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.

19.3.3 Voltage Regulation

In ECE370 we saw that voltage regulation (VR) is the percent change in voltage that occurs when a loaded circuit is unloaded. The NEC recommends that VR be limited to 3% on any branch or feeder and that the overall VR from the service entrance to any service outlet be limited to 5%. This is shown diagrammatically in figure 19.6.

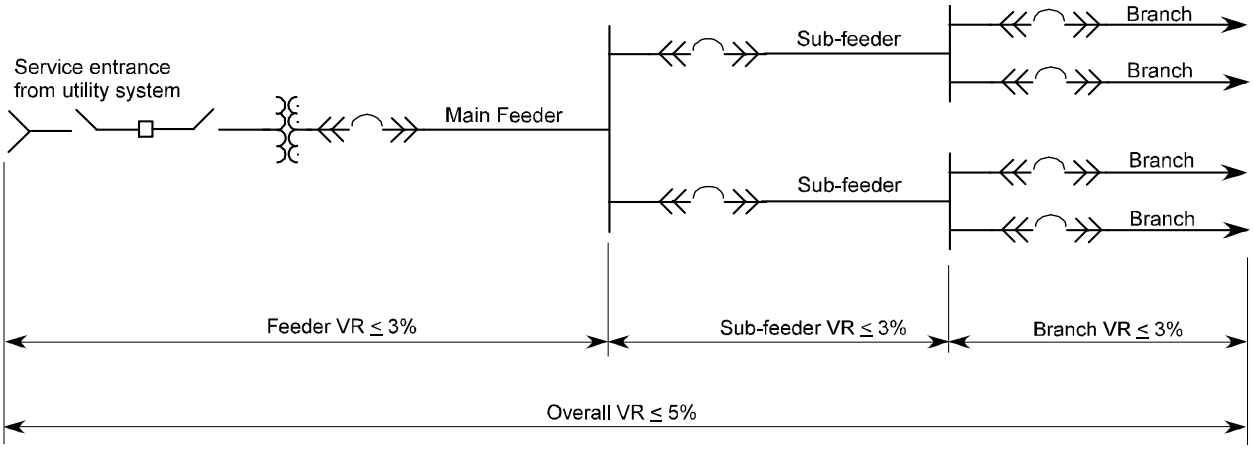

Figure 19.6 Voltage Regulation Relationships

To calculate VR requires that the impedance of the feeder be known so that it can be multiplied by the load current to produce the voltage drop. This procedure is awkward when designing feeders because the impedance is not known until the feeder cable is selected; so once again the use of tables becomes useful. The principal factors that affect VR are type of conduit, feeder length, conductor material, conductor gauge, and load power factor. The effect that these quantities have on voltage drop has been calculated and is presented in table 19.6, which is based on material from Canada Wire and Cable Limited.

Notice that the values listed in the table are voltage drops per 1000 ampere-feet of feeder cable.

