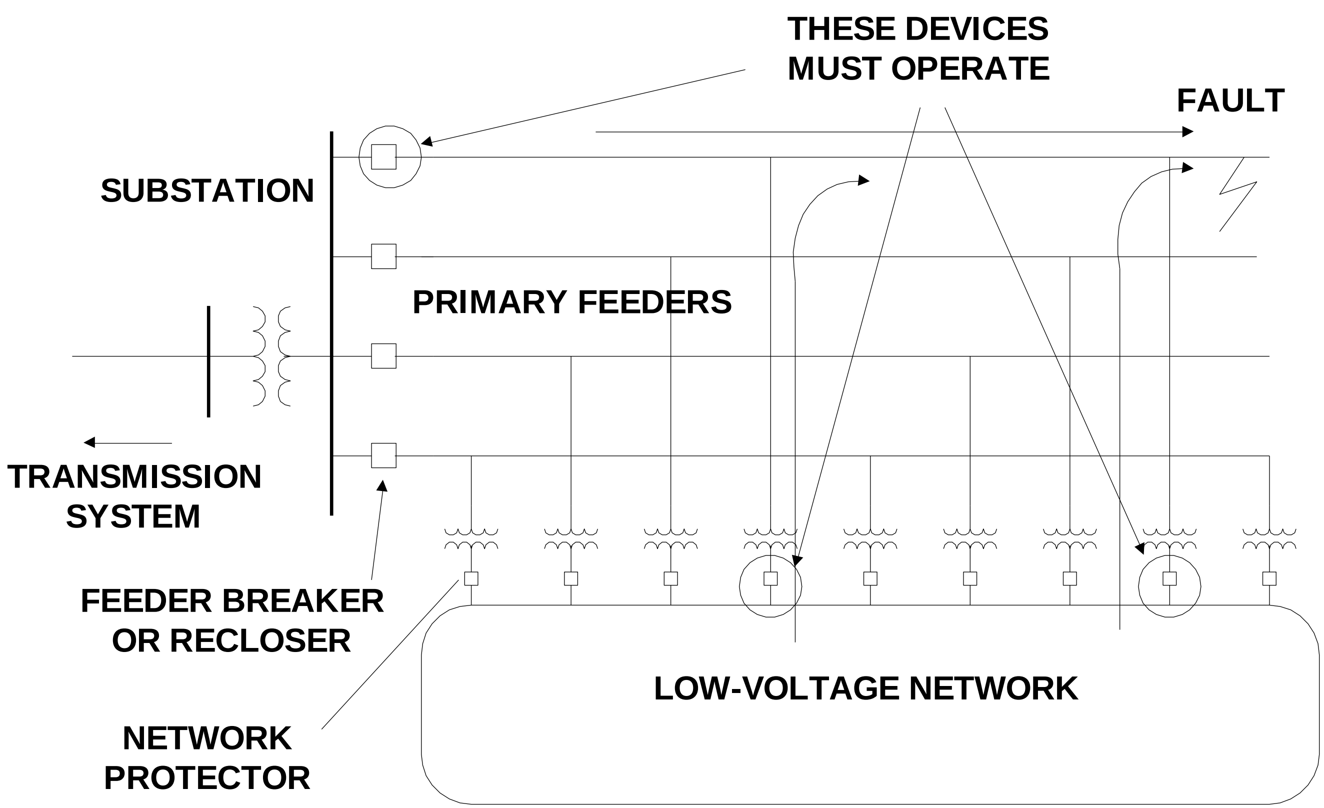
- Most distribution systems are radially configured because the protection system is
  - Simpler to operate
  - Less expensive to build

- Smart, or “Integrated”, Grid with multiple sources is changing that
  - Current flows in more than one direction
  - Overcurrent relaying/fuses inadequate on microgrids
    - May not have sufficient fault current to blow fuses, operate relays

Radial System Protection Principles

- Radial Distribution Systems are employed because protection is economical
- DER provides multiple sources for faults
- System must revert to radial configuration for the fault clearing to proceed when using conventional radial system overcurrent protection.

