svonavec-SR EE-period 5-8 - offsite learning packet day 6

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"... as for me and my house, we will serve the Lord" [Joshua 24:15]

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Voltage Drop Calculations

Part TWO

Electrical equipment is designed to operate at within a given voltage range, typically no less than 10% and no more than 5% from it's voltage rating.

Example: A typical 230 volt load is designed to operate at not less than 207 volts (-10%) and not more than 242 volts (+5%), Figure 1.

Author's Comment: Figures are not posted on the internet.

The actual operating voltage dependents on the output voltage from the electric utility and the voltage drop of the circuit conductors. Keep in mind that the voltage from the electric utility is not constant; its lower during peak utility loading and higher during off-peak load periods.

Generally, overvoltage in an electrical system is not a problem, unless there is a wiring error in the electrical system1, however reduced or under voltage can caused inconvenience by flickering lights2, erratic performance of electro-mechanical devices such as relays and contactors, fires, and equipment failures. In particular, sensitive electronic equipment operating at reduced voltage will not have sufficient "ride-through" capability for voltage sags, and fire pump equipment possibly could fail at inadequate voltage.

Electric utilities are required by public service commissions to supply electrical power with sufficient voltage and capacity for the loads to be served and for most installations, this is not a problem. Reduced or under voltage is often caused by excessive long service, feeder, and or branch circuit conductors. The sizing of these conductors is important to insure proper operating voltage for a safe and efficient electrical systems.

The actual equipment operating voltage is dependent on the originating voltage, the conductor size (actually its resistance), and the magnitude of the current flowing through the circuit conductors. The originating voltage at times can be increased by adjusting the taps on the transformer and the circuit voltage drop can be reduced by decreasing the load or increasing the conductor circular mil area.

Last month I explained that the Fine Print Notes (FPN) in the NEC about voltage drop is not enforceable as a Code rule. However, The National Electrical Code does require conductors to be sized to accommodate voltage drop for the following purposes:

- Grounding Conductors – Section 250-122(b)
- Motion Picture/Television Studios – Section 530-71(d)
- Fire Pumps – Section 695-7

The following formulas can be used to properly size conductors to prevent excessive voltage drop:

CM (single-phase) = (2 x K x I x D)/VD

CM (three-phase) = (1.732 x K x I x D)/VD

Author's Comment: Download a free Windows 95 Voltage Drop Calculator from www.mikeholt.com.

"CM" = Circular-Mils: The circular mils of the circuit conductor as listed in Chapter 9, Table 8.

"K" = Direct Current Constant: The direct current constant value to be used for copper is 12.9 ohms and 21.2 ohms is used for aluminum conductors.

"Q" = Alternating Current Adjustment: Alternating current circuits No. 2/0 and larger must be adjusted for the effects of self-induction (skin effect). The "Q" adjustment factor is determined by dividing alternating current resistance as listed in NEC Chapter 9, Table 9, by the direct current resistance as listed in Chapter 9, Table 8.

"I" = Amperes: The load in amperes at 100 percent, not 125 percent for motors or continuous loads.

"D" = Distance: The distance the load is located from the power supply, not the total length of the circuit conductors.

"VD" = Volts Dropped: The voltage drop of the circuit conductors as expressed in volts.

Example – Single-Phase

A 5 horsepower motor is located 100 feet from a 120/240 volt panelboard. What size conductor should be used if the motor nameplate indicates the voltage range is between 208-230 volts. Limit the voltage drop to 7.2 volts (3% of the voltage source) and the terminals are rated 75°C, Figure 2.

(a) No. 10 THHN (b) No. 8 THHN (c) No. 6 THHN (d) No. 4 THHN

• Answer: (a) No. 10 THHN

Section 430-22(a) requires motor conductors to be sized not less than 125 percent of the motor full-load current (28 amperes) as listed in Table 430-148. A No. 10 is rated 35 amperes at 75°C [Table 310-16 and Section 110-14(c)] and it is suitable to meet the NEC requirements (28 ampere x 1.25 = 35 ampere). In addition, a No. 10 conductor limits the voltage drop to meet the manufacture's voltage limitation rating [110-3(b)].

