

Technical White Paper: Evaluating 90 °C vs. 105 °C Rated Cables for URD Power Distribution Systems



Matthew Kubikowski, Engineer – Marmon Utility
Bruce Miller, Engineer – Marmon Utility

Abstract

When designing underground distribution AC systems for 90 °C or 105 °C conductor operating temperature, 105 °C operation may appear advantageous for higher thermal loads in most applications. However, a comprehensive evaluation reveals that 90 °C operation temperature is not only the optimal choice for lower losses and more reliable systems but can also prevent severe overheating and premature breakdown of power cables systems. Systems designed for 90 °C operating temperature allow for more options in terms of design, material choices such as tree-retardant, cross-linked polyethylene (TR-XLPE) or ethylene propylene rubber (EPR). This paper presents evaluations of thermal performance, accessory compatibility, and a loss study to support informed decision-making.

1. Introduction

In recent years, there has been a noticeable shift to 105 °C rated cables in some utility specifications. Operating at higher temperatures will achieve a higher ampacity rating; however, there are trade-offs to consider when choosing 105 °C versus 90 °C rated cables. This paper will clearly outline the benefits and drawbacks of increasing operating temperature for underground residential distribution systems.

2. Thermal Performance Study

2.1 Ampacity ratings of 90 °C vs. 105 °C Cables:

Using CYME software, a comprehensive ampacity study was conducted on three cable designs, called cable 1, 2, and 3, with identical installation criteria.

- **Cable 1:** #1/0 AWG aluminum conductor 15 kV 133% insulation level, one-third neutral (6 x #14AWG bare copper), with a linear low-density polyethylene (LLDPE) jacket.
- **Cable 2:** 500 kcmil copper conductor 15 kV 133% insulation level, one-third neutral (16 x #10AWG bare copper), with a LLDPE jacket.
- **Cable 3:** 750 kcmil copper conductor 15 kV 133% insulation level, one-third neutral (24 x #10AWG bare copper), with a LLDPE jacket.

Table 1

Cable Descriptions	Ampacity (amps)		Percent Change (%)
	90°C operating temperature	105°C operating temperature	
Cable 1	155	169	9.03
Cable 2	466	510	9.44
Cable 3	540	592	9.62

2.2 Losses for 90 °C vs. 105 °C cables

Losses are always present in electrical circuits due to nonzero resistance in all elements of a circuit. Resistance will cause heat, which translates to unwanted energy loss. Electrical losses from the conductor are defined as:

$$P = I^2 Rn$$

Where:

I = current in amps

n = circuit type ($n = 2$ for AC single phase $n = 3$ for 3-phase balanced AC circuits).

P = power losses in watts

R = resistance as a function of temperature in ohms

Resistance is defined as:

$$R = R_o [1 + \alpha(T - T_o)]$$

Where:

R = resistance adjusted for varying temperature in ohms

R_o = initial resistance in ohms

T = actual temperature in °C

T_o = reference temperature in °C

α = temperature coefficient of resistance

Using the same three cable designs as described in section 2.1 and identical installation parameters, the conductor losses, and concentric wire losses in watts/ft are shown below, dielectric losses will also increase with temperature but have been omitted due to their insignificant contribution to total system losses (<1%):

Loss Study for Cable 1:

Table 2.1

Conductor Temperature	Conductor Losses [W/ft]	Concentric Wire Losses [W/ft]
90 °C	5.78	0.02
105 °C	7.13	0.02
Percent increase	23.35%	0.00%*

*Change is negligible due to relatively small cmil area of shield.

Loss Study for Cable 2:

Table 2.2

Conductor Temperature	Conductor Losses [W/ft]	Concentric Wire Losses [W/ft]
90 °C	6.19	0.99
105 °C	7.72	1.15
Percent increase	24.72%	16.16%

Loss Study for Cable 3:

Table 2.3

Conductor Temperature	Conductor Losses [W/ft]	Concentric Wire Losses [W/ft]
90 °C	5.88	1.78
105 °C	7.38	2.08
Percent increase	25.51%	15.54%

2.4 Accessories

Connectors, splices, and terminations utilized in power distribution systems are manufactured with thermal thresholds of 90 °C and 105 °C. The correct accessory must be chosen for the proper cable temperature. The 105 °C accessories are typically more expensive and take longer to install (i.e. mechanical shrink vs heat shrink accessories). Even when choosing the proper accessory, extra consideration should be given to prevent severe overheating of connectors.

