Primary Distribution Voltage Levels

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Most

Primary Distribution Voltage Levels

distribution voltages are ***between 4 and 35 kV***. In this article, unless otherwise specified, voltages are given as line-to-line voltages; this follows normal industry practice, but it is sometimes a source of confusion.

The four major voltage classes are 5, 15, 25, and 35 kV. A voltage class is a term applied to a set of distribution voltages and the equipment common to them; it is not the actual system voltage.

For example, a 15-kV insulator is suitable for application on any 15-kV class voltage, including 12.47 kV, 13.2 kV, and 13.8 kV. Cables, terminations, insulators, bushings, reclosers, and cutouts all have a voltage class rating. Only voltage-sensitive equipment like surge arresters, capacitors, and transformers have voltage ratings dependent on the actual system voltage.

Utilities most widely use the ***15-kV*** voltages as shown by the survey results of North American utilities in ***Figure 1***. The most common ***15-kV*** voltage is ***12.47 kV***, which has a ***line-to-ground voltage of 7.2 kV***.

The dividing line between distribution and subtransmission is often gray. Some lines act as both subtransmission and distribution circuits. A 34.5-kV circuit may feed a few 12.5-kV distribution substations, but it may also serve some load directly.

Some utilities would refer to this as ***subtransmission***, others as ***distribution***.

The last half of the 20th century saw a move to higher voltage primary distribution systems. Higher-voltage distribution systems have advantages and disadvantages (*see Advantages and disadvantages of higher voltage* *distribution below*).

The great advantage of higher voltage systems is that they ***carry more power*** for a given current.

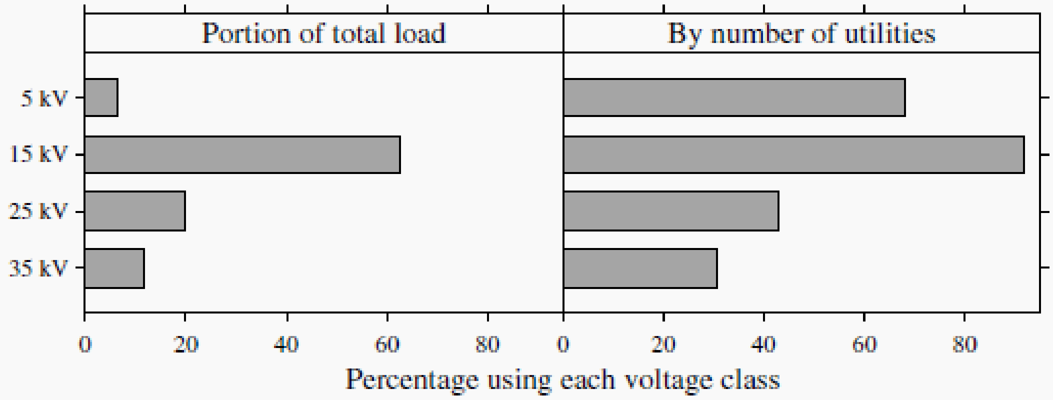

Figure 1 - Usage of different distribution voltage classes (n = 107). (Data from IEEE Working Group on Distribution Protection, 1995)

Higher Voltage Distribution

Advantages

Voltage drop - A higher-voltage circuit has less voltage drop for a given power flow.
Capacity - A higher-voltage system can carry more power for a given ampacity.
Losses - For a given level of power flow, a higher-voltage system has fewer line losses.
Reach - With less voltage drop and more capacity, higher voltage circuits can cover a much wider area.
Fewer substations - Because of longer reach, higher-voltage distribution systems need fewer substations.

Disadvantages

Reliability - An important disadvantage of higher voltages: longer circuits mean more customer interruptions.
Crew safety and acceptance - Crews do not like working on higher-voltage distribution systems.
Equipment cost - From transformers to cable to insulators, higher-voltage equipment costs more.

Information above shows maximum power levels typically supplied by various distribution voltages.

Less current means lower voltage drop, fewer losses, and more power-carrying capability. Higher voltage systems need fewer voltage regulators and capacitors for voltage support. Utilities can use smaller con-ductors on a higher voltage system or carry more power on the same size conductor.