Conductor required to limit voltage drop to 3%

CM = (2 x K x I x D)/VD

CM = Wire size, Chapter 9, Table 8

K = 12.9 ohm, copper

I = 28 ampere

D = 100 feet

VD = 240 volts x 3% = 7.2 volts

CM = (2 x 12.9 ohms x 28 amperes x 100 feet)/7.2 volts

CM = 10,033, No. 10, Chapter 9, Table 8

Example – Three-Phase

Example: A 25 horsepower, 208 volt three-phase fire pump motor is located 175 feet the service. The fire pump motor controller is located 150 feet from the service (motor 25 feet from controller). What size conductor must be installed to the fire pump motor? Note: Terminals are rated 75°C. Figure 3.

(a) No. 4 THHN (b) No. 3 THHN (c) No. 2 THHN (d) No. 1 THHN

• Answer: (b) No. 3 THHN

When sizing conductor's for fire pump motors the following rules must be considered.

Calculation 1.

Section 695-6(c)(2) – No. 3. Branch circuit conductors must be sized no less than 125 percent of the fire pump motor full-load current as listed in Table 430-148 or 430-150, based on 75°C terminal rating [110-14(c)(1)] as listed in Table 310-16.

74.8 ampere x 1.25 = 93.4 ampere, No. 3 THHN at 75°C is rated 100 ampere

Calculation 2

Section 695-7 – No. 3. The operating voltage at the motor controller terminals shall not drop more than 15 percent below the controller-rated voltage when the motor starts (lock-rotor current).

CM = (1.732 x K x I x D)/VD

CM = Wire size, Chapter 9, Table 8

K = 12.9 ohms, copper

I = 404 ampere (locked-rotor, Table 430-151B)

D = 150 feet

VD = 31.2 volts (208 volts x 15%)

CM = (1.732 x 12.9 ohms x 404 ampere x 150 feet)/31.2 volts

CM = 43,396, Chapter 9, Table 8 = No. 3

Calculation 3

Section 695-7 – No. 4. The operating voltage at the terminals of the motor shall not drop more than 5 percent below the voltage rating of the motor while the motor is operating at 115 percent of the full-load current rating of the motor.

CM = (1.732 x K x I x D)/VD

CM = Wire size, Chapter 9, Table 8

K = 12.9 ohms, copper

I = 86 ampere (74.8 amperes @115%), Table 430-150

D = 175 feet

VD 5% = 10.4 volts (208 volts x 5%)

CM = (1.732 x 12.9 ohms x 86 ampere x 175 feet)/10.4 volts

CM = 32,332, Chapter 9, Table 8 = No. 4

Caution: For voltage drop, the No. 4 wire is okay from the controller to the motor, but Section 695-6(c)(2) requires the branch circuit conductors to be sized no less than No. 3.

I hope this short summary was helpfull. If you want to know more about this subject, please attend our seminar or order our home study video program today.

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Conductor required to limit voltage drop to 3%

SENIOR ELECTRICITY LAB LESSON

VOLTAGE DROP WORKSHEET

Resources:

Youtube.com (search for mike holts voltage drop)

NEC Table 9

Calculate the following:

1) 120 volt 35 Amp circuit traveling a distance of 175 ft

- What size wire will be used?__________________
- What is the total resistance accounted for ? remember the neutral!_________________
- What is the resistance per foot ____________
- What is the total voltage drop _____________
- What is the percent the voltage dropped _____________
- Will the wire size work?_________
- Explain

____

____

2) 240 volt 25 Amp circuit traveling a distance of 205 ft

- What size wire will be used?__________________
- What is the total resistance accounted for ? remember it takes (2) hots to make 240 volts !_________________
- What is the resistance per foot ____________
- What is the total voltage drop _____________
- What is the percent the voltage dropped _____________
- Will the wire size work?___________
- Explain