LV Network Systems



LV Network Protection Principles

- Designed for higher reliability than a radial system
  - Can withstand more failures (2 or more)

- Network protectors open very quickly on reverse power
  - Assumption: The only time the power will reverse is for a fault
  - Have to shut off all sources of fault current
  - This makes it very difficult to accommodate much DER on urban LV networks

Reclosing on Overhead Radial Circuits

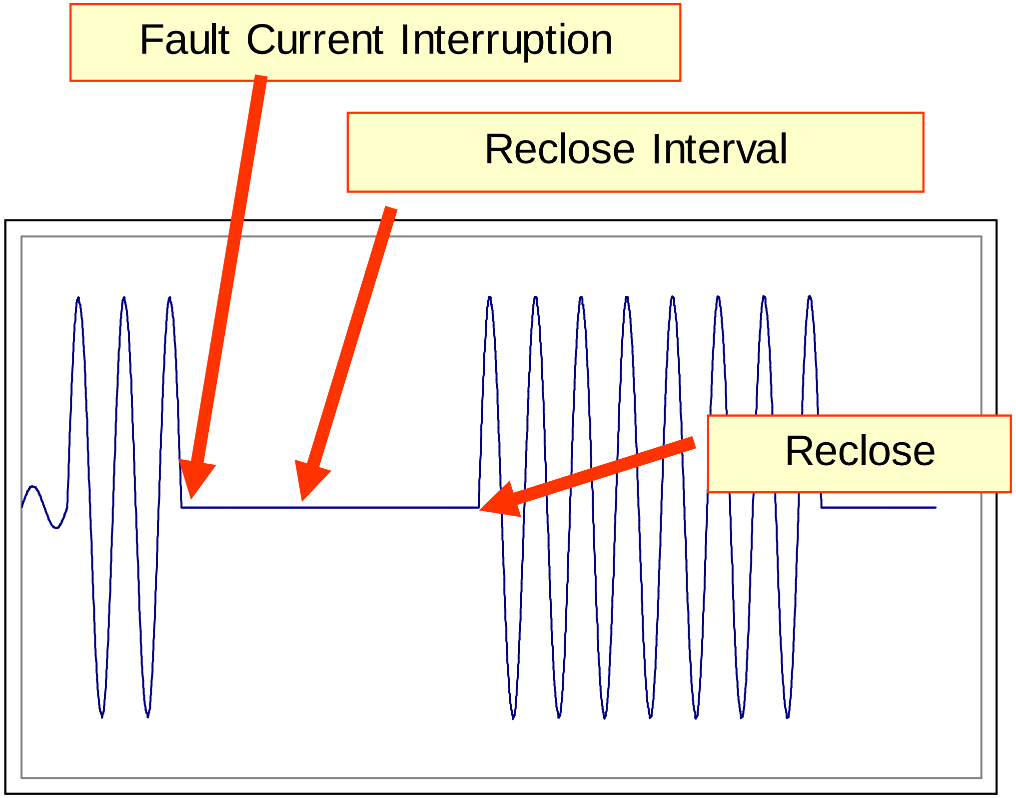
- Most faults on primary distribution (MV) are temporary
  - Lightning
  - Trees blow into lines

- Reclosing allows for prompt restoration of service
  - Interrupt the current and allow arc to disperse
  - Automatically reclose to restore service