Table 1 - Power Supplied by Each Distribution Voltage for a Current of 400 A

System Voltage (kV)	Total Power (MVA)
4.8	3.3
12.47	8.6
22.9	15.9
34.5	23.9

Utilities can run much longer distribution circuits at a higher primary voltage, which means fewer distribution substations. ***Some fundamental relationships are:***

Power – For the same current, power changes linearly with voltage.

when $I_2 = I_1$

$$P_2 = \frac{V_2}{V_1} P_1$$

Current – For the same power, increasing the voltage decreases current linearly.

when $P_2 = P_1$

Voltage drop – For the same power delivered, the percentage voltage drop changes as the ratio of voltages squared. A 12.47-kV circuit has four times the percentage voltage drop as a 24.94-kV circuit carrying the same load.

$$I_2 = \frac{V_1}{V_2} I_1$$

when $P_2 = P_1$

Area coverage – For the same load density, the area covered increases linearly with voltage: A 24.94-kV system can cover twice the area of a 12.47-kV system; a 34.5-kV system can cover 2.8 times the area of a 12.47-kV system.

$$V_{\%2} = \left(\frac{V_1}{V_2}\right)^2 V_{\%1}$$

$$A_2 = \frac{V_2}{V_1} A_1$$

where:
V_1, V_2 = voltage on circuits 1 and 2
P_1, P_2 = power on circuits 1 and 2
I_1, I_2 = current on circuits 1 and 2
$V_{\%1}$, $V_{\%2}$ = voltage drop per unit length in percent on circuits 1 and 2
A_1, A_2 = area covered by circuits 1 and 2

The ***squaring effect*** on voltage drop is significant. It means that doubling the system voltage quadruples the load that can be supplied over the same distance (with equal percentage voltage drop); or, twice the load can be supplied over twice the distance; or, the same load can be supplied over four times the distance.

Resistive line losses are also lower on higher-voltage systems, especially in a voltage-limited circuit. Thermally limited systems have more equal losses, but even in this case higher voltage systems have fewer losses.

Line crews do not like higher voltage distribution systems as much. In addition to the widespread perception that they are not as safe, gloves are thicker, and procedures are generally more stringent. Some utilities will not glove 25- or 35-kV voltages and only use hotsticks.

The ***main disadvantage*** of higher-voltage systems is reduced reliability. Higher voltages mean longer lines and more exposure to lightning, wind, dig-ins, car crashes, and other fault causes. A 34.5-kV, 30-mi mainline is going to have many more interruptions than a 12.5-kV system with an 8-mi main-line. To maintain the same reliability as a lower voltage distribution system, a higher-voltage primary must have more switches, more automation, more tree trimming, or other reliability improvements.

Higher voltage systems also have more voltage sags and momentary interruptions. More exposure causes more momentary interruptions. Higher voltage systems have more voltage sags because faults further from the substation can pull down the station's voltage (on a higher voltage system the line impedance is lower relative to the source impedance).

Cost comparison between circuits is difficult (*see Table 2 for one utility's cost comparison*). Higher voltage equipment costs more – cables, insulators, transformers, arresters, cutouts, and so on. But higher voltage circuits can use smaller conductors. The main savings of higher-voltage distribution is fewer substations.

Higher voltage systems also have lower annual costs from losses.

Table 2 – Costs of 34.5 kV Relative to 12.5 kV

Item	Underground	Overhead
Subdivision without bulk feeders	1.25	1.13
Subdivision with bulk feeders	1.00	0.85
Bulk feeders	0.55	0.55
Commercial areas	1.05–1.25	1.05–1.25

Source: Jones, A.I., Smith, B.E., and Ward, D.J., "Considerations for Higher Voltage Distribution," IEEE

Transactions on Power Delivery, vol. 7, no. 2, pp. 782–8, April 1992.

As far as ongoing maintenance, higher voltage systems require less substation maintenance, but higher voltage systems should have more tree trimming and inspections to maintain reliability. Conversion to a higher voltage is an option for providing additional capacity in an area. Conversion to higher voltages is most beneficial when substation space is hard to find and load growth is high.

If the existing subtransmission voltage is ***34.5 kV***, then using that voltage for distribution is attractive; addi-tional capacity can be met by adding customers to existing 34.5-kV lines (a neutral may need to be added to the 34.5-kV subtransmission line).

Higher voltage systems are also more prone to ferroresonance. Radio inter-ference is also more common at higher voltages.

Overall, the 15-kV class voltages provide a good balance between cost, reliability, safety, and reach. Although a 15-kV circuit does not naturally provide long reach, with voltage regulators and feeder capacitors it can be stretched to reach 20 mi or more. That said, higher voltages have advantages, especially for rural lines and for high-load areas, particularly where substa-tion space is expensive.

Many utilities have multiple voltages (as shown by the survey data in ***Figure 1***). Even one circuit may have multiple voltages. For example, a utility may install a 12.47-kV circuit in an area presently served by 4.16 kV. Some of the circuit may be converted to 12.47 kV, but much of it can be left as is and coupled through 12.47/4.16-kV step-down transformer banks.

Resource: *Electric distribution equipment and systems by T. A. Short (Buy the book at Amazon)*