____

____

Table 9 Alternating-Current Resistance and Reactance for 600-Volt Cables, 3-Phase, 60 Hz, 75°C (167°F) — Three Single Conductors in Conduit

Ohms to Neutral per Kilometer
Ohms to Neutral per 1000 Feet

Size (AWG or kcmil)	X_L (Reactance) for All Wires		Alternating-Current Resistance for Uncoated Copper Wires			Alternating-Current Resistance for Aluminum Wires			Effective Z at 0.85 *PF* for Uncoated Copper Wires			Effective Z at 0.85 *PF* for Aluminum Wires			Size (AWG or kcmil)
	PVC, Aluminum Conduits	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	
14	0.190 0.058	0.240 0.073	10.2 3.1	10.2 3.1	10.2 3.1	— —	— —	— —	8.9 2.7	8.9 2.7	8.9 2.7	— —	— —	— —	14
12	0.177 0.054	0.223 0.068	6.6 2.0	6.6 2.0	6.6 2.0	10.5 3.2	10.5 3.2	10.5 3.2	5.6 1.7	5.6 1.7	5.6 1.7	9.2 2.8	9.2 2.8	9.2 2.8	12
10	0.164 0.050	0.207 0.063	3.9 1.2	3.9 1.2	3.9 1.2	6.6 2.0	6.6 2.0	6.6 2.0	3.6 1.1	3.6 1.1	3.6 1.1	5.9 1.8	5.9 1.8	5.9 1.8	10
8	0.171 0.052	0.213 0.065	2.56 0.78	2.56 0.78	2.56 0.78	4.3 1.3	4.3 1.3	4.3 1.3	2.26 0.69	2.26 0.69	2.30 0.70	3.6 1.1	3.6 1.1	3.6 1.1	8
6	0.167 0.051	0.210 0.064	1.61 0.49	1.61 0.49	1.61 0.49	2.66 0.81	2.66 0.81	2.66 0.81	1.44 0.44	1.48 0.45	1.48 0.45	2.33 0.71	2.36 0.72	2.36 0.72	6
4	0.157 0.048	0.197 0.060	1.02 0.31	1.02 0.31	1.02 0.31	1.67 0.51	1.67 0.51	1.67 0.51	0.95 0.29	0.95 0.29	0.98 0.30	1.51 0.46	1.51 0.46	1.51 0.46	4
3	0.154 0.047	0.194 0.059	0.82 0.25	0.82 0.25	0.82 0.25	1.31 0.40	1.35 0.41	1.31 0.40	0.75 0.23	0.79 0.24	0.79 0.24	1.21 0.37	1.21 0.37	1.21 0.37	3
2	0.148 0.045	0.187 0.057	0.62 0.19	0.66 0.20	0.66 0.20	1.05 0.32	1.05 0.32	1.05 0.32	0.62 0.19	0.62 0.19	0.66 0.20	0.98 0.30	0.98 0.30	0.98 0.30	2
1	0.151 0.046	0.187 0.057	0.49 0.15	0.52 0.16	0.52 0.16	0.82 0.25	0.85 0.26	0.82 0.25	0.52 0.16	0.52 0.16	0.52 0.16	0.79 0.24	0.79 0.24	0.82 0.25	1
1/0	0.144 0.044	0.180 0.055	0.39 0.12	0.43 0.13	0.39 0.12	0.66 0.20	0.69 0.21	0.66 0.20	0.43 0.13	0.43 0.13	0.43 0.13	0.62 0.19	0.66 0.20	0.66 0.20	1/0
2/0	0.141 0.043	0.177 0.054	0.33 0.10	0.33 0.10	0.33 0.10	0.52 0.16	0.52 0.16	0.52 0.16	0.36 0.11	0.36 0.11	0.36 0.11	0.52 0.16	0.52 0.16	0.52 0.16	2/0
3/0	0.138 0.042	0.171 0.052	0.253 0.077	0.269 0.082	0.259 0.079	0.43 0.13	0.43 0.13	0.43 0.13	0.289 0.088	0.302 0.092	0.308 0.094	0.43 0.13	0.43 0.13	0.46 0.14	3/0
4/0	0.135 0.041	0.167 0.051	0.203 0.062	0.220 0.067	0.207 0.063	0.33 0.10	0.36 0.11	0.33 0.10	0.243 0.074	0.256 0.078	0.262 0.080	0.36 0.11	0.36 0.11	0.36 0.11	4/0
