MEDIUM VOLTAGE SYSTEMS

ELECTRIC LEAGUE
OF THE PACIFIC NORTHWEST

MEDIUM VOLTAGE vs LOW VOLTAGE

Course Objectives

Overview of Medium Voltage Applications to learn more about MV basics, MV architecture and systems, and MV equipment.

Presented as a comparison of Low Voltage Systems basics, including standards, architecture, systems, and equipment.

MEDIUM VOLTAGE vs LOW VOLTAGE

Course Objectives

On May 15, the Electric League is presenting a follow-up to the MV topic. Please make notes about what you want to learn about as the presentation progresses.

Questions that we cannot answer without going more in-depth than we have time to discuss will be considered for the agenda of the next session as will your requests for a deeper understanding.

MEDIUM VOLTAGE vs LOW VOLTAGE

ANSI C84.1-2020

Electric Power Systems and Equipment - Voltage Ratings (60 Hz)

Descriptions of nominal voltage ratings from 100V to 1,200kV.

The ‘Voltage Class’ of ‘Medium Voltage’ begins at 1,000V and runs up thru 69,000V in North America.

The ‘Voltage Class’ of ‘Low Voltage’ begins at 100V and runs up to 600V in North America.

Table 1 - Standard nominal system voltages and voltage ranges (Preferred system voltages in bold)

VOLTAGE CLASS	Nominal System Voltage (Note a)			Nominal Utilization Voltage (Note h)	Voltage Range A (Note b)			Voltage Range B (Note b)		
					Maximum	Minimum		Maximum	Minimum	
	2-wire	3-wire	4-wire	2-wire 3-wire 4-wire	Utilization and Service Voltage (Note c)	Service Voltage	Utilization Voltage	Utilization and Service Voltage	Service Voltage	Utilization Voltage
Low Voltage	Single-Phase Systems									
	120			115	126	114	108	127	110	104
		120/240		115/230	126/252	114/228	108/216	127/254	110/220	104/208
	Three-Phase Systems									
			208Y/120 (Note d)	200	218Y/126	197Y/114	187Y/108	220Y/127	191Y/110 (Note 1)	180Y/104 (Note 1)
			240/120	230/115	252/126	228/114	216/108	254/127	220/110	208/104
		240		230	252	228	216	254	220	208
			480Y/277	460Y/266	504Y/291	456Y/263	432Y/249	508Y/293	440Y/254	416Y/240
		480		460	504	456	432	508	440	416
		600 (Note e)		575	630 (Note e)	570	540	635 (Note e)	550	520
Medium Voltage		2400			2520	2340	2160	2540	2280	2080
			4160Y/2400		4370/2520	4050Y/2340	3740Y/2160	4400Y/2540	3950Y/2280	3600Y/2080
		4160			4370	4050	3740	4400	3950	3600
		4800			5040	4680	4320	5080	4560	4160
		6900			7240	6730	6210	7260	6560	5940
			8320Y/4800		8730Y/5040	8110Y/4680		8800Y/5080	7900Y/4560	
			12000Y/6930		12600Y/7270	11700Y/6760		12700Y/7330	11400Y/6580	(Note f)
			12470Y/7200		13090Y/7560	12160Y/7020	(Note f)	13200Y/7620	11850Y/6840	
			13200Y/7620		13860Y/8000	12870Y/7430		13970Y/8070	12504Y/7240	
			13800Y/7970		14490Y/8370	13460Y/7770		14520Y/8380	13110Y/7570	
		13800			14490	13460	12420	14520	13110	11880
			20780Y/12000		21820Y/12600	20260Y/11700		22000Y/12700	19740Y/11400	
			22860Y/13200		24000Y/13860	22290Y/12870		24200Y/13970	21720Y/12540	(Note f)
		23000			24150	22430	(Note f)	24340	21850	
			24940Y/14400		26190Y/15120	24320Y/14040		26400Y/15240	23690Y/13680	
			34500Y/19920		36230Y/20920	33640Y/19420		36510Y/21080	32780Y/18930	
		34500			36230	33640		36510	32780	
					Maximum Voltage (Note g)					
		46000			48300					
		69000			72500					
High Voltage		115000			121000					
		138000			145000					
		161000			169000					
		230000			242000					
Extra-High Voltage		345000			362000					
		400000			420000					
		500000			550000					
		765000			800000					
Ultra-High Voltage		1100000			1200000					

Note 1: Many 220-volt motors were applied on existing208 volt systems on the assumption that the utilization voltage would not be less than 187 volts. Caution should be exercised in applying the Range B minimum voltages of table 1 to existing 208-volt systems supplying such motors.