Size AWG or MCM	COPPER						ALUMINUM					
	Magnetic Conduit or Armour			Non-Mag. Conduit or Armour			Magnetic Conduit or Armour			Non-Mag. Conduit or Armour		
	80% P.F.	90%P.F.	100% P.F.	80% P.F.	90% P.F.	100% P.F.	80% P.F.	90% P.F.	100% P.F.	80% P.F.	90% P.F.	100% P.F
14	2.540	2.790	3.067	2.535	2.780	3.060						
12	1.570	1.749	1.917	1.565	1.749	1.923	2.460	2.748	3.020	2.448	2.743	3.020
10	.993	1.103	1.200	.987	1.103	1.201	1.553	1.732	1.900	1.547	1.726	1.900
8	.635	.699	.750	.629	.693	.751	.993	1.103	1.195	.981	1.091	1.195
6	.421	.462	.485	.461	.456	.485	.647	.710	.762	.641	.710	.768
4	.277	.300	.306	.271	.294	.306	.421	.456	.491	.410	.450	.479
2	.185	.196	.196	.179	.191	.191	.271	.294	.300	.266	.289	.306
1	.150	.162	.150	.150	.156	.150	.225	.237	.242	.219	.231	.242
1/0	.127	.133	.121	.121	.127	.121	.185	.196	.191	.179	.191	.191
2/0	.109	.110	.098	.098	.104	.092	.150	.156	.150	.144	.150	.150
3/0	.092	.092	.081	.081	.087	.075	.127	.133	.121	.121	.127	.121
4/0	.081	.075	.064	.069	.069	.057	.104	.104	.098	.098	.104	.098
250	.070	.070	.054	.064	.064	.051	.092	.092	.081	.086	.087	.081
300	.064	.064	.045	.056	.055	.042	.081	.081	.069	.075	.075	.069
350	.058	.055	.039	.051	.049	.036	.075	.075	.058	.069	.069	.057
400	.055	.051	.035	.047	.044	.032	.069	.069	.053	.064	.064	.050
500	.049	.045	.029	.042	.039	.026	.058	.057	.043	.053	.051	.040
600	.046	.041	.024	.038	.034	.022	.055	.051	.036	.048	.046	.034
700	.043	.038	.021	.036	.032	.019	.051	.047	.032	.044	.041	.029
750	.042	.037	.020	.034	.031	.017	.049	.046	.030	.042	.039	.028
1000	.038	.032	.016	.029	.025	.013	.044	.040	.024	.039	.036	.024

* Values are per 1000 ampere-feet for three single conductors in conduit.

1. Values are based on three-phase, line-to-neutral voltages. For line-to-line voltage drops, multiply by a factor of 1.73. For single-phase circuits, multiply by a factor of 2.0.

2. Values are for conductor operating temperatures up to 75°C. For conductors operating at 90°C, multiply by a factor of 1.1.

Table 19.6 Voltage Drops for 60 Hz Systems

Taken from Electric Systems in Buildings by S. David Hughes

EXAMPLE 19.5

A 480 V load that has a pf of 0.9 lag is fed via a three-phase feeder that is 500' long, carries 250 A and is 250 MCM copper; and a branch that is 250' long, carries 120 A and is #2 copper. Both feeder and branch are enclosed in steel conduit. Determine the individual and overall VR.

Solution

Strategy: Table 19.6 will provide the feeder and branch voltage drops once the ampere-feet are known. Dividing this by the rated voltage gives the regulation

The overall VR is 3.16 + 2.12 = 5.28%. This is above the 5% standard and could be corrected by either improving the load pf (which would reduce both feeder and branch VR) or by increasing the gauge of the feeder to bring its VR below 3%.

EXAMPLE 19.6

A 480 V three-phase feeder is required to supply two loads. Load 1 is 30 kW fluorescent lighting with 0.9 lag pf, which is continuous. Load 2 is a 20 kW heater, also at 0.9 lag pf and is non-continuous. Specify the size of the feeder conductor given the following information. Length of feeder is 250' and it runs in free air at an ambient temperature of 35^0 C. Conductors should be copper, with type XHHW, 75^0 C insulation in steel conduit. The available symmetrical short-circuit current is 39 kA and the circuit is protected by a circuit breaker.

Solution

Strategy: Conductor gauge is determined by three factors: ampacity, heating during faults, and voltage regulation. For ampacity we need to calculate 125% of continuous load plus 100% non-continuous loads. Short-circuit performance is assessed in the same way as example 19.4, except that the constant of proportionality corresponding to copper conductors with XHHW insulation is 71.95×10^{-3}, as given in section 19.3.2. Voltage regulation is determined from table 19.6, in a manner similar to example 19.5. When gauge sizes based on each of the three criteria have been determined, the largest gauge is chosen so that all criteria are met.

Next, we must check the minimum size required for a symmetrical short-circuit current of 39 kA. For a low-voltage circuit breaker this corresponds to I_{ASY} = 39 x 1.3 = 50.7 kA. For copper conductor with XHHW insulation K = 71.95 x 10^{-3}. The low-voltage circuit breaker operates in 2 cycles (0.0333 s). This gives the area of the conductor as: