

OpenDSS Training Workshop

Distribution System Basics

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Instructor



■ Roger C. Dugan, *Life Fellow, IEEE*

- Roger is a Sr. Technical Executive with EPRI in Knoxville, Tennessee USA. He has over 50 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.

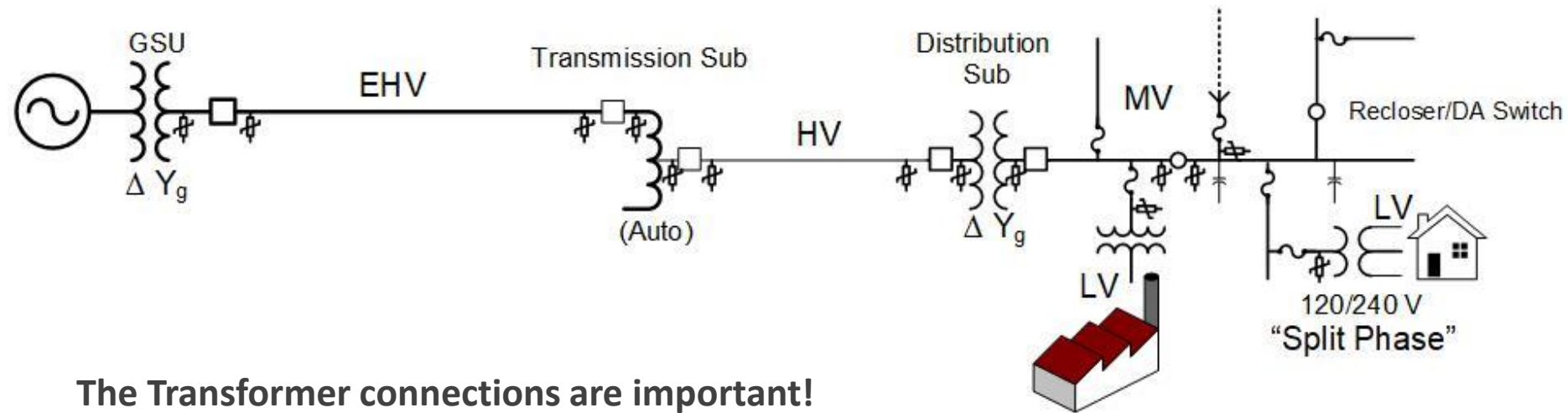
Today's Agenda

- Distribution System Basics
- Introduction to OpenDSS
- OpenDSS Basics and Scripting



Introduction to Distribution Systems

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

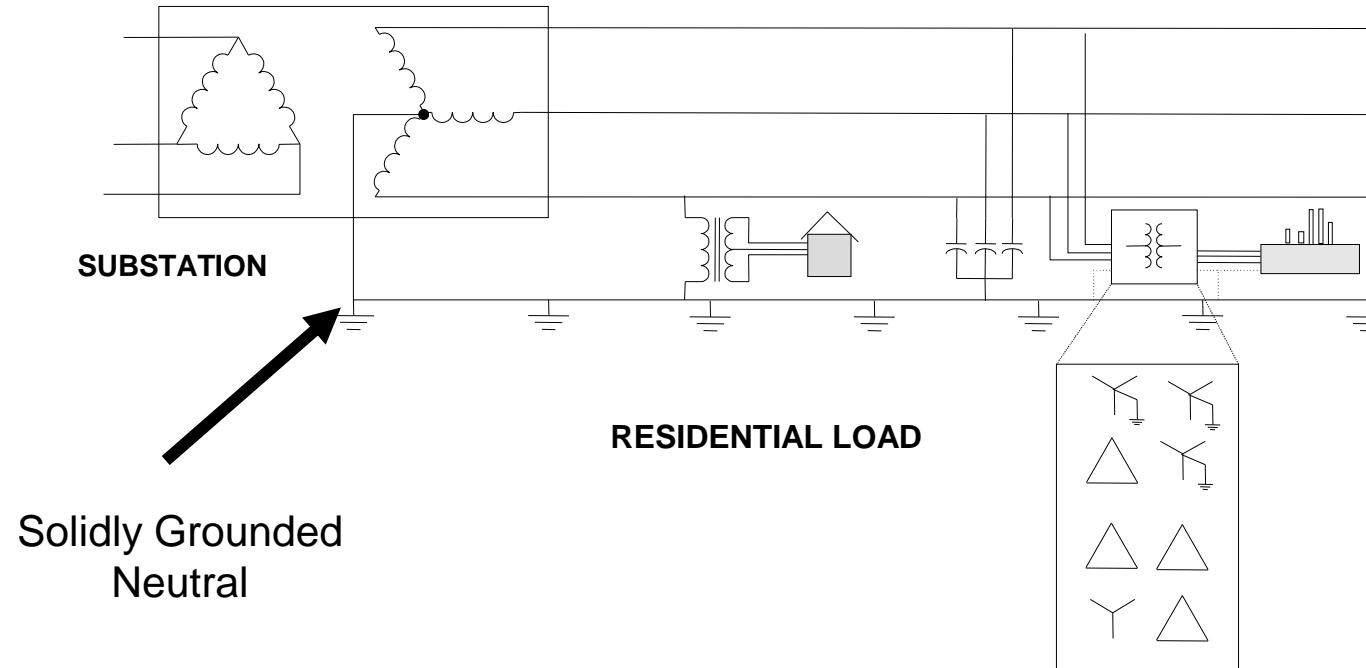
- Provides a well-grounded source for distribution MV system
- Short circuits zero-sequence harmonics coming from loads
- Has a 30-degree phase shift from HV to MV
 - By ANSI standards: MV lags HV by 30 degrees (Dyn1)
 - In Europe, MV leads by 30 degrees (Dyn11 or Dyn5)
- Some distribution sub transformers 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