<u>Standards</u>

What is ‘Medium Voltage’

MEDIUM VOLTAGE vs LOW VOLTAGE

ANSI C84.1-2020

‘Medium Voltage’
Industrial facilities, substations, large commercial buildings, campus distribution, large industrial loads, utilities

‘Low Voltage’
Residential, commercial buildings, small industrial loads, IT systems

VOLTAGE CLASS	Nominal System Voltage (Note a) 2-wire	3-wire	4-wire	Nominal Utilization Voltage (Note h) 2-wire 3-wire 4-wire
Low Voltage	120	120/240		115 115/230
		240 480 600 (Note e)	208Y/120 (Note d) 240/120 480Y/277	200 230/115 230 460Y/266 460 575
Medium Voltage		2400 4160 4800 6900 13800 23000 34500 46000 69000	4160Y/2400 8320Y/4800 12000Y/6930 12470Y/7200 13200Y/7620 13800Y/7970 20780Y/12000 22860Y/13200 24940Y/14400 34500Y/19920	
High Voltage		115000		

Standards

Where is ‘Medium Voltage’

MEDIUM VOLTAGE vs LOW VOLTAGE

MV is often classified into the following typical **subclasses**:

Low Medium Voltage (1 kV – 5 kV)

1. Common in industrial facilities, commercial buildings, and smaller distribution systems.
2. Common voltages: **2.4 kV, 4.16 kV**.

Standard Medium Voltage (5 kV – 15 kV)

1. Used in industrial power systems, commercial campuses, and primary distribution networks.
2. Common voltages: **7.2 kV, 12.47 kV, 13.2 kV, 13.8 kV**.

Higher Medium Voltage (15 kV – 35 kV)

1. Common in utility distribution networks and larger industrial applications.
2. Common voltages: **22.9 kV, 24.94 kV, 25 kV, 34.5 kV**.

Upper Medium Voltage (35 kV – 69 kV)

1. Used for sub-transmission, long-distance distribution, and interconnection between substations.
2. Common voltages: **46 kV, 69 kV**.

Standards

MEDIUM VOLTAGE vs LOW VOLTAGE

Why Medium Voltage:

	Low Voltage (≤ 600 V)	Medium Voltage (600 V – 35 kV)
Typical Applications	Offices, retail, small schools, small commercial buildings	Campuses, hospitals, data centers, industrial facilities
Load Size	< 1–2 MW	> 2–2.5 MW
Cable Run Distance	Short (< 500 ft)	Long (hundreds to thousands of feet)
System Complexity	Simple	More complex
Installation Cost	Lower	Higher (gear, protection, training)
Safety Requirements	Less stringent; general electricians	Requires MV-qualified personnel
Maintenance	Easier; lower risk	Specialized and more stringent
Ideal for Distribution	Small buildings, centralized panels	Large areas with distributed transformers

MEDIUM VOLTAGE vs LOW VOLTAGE

MV and LV utilize similar but different **Design and Construction Standards**:

	Low-Voltage (LV) Systems	**Medium-Voltage (MV) Systems**
Regulatory Standards **Best Practices**	- NEC (NFPA 70) - IEEE 141 [Red Book] - IEEE 242 [Gray Book] - National Equipment Manufacturers Association (NEMA) - Underwriters Labs (UL)	- NEC (NFPA 70 – *Over 1000 Volts ac*) - IEEE 1584 (Arc Flash Analysis) - IEEE C37 Series (Switchgear) - IEEE C57 Series (Transformers) - Nationally Recognized Testing Laboratory (NRTL)

<u>**Standards**</u>

MEDIUM VOLTAGE ARCHITECTURE

A list of the most common MV architectures you're likely see. We'll describe each a bit more in detail on the following slides:

- Radial System
- Selective System
  - Primary
  - Secondary
- Primary Loop
- Ring Bus

MEDIUM VOLTAGE ARCHITECTURE

This is what we commonly refer to as a Unit Substation (USS) in our market. There is a single primary service and distribution transformer suppling all the feeders/loads.

Pro:

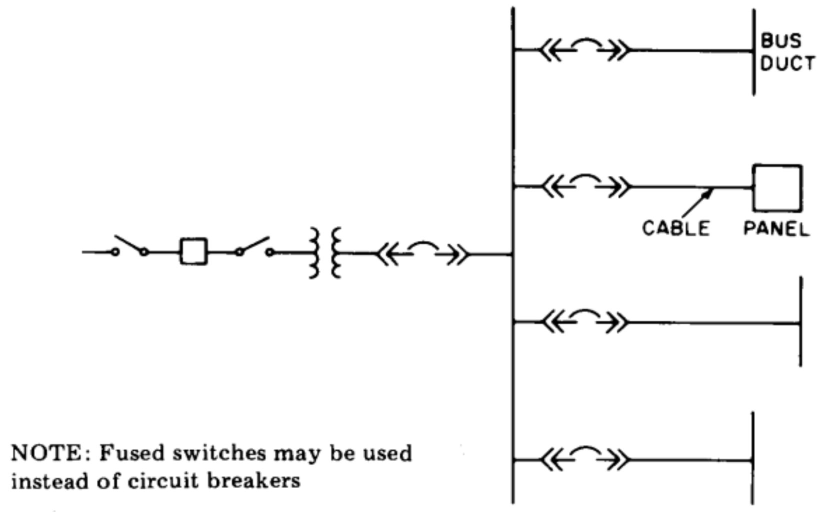
- Operation and expansion are simple
- Low cost

Con:

- Susceptible to outages
- Equipment must be shut down for maintenance

Common Uses:

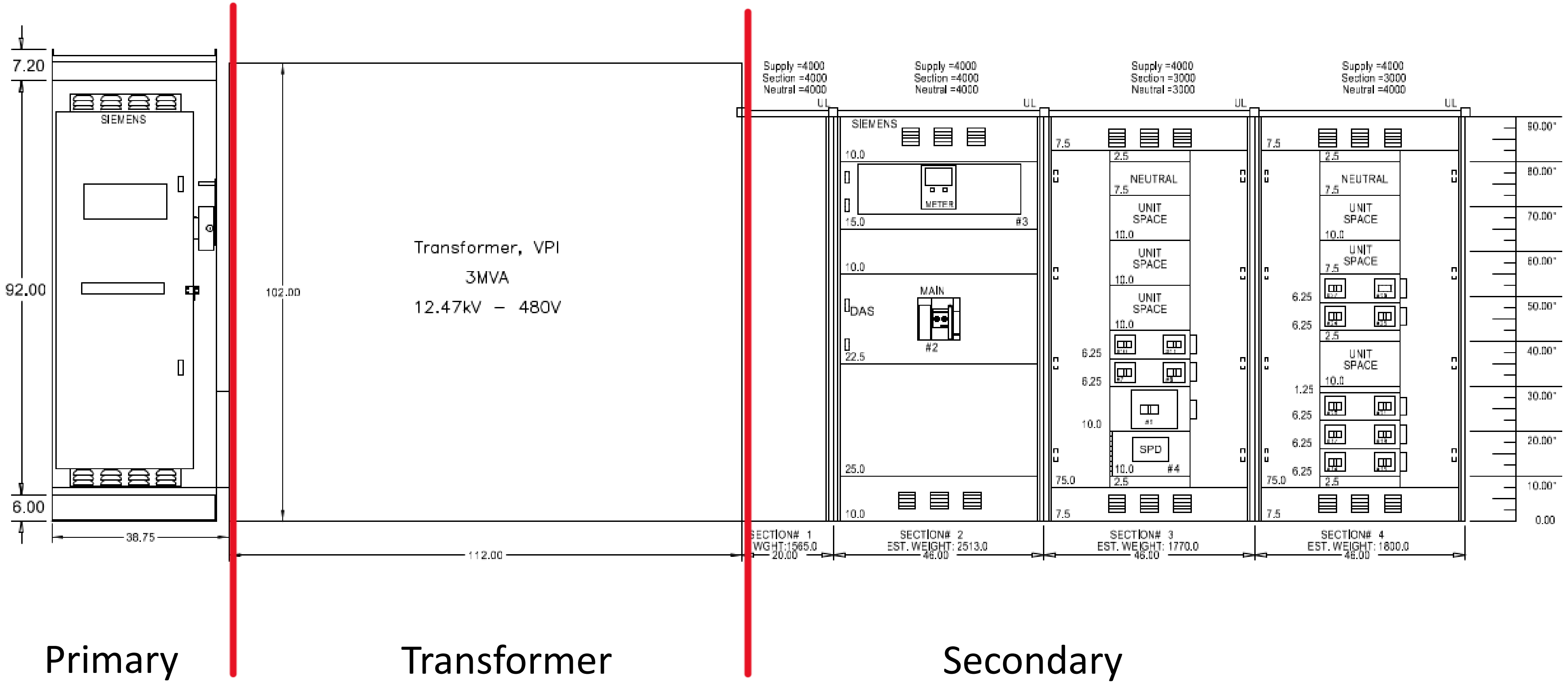
- Buildings where downtime is not critical



Source: IEEE 141-1993 Figure 2-1

Radial System

MEDIUM VOLTAGE ARCHITECTURE



Primary

Transformer

Secondary

<u>Radial System</u>

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MEDIUM VOLTAGE ARCHITECTURE

There are two different selective systems; Primary and Secondary. Both provide a redundant source of power to the loads.

Pro:

- Redundancy with protection against loss of primary source

Con:

- Typically, an interruption in power to loads during source transfer
- Moderate Cost

Common Uses:

- Selector Switch (Primary)
- Main-TIE-Main (secondary)

