

19.3 Design of Feeders for Industrial Power Systems

Most feeders are comprised of cables enclosed in *raceways*. Raceways are defined as enclosed channels designed expressly for holding wires, cables, or busbars. The most common type of raceway is the *conduit*, which is a pipe that can be either rigid or flexible, and can be made from conducting or non-conducting material.

The size of feeder conductor is selected on the basis of three criteria:

- Continuous current rating of the load.
- Short-circuit current rating of the highest fault.
- Voltage regulation.

The conductor size selected is the smallest that will satisfy all three criteria.

19.3.1 Continuous Current Rating

The current rating of a feeder is called the *ampacity* and the *National Electric Code* (NEC) requires that a 25% margin (to accommodate overloads) be applied when sizing conductors. The 25% margin is applied as follows:

- When a feeder supplies a combination of continuous and non-continuous non-motor load, its ampacity shall not be less than 125% of the continuous load plus 100% of the non-continuous load.
- When a feeder supplies several motors, its ampacity shall not be less than 125% of the largest motor load plus 100% of the remaining motor load.
- When a feeder supplies a mixture of motor and non-motor load the two foregoing criteria should be applied to each component and their results summed.

The current that a conductor can safely carry is determined by its allowed steady-state operating temperature, which in turn is determined by the type of insulation used. The conductor material (copper or aluminum) also determines the required area of the conductor.

There are several standard tables that enable rapid selection of conductors to be performed depending on such things as number of conductors in the raceway, whether the conductor is in free air or is buried, and one has been reproduced from the NEC in table 19.2 for example purposes.

Table 310-16. Ampacities of Insulated Conductors Rated 0-2000 Volts, 60° to 90°C (140° to 194°F) Not More Than Three Conductors in Raceway or Cable or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

Size	Temperature Rating of Conductor. See Table 310-13.								Size
	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	
AWG kcmil	TYPES †TW, †UF	TYPES †FEPW, †RH, †RHW, †THHW, †THW, †THWN, †XHHW †USE, †ZW	TYPE V	TYPES TA, TBS, SA SIS, †FEP, †FEPB, †RHH, †THHN, †THHW, †XHHW	TYPES †TW, †UF	TYPES †RH, †RHW, †THHW, †THW, †THWN, †XHHW †USE	TYPE V	TYPES TA, TBS, SA, SIS, †RHH, †THHW, †THHN, †XHHW	AWG kcmil
COPPER				ALUMINUM OR COPPER-CLAD ALUMINUM					
18	.....	.....	.....	14	.....	.....	.....	.....	.....
16	.....	.....	18	18	.....	.....	.....	.....	.....
14	20†	20†	25	25†	.....	.....	.....	.....	.....
12	25†	25†	30	30†	20†	20†	25	25†	12
10	30	35†	40	40†	25	30†	30	35†	10
8	40	50	55	55	30	40	40	45	8
6	55	65	70	75	40	50	55	60	6
4	70	85	95	95	55	65	75	75	4
3	85	100	110	110	65	75	85	85	3
2	95	115	125	130	75	90	100	100	2
1	110	130	145	150	85	100	110	115	1
1/0	125	150	165	170	100	120	130	135	1/0
2/0	145	175	190	195	115	135	145	150	2/0
3/0	165	200	215	225	130	155	170	175	3/0
4/0	195	230	250	260	150	180	195	205	4/0
250	215	255	275	290	170	205	220	230	250
300	240	285	310	320	190	230	250	255	300
350	260	310	340	350	210	250	270	280	350
400	280	335	365	380	225	270	295	305	400
500	320	380	415	430	260	310	335	350	500
600	355	420	460	475	285	340	370	385	600
700	385	460	500	520	310	375	405	420	700
750	400	475	515	535	320	385	420	435	750
800	410	490	535	555	330	395	430	450	800
900	435	520	565	585	355	425	465	480	900
1000	455	545	590	615	375	445	485	500	1000
1250	495	590	640	665	405	485	525	545	1250
1500	520	625	680	705	435	520	565	585	1500
1750	545	650	705	735	455	545	595	615	1750
2000	560	665	725	750	470	560	610	630	2000

AMPACITY CORRECTION FACTORS									
Ambient Temp. °C	For ambient temperatures other than 30°C (86°F), multiply the ampacities shown above by the appropriate factor shown below.								Ambient Temp. °F
21-25	1.08	1.05	1.04	1.04	1.08	1.05	1.04	1.04	70-77
26-30	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	79-86
31-35	.91	.94	.95	.96	.91	.94	.95	.96	88-95
36-40	.82	.88	.90	.91	.82	.88	.90	.91	97-104
41-45	.71	.82	.85	.87	.71	.82	.85	.87	106-113
46-50	.58	.75	.80	.82	.58	.75	.80	.82	115-122
51-55	.41	.67	.74	.76	.41	.67	.74	.76	124-131
56-60	.....	.58	.67	.71	.....	.58	.67	.71	133-140
61-70	.....	.33	.52	.58	.....	.33	.52	.58	142-158
71-80	.....	.....	.30	.41	.....	.....	.30	.41	160-176