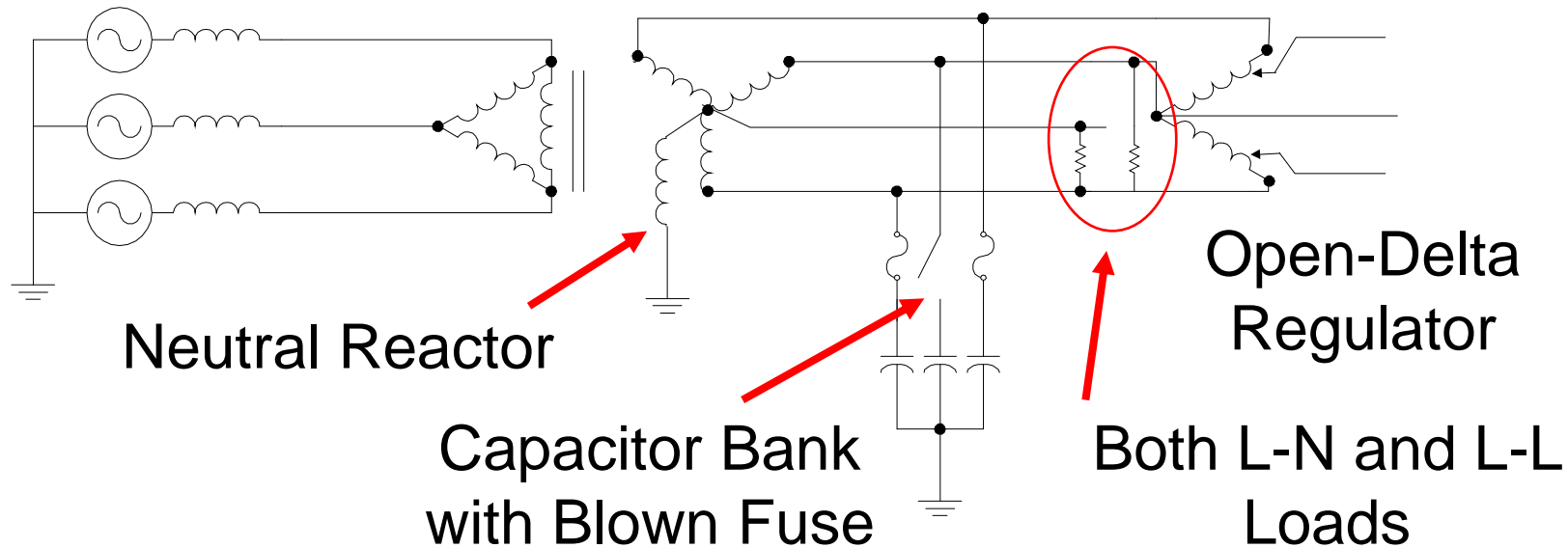


Unigrounded/Delta 3-wire also common on the West Coast

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:

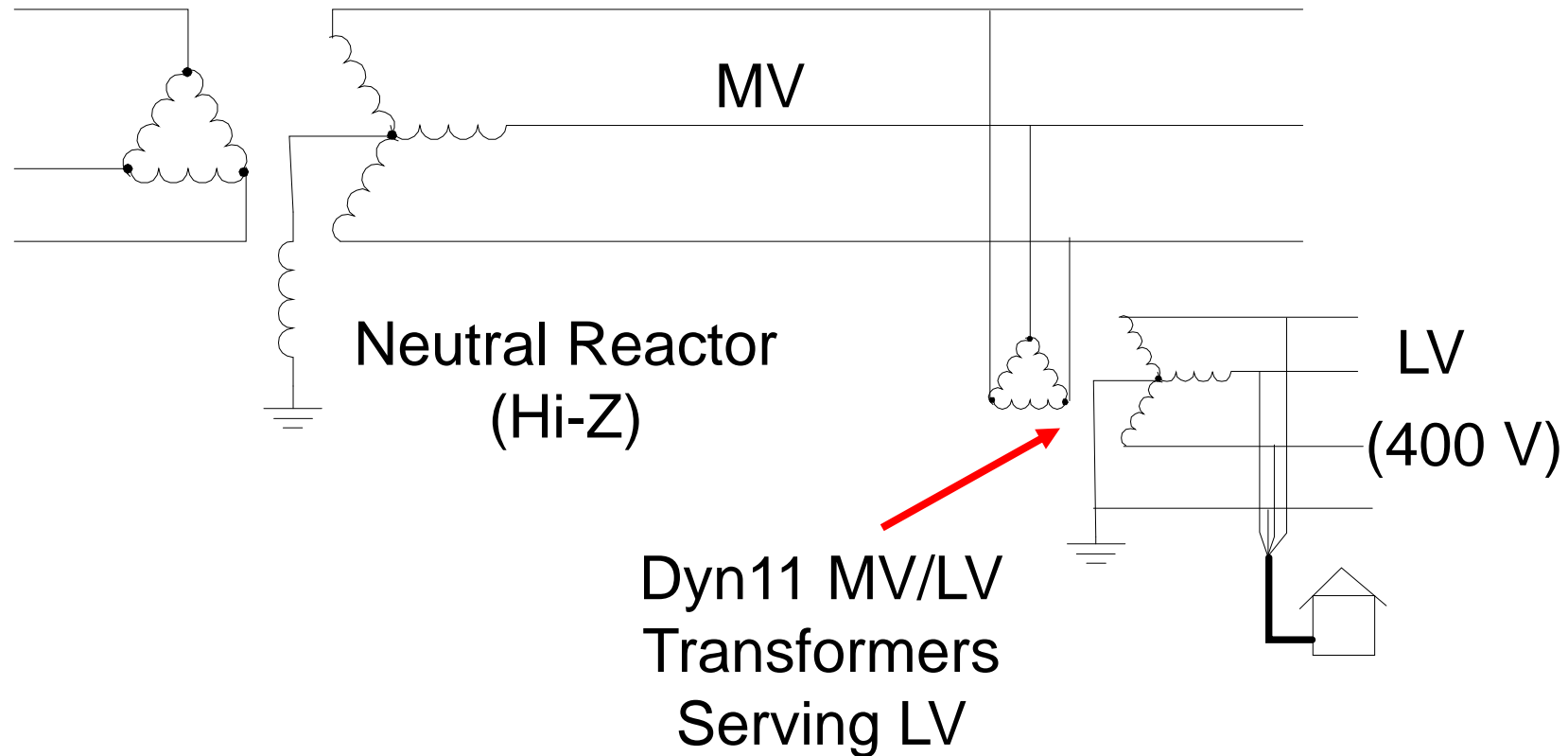


OpenDSS was designed to handle this model ... and more!