Primary

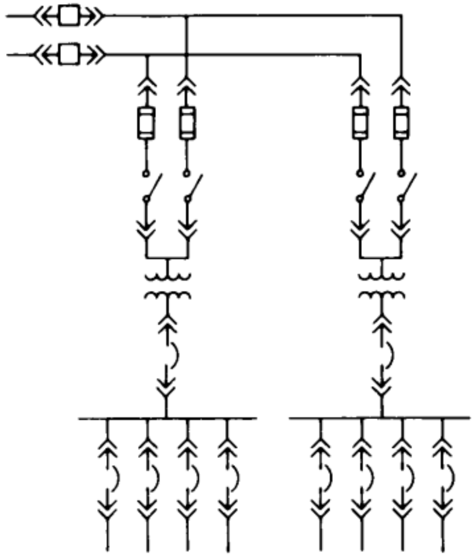


Figure 2-3

Secondary

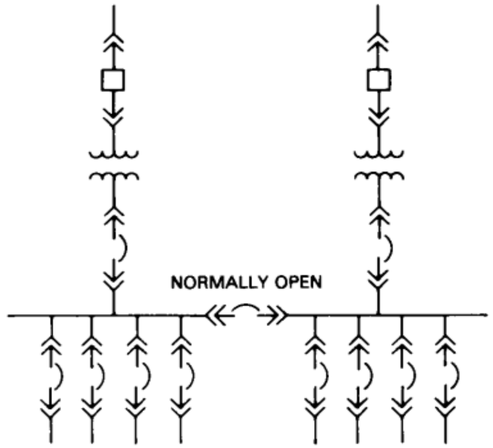


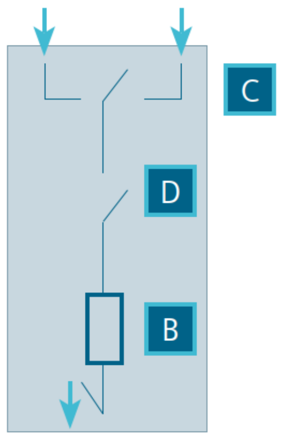
Figure 2-5a

Source: IEEE 141-1993

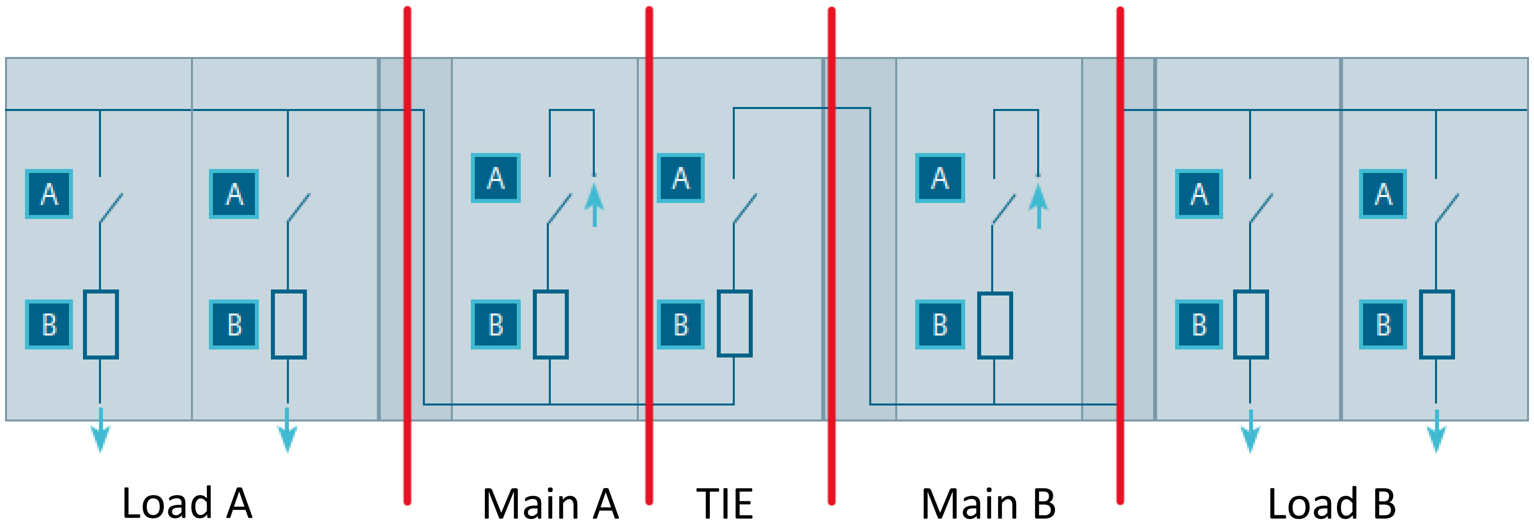
Selective System

MEDIUM VOLTAGE ARCHITECTURE

Selector (Primary)



Main-Tie-Main (Secondary)



Selective System

MEDIUM VOLTAGE ARCHITECTURE

Two Primary sources feed the loads in a "loop" configuration. In a 'CLOSED' loop system all the switches shown in Fig. 2-4 will be closed. In an 'OPEN' loop system, one switch will be open; this is essentially mimicking a selective system.

Pro:

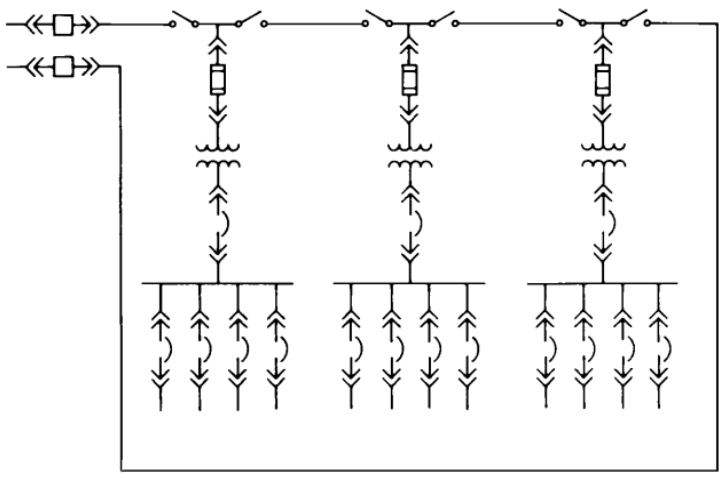
- Does not experience loss of power when one of the sources fails.
- Can isolate faults

Con:

- Moderate cost
- Complexity and typically requires a trained staff

Common Uses:

- Campuses, Large Commercial buildings



Source: IEEE 141-1993 Figure 2-4

Primary Loop System

MEDIUM VOLTAGE ARCHITECTURE

When multiple primary sources are connected in parallel to supply a common load. The Network Protectors will open to prevent back-feeding a failed source. Think of paralleling switchgear.

