Power Arrangements

NFPA 70®, *National Electrical Code*® (*NEC*®), and NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*, both allow for different methods of providing power to a fire pump. Each method has its own unique challenges to ensure that the fire pump is able to perform in the intended manner. Regardless of the method used to supply the pump, the end result must be a fire pump that is able to operate under less than ideal conditions. Often these pumps are operating while the building is on fire and conditions quickly deteriorate. The electrical system must be designed and installed in a way that will continue to supply the fire pump so that the sprinkler system can mitigate the damage to the building and provide occupants the necessary time to evacuate. The combination of the *NEC* and NFPA 20 provides the performance and installation requirements for the electrical system to deliver power in a way that ensures the reliability of the fire pump.

Several considerations need to be made when a building project requires the installation of an electric fire pump, one of which is the power arrangement. This review will identify and explain the power arrangements and requirements of NFPA 20 and the *NEC*. It will provide guidance on determining the answers to common questions such as the following: what is the power source; where is the power source coming from; is the power source reliable; can a generator be used as a primary source of power; what are the power arrangement options; will auxiliary power be needed; and what are the auxiliary power options? It will also explain overcurrent protection and transformers as they relate to the power supply for a fire pump.

PERMISSIBLE POWER ARRANGEMENTS

Where does the user begin in order to determine acceptable power arrangements for electric-driven fire pump installations? Power arrangements for fire pump installations are covered in Chapter 9 of NFPA 20 and Article 695 of the *NEC*. NFPA 20 provides three power arrangements: Arrangement A, Arrangement B, and Arrangement C (see Figure A.9.2 of NFPA 20). The following paragraphs will discuss some of the unique nuances of these arrangements and how NFPA 20 and the *NEC* tie together.

Arrangement A

Arrangement A is the first power supply arrangement referenced in Figure A.9.2 of NFPA 20 and shows a fire pump controller connected directly to the utility service. This means there are no disconnects, OCPDs, or transformers between the utility and the fire pump controller. For example, if a fire pump motor is rated for 480V three-phase power, the fire pump would be connected to a service with the same voltage characteristics, meaning that the utility would have to have 480V three-phase power available at the point where the service conductor supplying the fire pump controller connects to the utility. In general, most electric-driven fire pumps require three-phase power. This can cause complications where a utility provider only has single-phase power available and often raises the question, "Can a phase converter be used on a fire pump installation?" It is important to note that if a utility only provides single-phase service it is not permissible to use a phase converter to run a three-phase fire pump motor, in accordance with 9.1.7 of NFPA 20. Subsection 9.1.7 simply states that phase converters shall not be used to supply power to a fire pump. This means that where a single-phase power source is available, a single phase fire pump motor must be installed.

The utility service connection in Arrangement A may be to a transformer owned by the utility (as opposed to a transformer owned by the building owner, as shown in Arrangement B), or to the building service entrance conductors ahead of the building service disconnect. Since there is no OCPD between the utility service connection and the fire pump controller in this arrangement, the controller becomes the fire pump service disconnect and is equipped with the OCPD. This disconnect must be suitable for use as service equipment. It is important to note that this arrangement could present a risk to service personnel. To de-energize the fire pump controller, disconnection of the service by the utility is necessary. Depending on the configuration, the disconnection of power by the utility may or may not disconnect power for the building service as well. Due to the possibility of disconnecting power to the entire building, service work on fire pump controllers is often performed while the controller is energized. Paragraph 14.2.6.1.5 of NFPA 20 requires that personal protective equipment (PPE) be worn in accordance with *NFPA 70E, Standard for Electrical Safety in the Work Place*, or equivalent. Although NFPA 20 applies to new installations, the requirements of *NFPA 70E* or equivalent should be followed whenever necessary energized electrical work is performed.

Arrangement B

Arrangement B is the second power supply arrangement referenced in Figure A.9.2 of NFPA 20 and shows a fire pump controller connected to the utility service via an OCPD and an on-site transformer. Where voltage from the supply is different than the voltage required by the fire pump, the addition of a transformer (owned by the building owner) to step down or up the voltage supplied by the utility is required.