† Unless otherwise specifically permitted elsewhere in this Code, the overcurrent protection for conductor types marked with an obelisk (†) shall not exceed 15 amperes for 14 AWG, 20 amperes for 12 AWG, and 30 amperes for 10 AWG copper; or 15 amperes for 12 AWG and 25 amperes for 10 AWG aluminum and copper-clad aluminum after any correction factors for ambient temperature and number of conductors have been applied.

Table 19.2 Ampacities of Not More Than Three Single Insulated Conductors

Notice that this table refers to *not more than three single insulated conductors*. This is normally taken to mean three current-carrying conductors, so a question arises concerning the neutral in a three-phase four-wire system. We have seen in previous courses that the neutral does not carry any 60 Hz current under balanced conditions and so should not normally be counted. There is one exception to this and that is where more than 50% of the load current is made up electric discharge lighting, electronic data processing systems, or similar types of equipment that produce high third-harmonic currents. Since these harmonic currents add instead of canceling, they will flow into the neutral and the neutral must be counted as a current carrying conductor.

When more than three conductors carry current their ampacities must be derated by applying the percentage factors in table 19.3, which is also based on NEC table 310-16.

Number of Conductors	Percent of Ampacity from Table 19.2
4 – 6	80
7 – 9	70
10 – 24	70
25 – 42	60
43 and above	50

Table 19.3 Derating Factors for More Than Three Conductors

It is worth noting that in the United States conductor areas are stated in units of *circular mils*. A circular mil (cmil) is the area of a circle that has a diameter of one mil (0.001"). For small conductors (up to 300 kcmil) the size is given by the American Wire Gauge (AWG) number (formally known as Brown & Sharpe or B&S). Gauge sizes decrease as the wire diameter increases, with the diameter doubling over every six gauge numbers. Eventually zero is reached, number 0 is usually written as 1/0 and pronounced "one-aught", and it has a diameter of 325 mils. The next size is 00, written as 2/0 and pronounced "two-aught", followed by 3/0 and 4/0. For diameters above 4/0 the size is expressed in MCM (thousands of cmil) i.e. 250,000 cmil is referred to as 250 MCM. Table 19.4 relates selected gauge numbers to MCM.

Gauge #	MCM
8	16.5
6	26.25
4	41.74
3	52.63
2	66.37
1	83.69
1/0	105.5
2/0	133.1
3/0	167.8
4/0	211.6
250 MCM	250

Table 19.4 Area in MCM of Selected Gauge Numbers

EXAMPLE 19.1

Determine the ampacity of a three-phase, four-wire feeder using 350 MCM copper conductors, 75⁰ C insulation, in a raceway in free air, 40⁰ C ambient temperature, and feeding a fluorescent lighting load.

Solution

Strategy: Table 19.2 will give the basic ampacity for not more than three conductors, based on the air temperature being 30⁰ C. Since there is more than 50% fluorescent lighting (which generates harmonics) the neutral must be counted as a fourth conductor and a correction factor applied. Also, an additional correction factor has to be applied to account for the ambient temperature being 40⁰ C.

Assumptions: The circuit operates below 2000 V so that table 19.2 applies.

Analysis:

EXAMPLE 19.2

Three motors are being supplied at 460 V via a three-phase, four-wire feeder. The motor sizes are 50 hp, 25 hp and 10 hp. Each motor is 90% efficient and operates at 0.95 lag pf. Determine the gauge of aluminum conductors for 85⁰ C insulation, in a raceway in free air, 45⁰ C ambient temperature. None of the motors have variable-speed drives.

Solution

Strategy: Table 19.2 will give the gauge of conductors once the ampacity is known. Ampacity is 125% of the largest motor's current plus the remaining motor's currents, allowing for temperature de-rating. Individual motor current is given by Apparent Power divided by $\sqrt{3}$ times the line voltage; while the Apparent Power is Real Power divided by power factor (pf), and Real Power in is 746 times the horsepower (hp) out divided by the efficiency (η).

Assumptions: Motors without variable-speed drives do not generate harmonics, so the neutral is not counted as a current-carrying conductor.

Analysis:

Based on 1 hp = 746 W and the real power in is equal to power out divided by efficiency, we can say the following:

The magnitude of current drawn by any motor is: $I = \frac{746\text{hp}}{\sqrt{3}V\eta\text{pf}}$