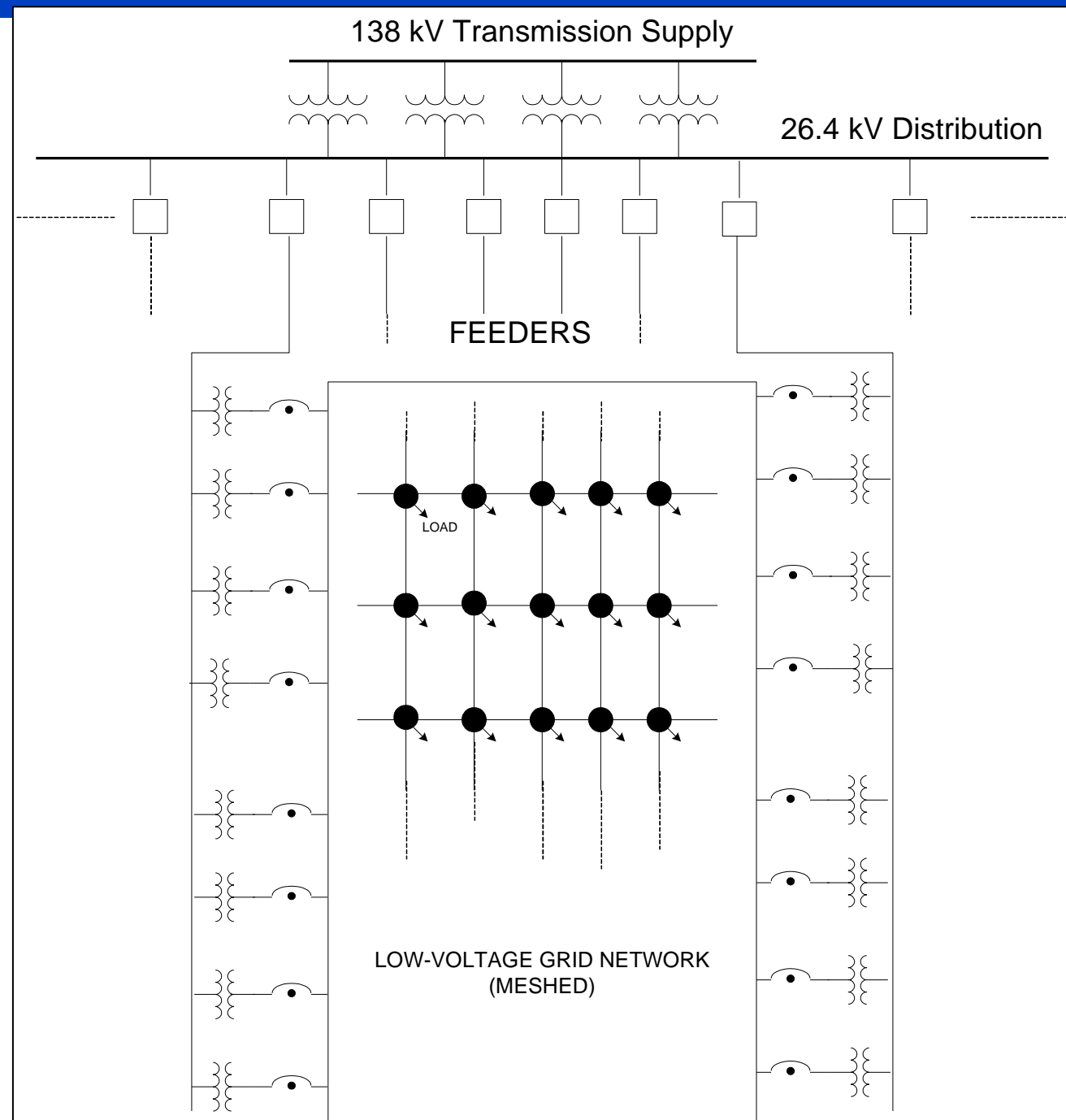
The Typical European Style System

- 3-wire ungrounded primary (MV)

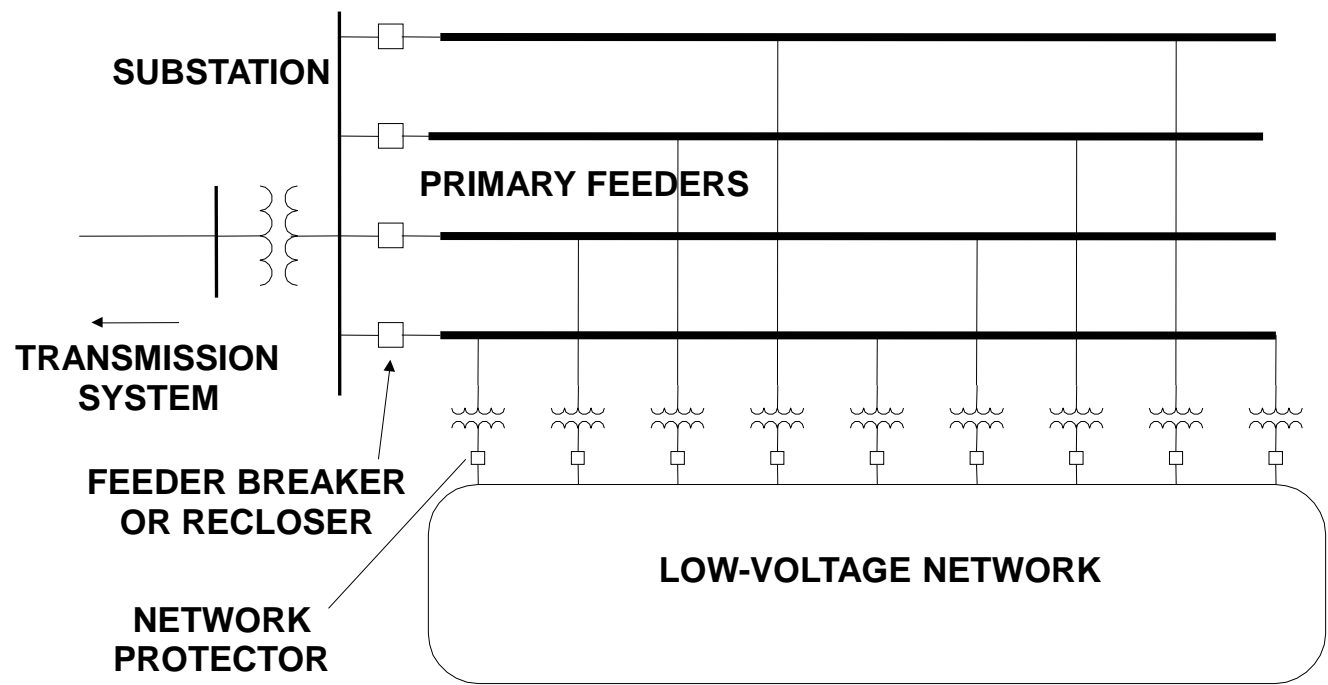
Three-phase throughout, including secondary (LV)