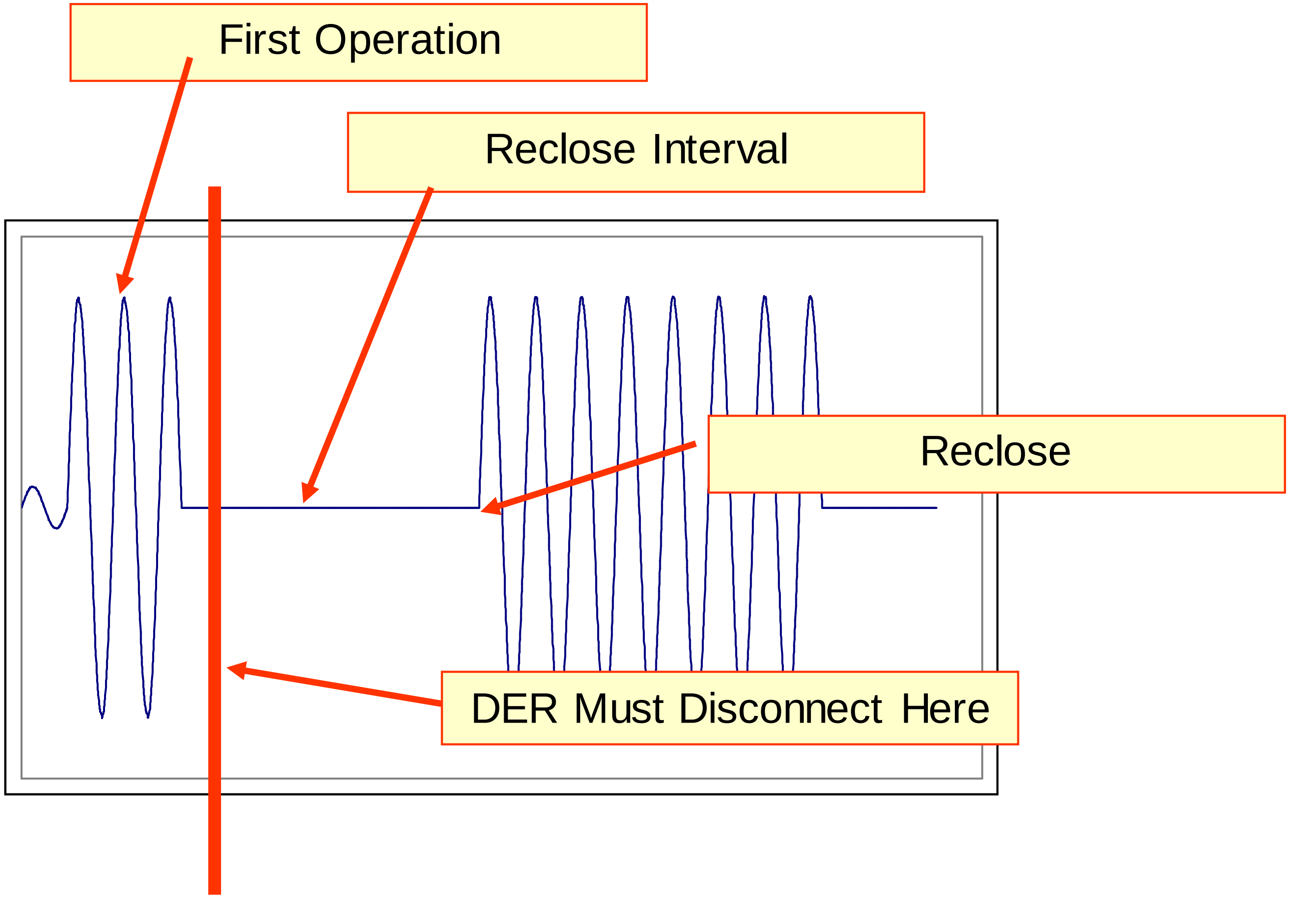
- Very common on North American distribution systems

- Typically do not reclose on underground cable systems

Reclosing can save sustained interruptions



DER Must Disconnect Early in the First Reclose Interval



Summary: Distribution Systems

- Structure and operations are dictated by the economics of the protection system and desired Reliability
- It will be too costly to modify the protection system just to accommodate DER devices
- DER must disconnect for fault clearing on same feeder or LV network
- The greater value for DER is generally on the end-user side or to subtransmission feed to distribution
- DER can economically defer investments in distribution infrastructure under some circumstances

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