Pro:

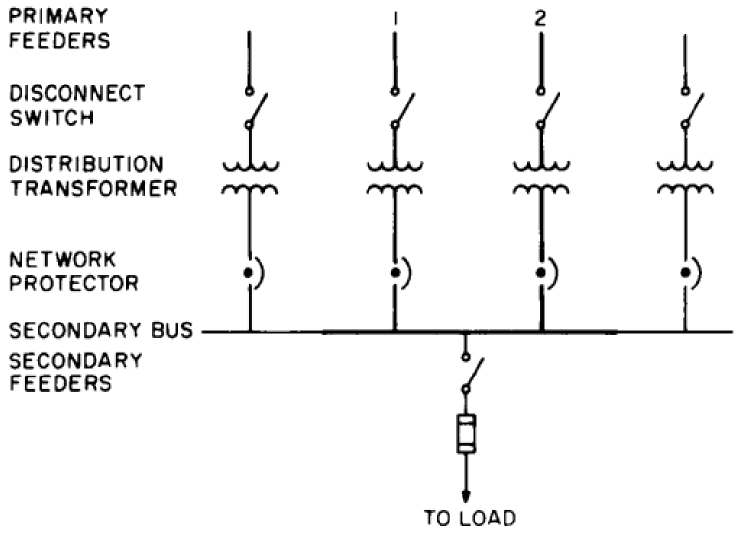
- Most Reliable with minimal downtime
- Excellent for critical loads

Con:

- Very high cost
- Very Complex and should have a trained staff

Common Uses:

- Hospitals, data centers, utility network



Source: IEEE 141-1993 Figure 2-6

Spot Network System

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are made up of similar **categories of components**:

Conductors and Pathways

- **Overhead** cable systems, typically utilizing bare steel-reinforced aluminum conductor.
- **Underground** cable systems, split into direct buried cable and conductors in duct banks.
- **In-Building** cable systems, primarily conductors in conduit, cables in cable tray or cable bus, and occasionally busway assemblies.

Power Transformers

- Dry-type insulation systems.
- Liquid-filled insulation systems.
- Multiple cooling schemes and temperature-rise ratings.

Circuit Protective Devices

- Fuses (multiple curve choices and assemblies).
- Circuit breakers (separation of breakers and protective relaying).

Equipment

- Pole-mounted.
- Pad-mounted.
- Submersible.

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Conductors and Pathways**:

Cables and Wires

Overhead cable systems, typically utilizing bare steel-reinforced aluminum conductor.

Underground cable systems, split into direct buried cable and conductors in duct banks.

In-Building cable systems, primarily conductors in conduit, cables in cable tray or cable bus, and occasionally busway assemblies.

Overhead cable systems

Bare or Covered Conductors – Usually bare aluminum or ACSR (Aluminum Conductor Steel-Reinforced).

Insulators – To support and insulate conductors on poles.

Crossarms & Poles – Wood, concrete, or steel structures. Typically wood.

Lightning Arresters – Protect against voltage spikes.

Components

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Conductors and Pathways**:

Underground cable systems

MV Power Cables – Often EPR (Ethylene Propylene Rubber [preferred]) or XLPE (cross-linked polyethylene) insulated, armored or unarmored.

Cable Trays/Duct Banks/Conduits – For cable routing and protection.

Splice Boxes / Manholes – For cable joints and installation and maintenance access.

Heat Shrink or Cold Shrink Joints/Terminations – For environmental sealing and insulation.

Grounding/Sheath Bonding – To manage fault currents and minimize interference.

In-Building MV Cable Systems

MV Cables (Fire-rated if needed) – Routed through risers, shafts, or dedicated cable rooms.

Terminations – At switchgear, transformers, or motor control centers.

Switchgear / Switchboards – For control and protection.

Conduits, Trays, or Cable Bus Systems – Depending on layout and fire regulations.

Grounding/Bonding Systems – Critical for personnel safety and equipment protection.

Components

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Conductors and Pathways**:

Underground/In-Building Cable systems

	Low Voltage	Medium Voltage
Voltage Range	Up to 1 kV	1 kV – 35 kV
Insulation	Single layer	Multi-layer (incl. shields)
Shielding	Optional	Required
Conductor Shield	NONE	Semi-conductive layer
Insulation Shield	NONE	Semi-conductive + grounding layer
Jacket & Armor	Basic	Often reinforced
Applications	Building wiring	Utility, industrial, substations

Components

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Power Transformers**:

Dry-type

Thermal Management: Dry-type transformers (IEEE C57.12.01) are limited in kVA due to air-based cooling, which is less efficient.