According to a 2019 study by NEETRAC of Georgia Tech on High Temperature Operation of Extruded Distribution Cable Systems, it was found that “the connector temperature exceeds the conductor temperature when the conductor is operated at 90 °C and far exceeds the conductor temperature when the conductor is operated at 105 °C or 120 °C. Polymeric joint housings will readily degrade and fail at these highly elevated connector temperatures.” [4] A recreation of table 3 from the aforementioned NEETRAC white paper shown below shows connector temperatures for 750 kcmil and #1/0 AWG cables at increasing conductor temperatures.

Table 3

Connectors	Conductor Temperature				
	40 °C	70 °C	90 °C	105 °C	120 °C
Connectors for 750 kcmil cables	-	-	104 °C	122 °C	141 °C
Connectors for #1/0 AWG cables	45 °C	71 °C	140 °C	194 °C	400 °C+

Note:

- 10% of #1/0 AWG samples were removed during 90 °C cycles as a result of severe overheating [4].
- 30% of #1/0 AWG samples were removed by the end of the 105 °C cycles as a result of severe overheating [4].

3. Direct Bury Installation and Soil Thermal Stability

When direct burying power cable, additional consideration should be taken for soil thermal stability, especially in the cases of 105 °C normal operating temperature. Soil thermal stability is a function of four basic factors: soil properties (structure, density, moisture content), heat generated by the cable, cable geometry, and the amount of time cables are energized. The thermal resistivity of dry soil can be three times that of wet or moist soil, derating the ampacity of a given cable [11]. According to a paper by W.Z Black of Georgia Tech, “The single most influential factor that affects the rating of buried power cables is the soil thermal resistivity [10].”

Operating at 105 °C is more detrimental to soil thermal stability than 90 °C since higher temperatures will drive off moisture at a higher rate, due to the boiling temperature of water being exceeded, resulting in thermal runaway as the thermal mass now must dissipate into a less thermally conductive material. Thermal runaway will lead to an area where heat cannot efficiently dissipate into the earth causing severe cable overheating, and in turn, cable failure. Whether specifying 90 °C or 105 °C rated cables, it is important for utilities to do full soil resistivity studies before direct burying cable to ensure soil thermal stability; however, 90 °C operating temperature will provide more predictive thermal stability.

4. Conclusion

There are varying degrees of understanding regarding the impacts of operating medium voltage cables at elevated temperatures. From an efficiency standpoint, the ampacity gains from operating at 105 °C compared to 90 °C are 9% on average, but the tradeoff is the conductor losses will increase by 24% on average and metallic shield losses increase by 15% on average. Operating at higher temperatures will lead to a less efficient system when compared to 90 °C operating temperatures. Accessories add additional challenges when operating at 105 °C as shown by testing done by NEETRAC with connector temperatures greatly exceeding expected temperatures when operating at 105 °C and even 90 °C. Operating at 90 °C ensures temperatures at the jacket are not exceeding recommended temperatures and provides soil thermal stability, preventing thermal runaway. Cables rated 90 °C provide the ideal combination of performance and reliability for many power distribution applications.

References

- [1] IEEE Standard 835-2019: "Thermal Rating of Distribution Systems"
- [2] Marmon Utility Engineering Reports: "Thermal Performance Analysis of Kerite 90°C and 105°C Cables"
- [3] Field Study: "Accessory Failures in Distribution Systems Operating Above 90°C," Utility Engineering Journal, 2023
- [4] NEETRAC White Paper: High Temperature Operation of Extruded Distribution Cable Systems (Oct 2018)
- [5] ICEA Standard S-94-649 (2021)
- [6] CSA Standard C68.5:20
- [7] UL Standard 1072 (2013)
- [8] AEIC Standard CS8 (2020)
- [9] ICEA Standard P-45-482
- [10] ICC Presentation: "Soil Thermal Stability and Its Effect on Cable Ratings" by W. Z. Black School of Mechanical Engineering Georgia Institute of Technology
- [11] "Practical Aspects of Applying Soil Thermal Stability Measurements to the Rating of Underground Power Cables", M. Martin Jr., R.A. Bush, W.Z. Black, J.G. Hartley (1981)

Appendix A:

One-third Neutral

Table A1

Conductor Size	Neutral Configuration	Circular Mil area
#1/0 AWG Aluminum	6 x #14 AWG bare copper	24,576
500 kmcil Copper	16 x #10 AWG bare copper	166,138
750 kmcil Copper	24 x #10 AWG bare copper	249,207