Urban Low- Voltage Network Systems



Urban LV Network Systems – Another View



Urban LV Network Systems

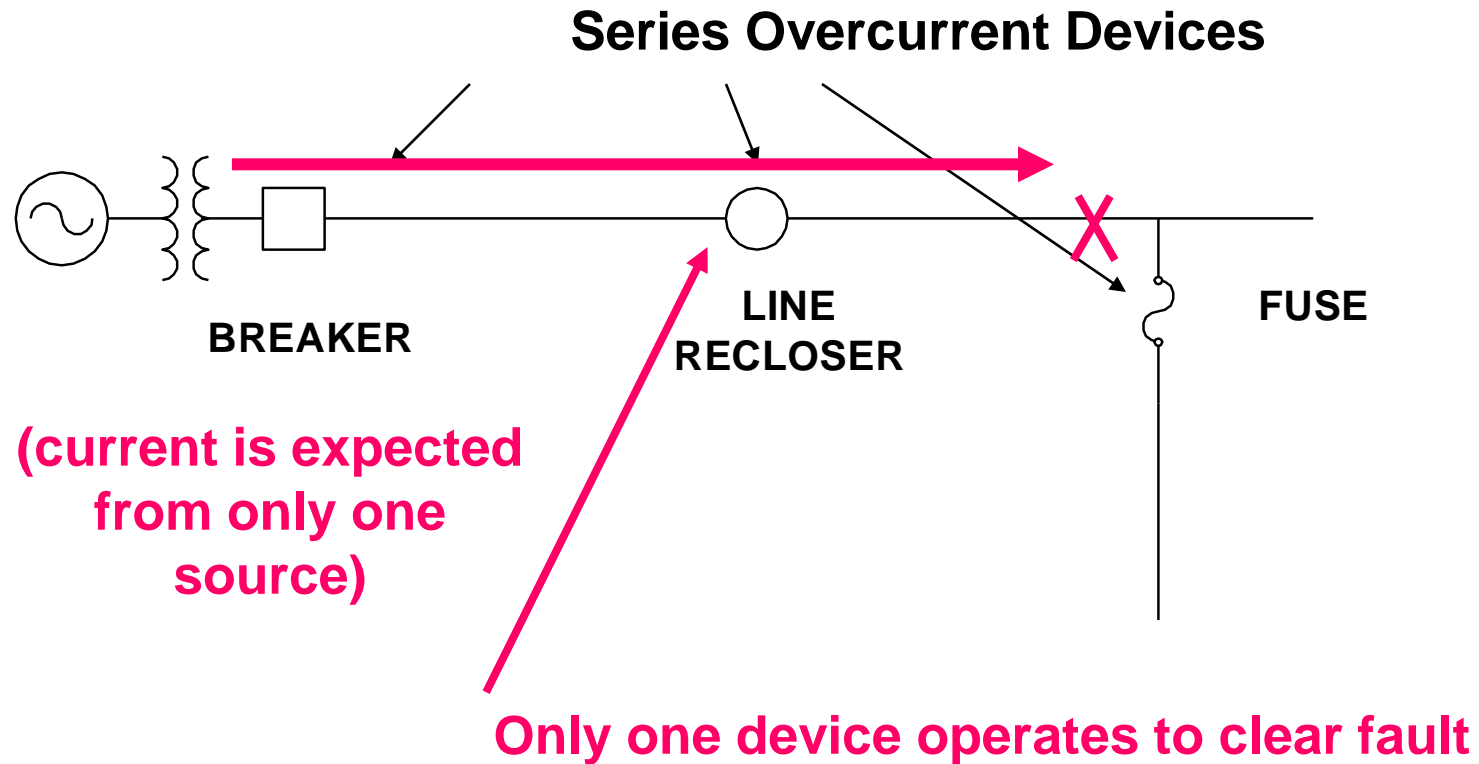
- Used in downtown areas (e.g., Manhattan) requiring extraordinary reliability
- In a number of major cities
 - New York
 - Seattle
 - Chicago
- Reliability is on the order of 100 times better than radial
- Much more costly to build
- Use devices not found on other distribution systems
 - Network transformer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

Why are most distribution systems radial?