Typical kVA Ranges: Smaller to medium range, with limitations at the higher end due to thermal constraints (e.g., up to 10,000 kVA for standard applications).

Application Context: often used indoors or in industrial/commercial applications with lower power demands.

Liquid-filled

Thermal Management: Liquid-immersed transformers (IEEE C57.12.00) can handle higher kVA ratings due to better cooling and heat dissipation properties of the liquid medium.

Typical kVA Ranges: Broad range from small to large-scale applications (e.g., 10 kVA to hundreds of MVA for power transformers)..

Application Context: more common in utilities and outdoor environments with higher power needs.

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Power Transformers**:

Dry-type

Liquid-filled

<u>**Components**</u>

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Circuit Protective Devices**:

	Low Voltage (LV) Fuses	Medium Voltage (MV) Fuses
Voltage Range	≤ 1000 V AC (typically up to 600 V in UL applications)	> 1000 V to ~38 kV (per ANSI/IEEE)
Standards	UL 248-x (series of fuse standards)	ANSI C37.41, C37.42, C37.46, C37.47
Common Classes	Class H, K, R, J, T, CC, G, L	E-rated and R-rated (current-limiting); expulsion fuses (non-current-limiting)
Protection Type	Overload + short-circuit (varies by class)	Short-circuit protection only; overload handled by relays
Construction	Cartridge, blade, or ferrule-type	Current-limiting or expulsion, often enclosed or clip-mounted
Time-Current Characteristic	Fast-blow and time-delay available	Time-delay (E-rated) or motor-optimized (R-rated)

<u>**Components**</u>

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Circuit Protective Devices**:

	LV Breakers (UL/ANSI C37.13)	MV Breakers (ANSI C37.04/06/09)
Voltage Class	≤ 1kV	1kV–38kV (common), up to 69kV
UL Standard	UL 489 (MCCBs)/ UL 1066 (ACBs) ANSI C37.13 (ACBs)	ANSI C37.04 (general requirements), C37.06 (ratings), C37.09 (testing), C37.20.2 (metal-clad switchgear)
Protection	Built-in trip units - Thermal-magnetic, electronic (LSIG functions)	External protective relays - Controlled by protective relays (ANSI 50/51, 27, 59, etc.)
Interruption Medium	Air	Vacuum (common), SF_6 (or Green Gas), Air Blast
Energy Containment	Breakers rely on external barriers and chutes to contain arc safely	Arc is fully contained in interrupter (sealed vacuum bottle or gas tank) – safer for higher voltages
Coordination	Fully and selectively coordinated via series ratings (UL 489)	Relay curves and zone protection via Time-current coordination via protective relay settings
Monitoring	Trip unit diagnostics (LSIG, waveform capture)	Integrated SCADA, protective relays, condition monitoring

Components

Medium-Voltage Switchgear

Terminology

Terminology

1. Physical Installation

- Subsurface (Submersible), Vault, Padmount, Metal-Clad and Metal-Enclosed

  a. Indoor or Outdoor
  b. Above or Below Grade
  c. Cable Entry & Connections – Above or Below, Live Front or Dead Front
  d. Tamper Resistant – Prevent unauthorized access

Switchgear Type	Indoor	Outdoor	Above or Below Grade	Cable Termination Style	Above or Below Cable Entry
Metal-Enclosed Switchgear	x	x	Above	Live Front[1]	Both
Metal-Enclosed Gas Insulated Switchgear	x		Above	Live Front[2]	Below
Metal-Clad Switchgear	x	x [3]	Above	Live Front	Both
Padmount Switchgear		x	Above	Dead Front	Below
Subsurface (Submersible) Switchgear	x	x	Below	Dead Front	Below
Vault Switchgear	x		Above or Below	Dead Front	Below

Notes:

1) *Traditional Metal-Enclosed Switchgear is Live Front Connections Only and Some Metal-Enclosed Switchgear includes Live Front or Dead Front Connection options.*
2) *Metal-Enclosed Gas Insulated Switchgear cable connections typically require a minimum of a 36.5" H vault beneath the gear.*
3) *Metal-Clad Switchgear includes Aisleless and Walkin Outdoor Construction.*

Terminology

2. Insulating Mediums

Insulating material used for insulating energized parts from the structure ground

Types – Air, Fluid, Gas, & Solid Dielectric

- **Air –** Air is a readily available, most common and least expensive. Disadvantage is lower dielectric strength compared to others requiring larger equipment.
- **Fluid –** Provides both insulation and cooling, making it ideal for high-power applications. Requires maintenance and monitoring for contamination and degradation. Fluid types include Mineral Oil, E200 and FR3.
- **Gas –** Used as a primary insulation between live electrical components and the grounded metal enclosure. Historically SF6 was the gas utilized; however, many equipment suppliers are considering NOG (natural origin gas) alternatives as a replacement for SF6 for the future.
- **Solid Dielectric –** Consists of polymeric dielectric materials used as an encapsulated material for live parts. The combination of non-conductive materials with air gaps provide low dielectric losses, high mechanical strength and resistance to thermal and chemical deterioration of the switchgear.