250	0.135 0.041	0.171 0.052	0.171 0.052	0.187 0.057	0.177 0.054	0.279 0.085	0.295 0.090	0.282 0.086	0.217 0.066	0.230 0.070	0.240 0.073	0.308 0.094	0.322 0.098	0.33 0.10	250
300	0.135 0.041	0.167 0.051	0.144 0.044	0.161 0.049	0.148 0.045	0.233 0.071	0.249 0.076	0.236 0.072	0.194 0.059	0.207 0.063	0.213 0.065	0.269 0.082	0.282 0.086	0.289 0.088	300
350	0.131 0.040	0.164 0.050	0.125 0.038	0.141 0.043	0.128 0.039	0.200 0.061	0.217 0.066	0.207 0.063	0.174 0.053	0.190 0.058	0.197 0.060	0.240 0.073	0.253 0.077	0.262 0.080	350
400	0.131 0.040	0.161 0.049	0.108 0.033	0.125 0.038	0.115 0.035	0.177 0.054	0.194 0.059	0.180 0.055	0.161 0.049	0.174 0.053	0.184 0.056	0.217 0.066	0.233 0.071	0.240 0.073	400
500	0.128 0.039	0.157 0.048	0.089 0.027	0.105 0.032	0.095 0.029	0.141 0.043	0.157 0.048	0.148 0.045	0.141 0.043	0.157 0.048	0.164 0.050	0.187 0.057	0.200 0.061	0.210 0.064	500
600	0.128 0.039	0.157 0.048	0.075 0.023	0.092 0.028	0.082 0.025	0.118 0.036	0.135 0.041	0.125 0.038	0.131 0.040	0.144 0.044	0.154 0.047	0.167 0.051	0.180 0.055	0.190 0.058	600
750	0.125 0.038	0.157 0.048	0.062 0.019	0.079 0.024	0.069 0.021	0.095 0.029	0.112 0.034	0.102 0.031	0.118 0.036	0.131 0.040	0.141 0.043	0.148 0.045	0.161 0.049	0.171 0.052	750
1000	0.121 0.037	0.151 0.046	0.049 0.015	0.062 0.019	0.059 0.018	0.075 0.023	0.089 0.027	0.082 0.025	0.105 0.032	0.118 0.036	0.131 0.040	0.128 0.039	0.138 0.042	0.151 0.046	1000

Notes:

1. These values are based on the following constants: UL-Type RHH wires with Class B stranding, in cradled configuration. Wire conductivities are 100 percent IACS copper and 61 percent IACS aluminum, and aluminum conduit is 45 percent IACS. Capacitive reactance is ignored, since it is negligible at these voltages. These resistance values are valid only at 75°C (167°F) and for the parameters as given, but are representative for 600-volt wire types operating at 60 Hz.

2. *Effective Z* is defined as $R\cos(\theta) + X\sin(\theta)$, where θ is the power factor angle of the circuit. Multiplying current by effective impedance gives a good approximation for line-to-neutral voltage drop. Effective impedance values shown in this table are valid only at 0.85 power factor. For another circuit power factor (*PF*), effective impedance (*Ze*) can be calculated from *R* and X_L values given in this table as follows: $Ze = R \times PF + X_L \sin[\arccos(PF)]$.