Utility Fault-Clearing Practices

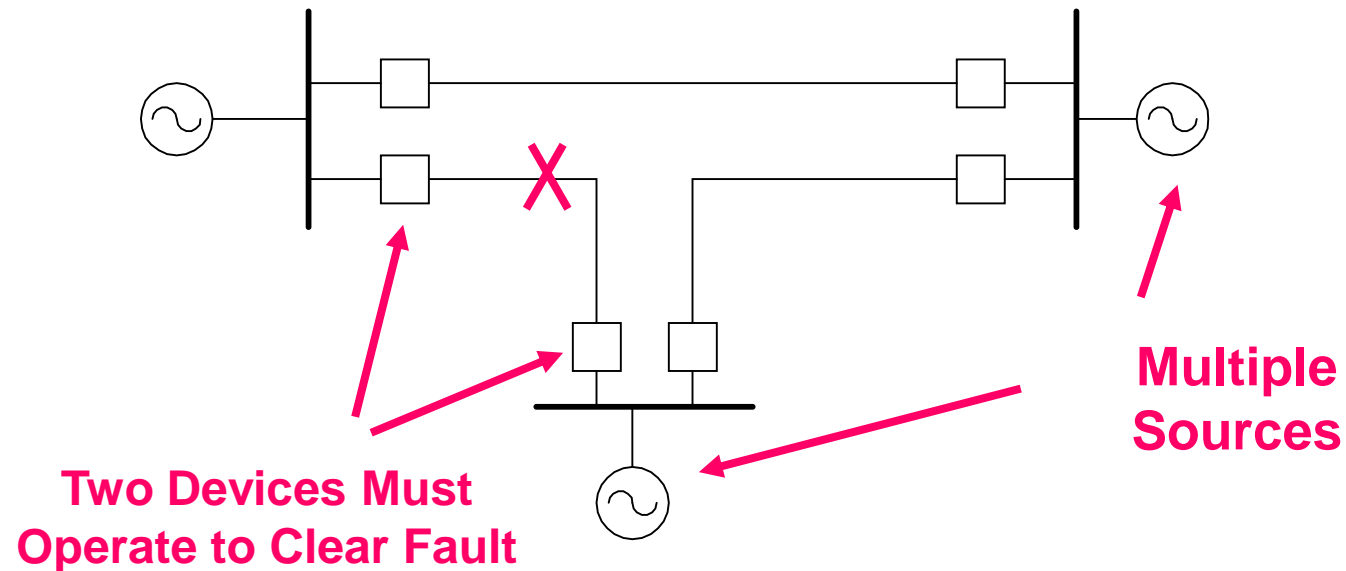
- This is the reason why most systems are radial
- Important to understand this for DER application on the “Integrated Grid”
 - Lower-cost, simpler protection for the inevitable short circuit
 - Series overcurrent relaying (fuses, reclosers, breakers)
- This is where many of the operating conflicts with DER 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.