Terminology

3. Switch/Interrupter Types

Padmount/Subsurface/Vault Terms

- Switched Way – Way with three phase group operated or single-phase switch used for open/close operation
- Protected Way – Way with Interrupter Device

Switch Types

- Switch in Air, Fluid, Gas or Vacuum
- Breaker in Air or Vacuum

Interrupting Device

- Fuses (Current-Limiting and Expulsion)
- Breaker with Protective Relay
- VFI (Vacuum Fault Interrupter) with Protective Relay

Switchgear Type	Switching Type (Open/Close Operation)				Interrupter Device (Overcurrent Protection)			
	Switch (Air)	Switch (Vacuum)	Switch (Fluid)	Breaker (Vacuum)	Switch w/ Fuses	VFI w/ Protective Relay	Breaker w/ Integral Trip Unit	Breaker w/ Protective Relay
Metal-Enclosed Switchgear	x			x	x	x	x	x
Metal-Enclosed Gas-Insulated Switchgear				x				x
Metal-Clad Switchgear				x				x
Padmount Switchgear		x	x	x	x	x		x
Subsurface (Submersible) Switchgear		x		x		x		x
Vault Switchgear		x		x		x		x

Terminology

4. Current and Voltage Ratings

- Continuous Current – 200A up to 4000A
- Voltage
  - IEEE Medium Voltage Range - 1 kV to 69 kV
  - Medium Voltage Classes – 5kV, 15kV, 27kV and 38kV
    - ❑ Basic Insulation Level (BIL) – Range is 60 kV to 250 kV
- Short Circuit Current Ratings
  - Short Time Withstand Current Rating – One or two or 2 second symmetrical current (Subsurface/Vault/Padmount Switchgear is 1 sec. & Metal-Enclosed and Metal-Clad Switchgear is 2 sec.)
    - ❑ Short Circuit Current – 10 kA up to 63 kA symmetrical
  - Momentary Withstand Current Rating - 10-cycle asymmetrical peak current
    - ❑ Momentary Withstand Current Rating – 16-101 kA asymmetrical

5. Standards

- 3rd party certifications
  - UL, CSA, IBC/CBC, OSHPD
- Design Standards
  - ANSI / IEEE, IEC, NEMA

Table 3. Standard Nominal System Voltages and Voltage Ranges (From IEEE Standard 141-1993)

Voltage Class	Nominal System Voltage	
	Three-Wire	Four-Wire
Low voltage	240/120 240 480 600	208Y/120 240/120 480Y/277 —
Medium voltage	2400 4160 4800 6900 13,200 13,800 23,000 34,500 46,000 69,000	4160Y/2400 8320Y/4800 12000Y/6930 12470Y/7200 13200Y/7620 13800Y/7970 20780Y/12000 22860Y/13200 24940Y/14400 34500Y/19920
High voltage	115,000 138,000 161,000 230,000	— — — —
Extra-high voltage	345,000 500,000 765,000	— — —
Ultra-high voltage	1,100,000	—

Major equipment categories

- Metal-clad switchgear
- Metal-enclosed switchgear
- MEGIS (metal-enclosed gas-insulated switchgear)
- Underground switchgear
  - Padmount
  - Vault
  - Subsurface
- VFI transformers

Design standards

Feature	IEEE C37.20.2 – 2022 (Metal-Clad)	IEEE C37.20.3 – 2023 (Metal-Enclosed)	IEEE C37.20.9 – 2019 (MEGIS)	IEEE C37.74-2014 IEEE C37.62-2020* (Vault/Padmount SWGR)
Continuous Current Rating	1200A, 2000A, 3000A, 4000A	600A, 1200A, 2000A, 3000A, & 4000A	200A, 600A, 1200A, 2000A, 2500A, 3000A, and 4000A	200A, 400A, 600A
Voltage	1kV-48.3kV	1 kV to 48.3 kV	1 kV to 52 kV	1 kV to 38 kV
Short Time Withstand	16-63kA, rms sym	12.5-63kA, rms sym	12.5 kA – 63 kA, rms sym	10 kA – 38 kA, rms sym
BIL Ratings	60 kV - 250 kV	60 kV – 250 kV	60 kV – 250 kV	95 kV – 150 kV
Ambient Temp. Requirement	-30°C to 40°C	-30°C to 40°C	-5°C to 40°C	-30°C to 40°C
Altitude	3300 ft and under	3300 ft and under	3281 ft and under	3281 ft and under

MV switchgear types

	Pad-mount Air or liquid	Pad-mount Vacuum interrupters	VFI SWGR	Solid Dielectric	Padmount Metal Enclosed	VFI XFMR	Metal-Enclosed	Metal Clad	Compact Switchgear
									
Voltage Class	15-38 kV	15-38 kV	15-38 kV	15-27 kV	15-38 kV	15-38 kV	5-38 kV	5-38 kV	5-38 kV
IEEE Standard	C37.74	C37.74	C37.74, C37.62	C37.74, C37.62		C57.12.00, C37.62	C37.20.3	C37.20.2	C37.20.9
Relative Cost	$	$	$	$	$$	$$$	$$$	$$$	$$$

QUESTIONS?

On May 15, the Electric League is presenting a follow-up MV session. Please share your notes about what you want to learn at the May session

Presentation will be available online at
electricleague.net/presentations

Thank you for joining us today!

Presentation will be available online at
electricleague.net/presentations

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Power Transformers**:

Cooling Systems for Liquid-filled Transformers
Transformers generate heat during operation. Proper cooling systems are essential to maintain optimal temperature levels and prevent damage.

Natural Cooling (ONAN)
Function: Relies on natural convection to circulate oil and air for cooling.
Application: Smaller or low-rating transformers.

Forced Air Cooling (ONAF)
Function: Fans force air over the cooling fins or radiators to enhance heat dissipation.
Application: Medium to large transformers with higher load requirements.

Cooling Systems for Liquid-filled Transformers

Forced Oil and Air Cooling (OFAF)
Function: Oil pumps circulate the insulating oil, while fans cool the oil in radiators.
Application: High-capacity transformers with significant cooling needs.

Oil to Water Cooling (OFWF)
Function: Heat exchangers transfer heat from oil to a water-cooling system.
Application: Transformers in environments where water cooling is more effective.

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Power Transformers**:

Cooling Systems for Liquid-filled Transformers

Radiators with Fans

Function: Radiators equipped with fans increase heat dissipation.

Application: Enhances cooling performance for both natural and forced systems.

Monitoring and Control Systems

Sensors:

- Temperature gauges for oil and winding.
- Pressure relief devices for oil expansion.

Control:

- Automatic activation of fans or pumps based on temperature thresholds.

Temperature-Rise for Liquid-filled Transformers

Temperature rise rating of a transformer is a key spec that tells you how hot the windings are allowed to get above ambient temperature during full load operation.

Temperature rise rating is the difference between the ambient temperature and the average or hottest winding temperature when the transformer is operating at rated load. If the ambient is 30°C (standard for rating), and the transformer has a 65°C rise, the winding temp may reach 95°C.

<u>**Components**</u>

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Power Transformers**:

Temperature-Rise for Liquid-filled Transformers

Typical temperature rises:

55°C - More conservative, often used for longer life.
65°C - Standard for many substation transformers.
55/65°C - Can be operated at either level.

Mode	Cooling	Temp Rise	Rating	Notes
Normal	ONAN	55°C	2500 kVA	Standard continuous
Boost	ONAF	55°C	2800 kVA	Higher output with fans, same insulation stress
Heavy Load	ONAN	65°C	2750 kVA	Accept higher temp rise
Max Load	ONAF	65°C	3000 kVA	Full output capacity

Components

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Power Transformers**:

Cooling Affects for Liquid-filled Transformers & Fault-Current Implications

Not significantly. Here's why:

%Z is fixed — it doesn't change with cooling or temp rise.

The **transformer's physical design** (winding size, spacing, core) determines %Z and short-circuit strength.

But in real-life **protection studies**, engineers typically:

- Use the **ONAN rating** for conservative fault calcs, or
- Use **maximum ONAF rating** if the transformer will regularly run in forced-cooled mode.
- cooling or temp rise.

Parameter	Affects Fault Current?	Notes
%Z Impedance	✅	Direct influence
KVA Rating	✅ (based on base current used)	Use max kVA if you want highest fault level
Cooling Mode (ONAN/ONAF)	❌	Impacts long-term load, not fault level
Temperature Rise (55/65°C)	❌	Affects insulation/life, not fault level

Components

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Power Transformers**:

Liquid-filled power transformers use insulating and cooling fluids to:

Insulate internal components like windings and cores.
Cool the transformer by transferring heat away from internal parts.
Protect against oxidation and moisture.

Fluid Type	Environmental Impact	Common Use Cases	Standards
Mineral Oil	Not biodegradable, flammable	Outdoor utility and industrial transformers	ASTM D3487
Natural Esters	Biodegradable, eco-friendly *Envirotemp FR3*	Urban, indoor, or environmentally sensitive sites	IEEE C57.147
Silicone Fluids	Low toxicity, not biodegradable *Dow Corning 561*	Indoor substations, tunnels, confined spaces	ASTM D4652

Components

MEDIUM VOLTAGE COMPONENTS

Medium Voltage systems are distributed utilizing various methods of **Power Transformers**:

Cooling Systems for Dry-type Transformers

Thermal Management: Dry-type transformers are limited in kVA due to air-based cooling, which is less efficient.

Typical kVA Ranges: Smaller to medium range, with limitations at the higher end due to thermal constraints (e.g., up to 10,000 kVA for standard applications).

Application Context: often used indoors or in industrial/commercial applications with lower power demands.

IEEE C57.12.01 – Cooling Class Designations

Code	Description
AA	Air-cooled by natural convection, ambient air only (no fans).
AF	Air Forced — ambient air is circulated using fans.
AA/FA	Transformer operates under natural cooling (AA) but has fans for forced air cooling (FA) as an optional/boost mode.

<u>**Components**</u>