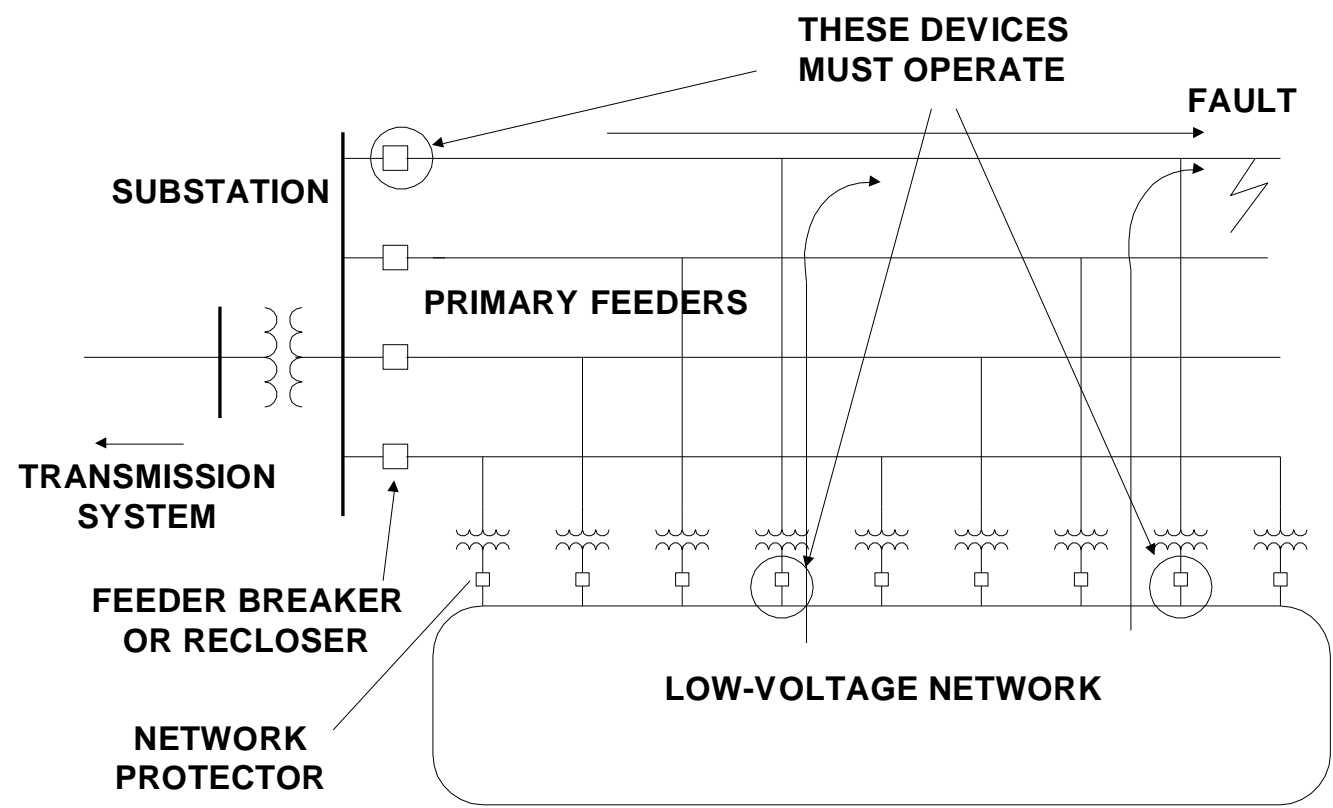
Radial Circuit Economics

- 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



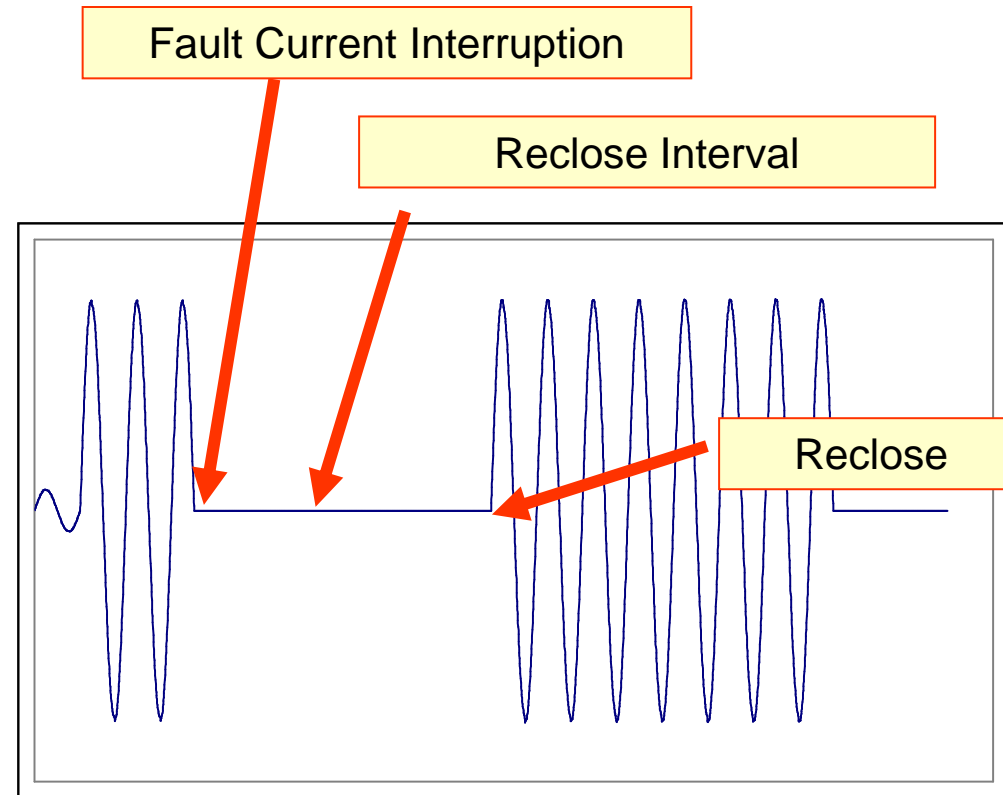
LV Network Protection Principles

- 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

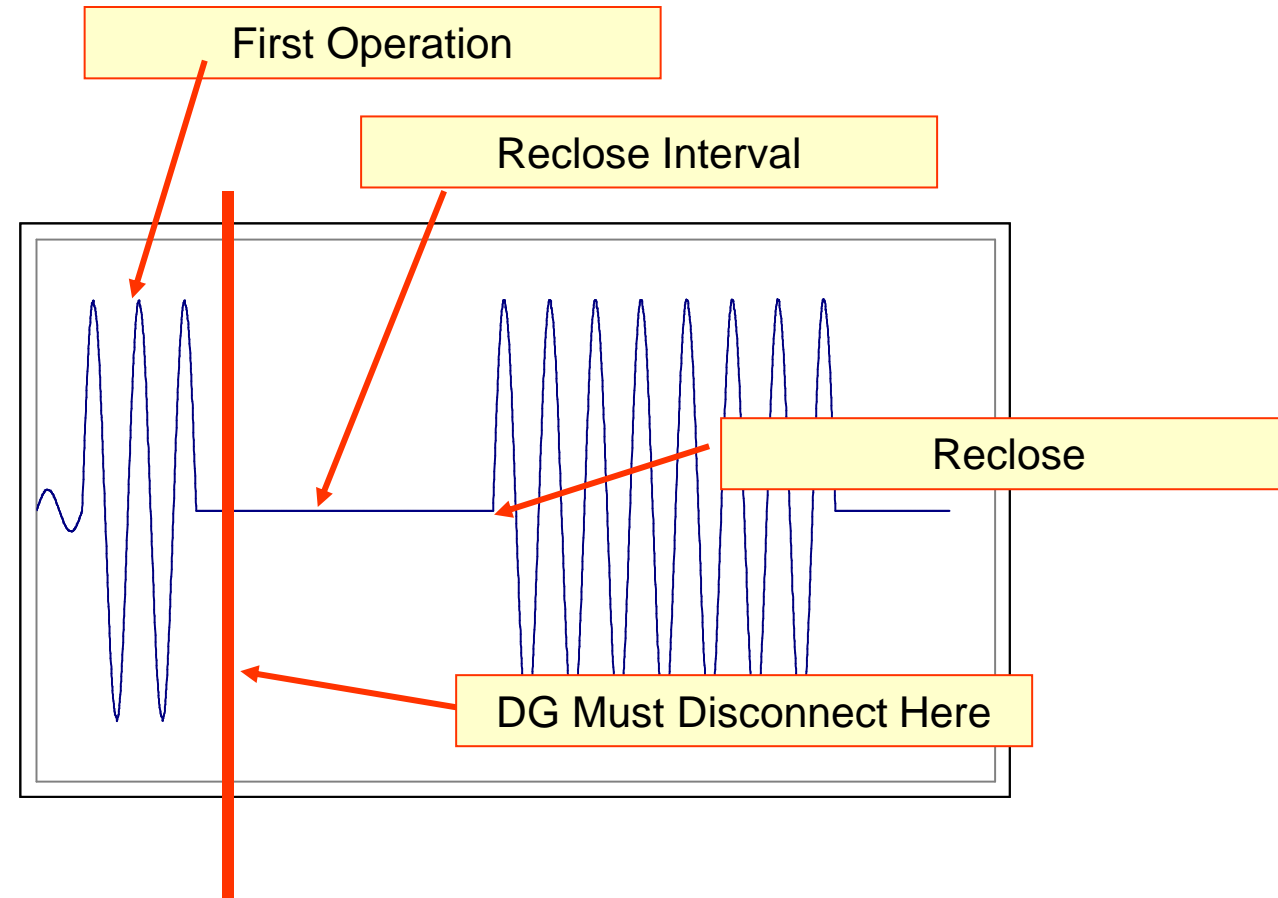
Reclosing on Overhead Radial Circuits

- 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 primary system (MV) 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 often on the end-user side or to subtransmission (HV) feed to the distribution system
- DER can economically defer investments in distribution infrastructure under some circumstances

A blue-tinted photograph of four people standing in a row. From left to right: a man with curly hair and glasses in a lab coat; a man with glasses in a lab coat; a woman wearing a hard hat and safety glasses in a lab coat; and a man with glasses in a button-down shirt. The text 'Together...Shaping the Future of Energy™' is overlaid in white in the center.

Together...Shaping the Future of Energy™