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The transformer requirements for this application differ from other transformer requirements in the *NEC* in that the transformer must be sized at 125 percent of the sum of the fire pump motor and pressure maintenance pump motor loads along with 100 percent of any associated fire pump maintenance accessory equipment loads. So, what does this all mean? First, it is important to understand that load is measured in amps or watts. The motor of the fire pump and pressure maintenance pump will be equipped with a nameplate providing the full–load current in amperes (FLA) value; however, this is not the load value to use. The loads found in Table 430.250 of the *NEC* should be used and will, under most circumstances, be higher than the value on the motor nameplate because they account for motor degradation.

It is important to take note of the disconnecting means and its location in Arrangement B. A typical transformer installation would be equipped with a disconnect means on both the line (primary) side and the load (secondary) side. However, in a fire pump installation, NFPA 20 and the *NEC* limit the installation to one disconnecting means located on the line side of the transformer. The limit of one disconnecting means is found in both 9.2.3 of NFPA 20, and 695.4 of the *NEC*.

Unlike Arrangement A, where the disconnecting means that is part of the controller acts as the fire pump service disconnect, the additional disconnecting means that is part of Arrangement B becomes the fire pump service disconnect and provides a method of isolating power so that maintenance can be performed on the transformer and any downstream equipment, such as the fire pump controller. This disconnect must be suitable for use as service equipment. Note that the requirement that only allows for one disconnecting means does not prohibit the fire pump controller from having a disconnecting means.

Arrangement C

When reviewing Arrangement C, note that it is very similar to Arrangement A with the exception of an added service disconnect in accordance with 9.2.3 of NFPA 20 and 695.4(B)(1) of the *NEC*. This disconnecting means provides a method of isolating power so that maintenance can be performed on any downstream equipment, such as the fire pump controller.

Relationship of NFPA 20 and the *NEC*

Subsection 9.2.2 of NFPA 20 and 695.3(A), 695.3(C), and 695.5 of the *NEC* provide routing options for the power supply to a fire pump(s). These options all relate to Figure A.9.2, Typical Power Supply Arrangements from Source to Motor, of NFPA 20. The following list outlines these relationship:

1. 9.2.2(1) of NFPA 20 and 695.3(A)(1) of the *NEC* relate to Arrangement A of Figure A.9.2.
2. 9.2.2(2) of NFPA 20 and 695.3(A)(2) of the *NEC* relate to Arrangement A, B, or C of Figure A.9.2.
3. 9.2.2(3) of NFPA 20 and 695.3(A)(3) of the *NEC* relate to Arrangement C of Figure A.9.2.
4. 9.2.2(4) of NFPA 20 and 695.3(C) of the *NEC* relate to Arrangement B or C of Figure A.9.2.
5. 9.2.2(5) of NFPA 20 and 695.3(A)(3) of the *NEC* relate to Arrangement B of Figure A.9.2.

When applying the *NEC*, it is important to understand that Article 695 cannot be used exclusively for the installation of a fire pump. Chapters 1 through 4 cover the general installation requirements of the *NEC* that, at least in part, will apply to all electrical installations included in the scope of the *Code*; and 90.3 tells us that the general rules of Chapters 1 through 4 can be supplemented or modified by rules found in Chapters 5, 6, and 7. These chapters may provide for more stringent, less stringent, or more specific requirements for the special occupancies covered by Chapter 5, the special equipment covered by Chapter 6, or the special conditions covered in Chapter 7. Chapters 5, 6, and 7 can also modify the requirements within each other.

POWER SOURCES AND RELIABILITY

NFPA 20 refers to power sources as either normal or auxiliary. The question is often asked whether an auxiliary power source is required for fire pump installations. It is not the intent of NFPA 20 to require auxiliary power for every fire pump installation; however, an evaluation of the power source's reliability is required to rule out the need for auxiliary power. Power sources consist of either a utility or private power generation facility. Chapter 9 of NFPA 20 and Article 695 of the *NEC* provide connection methods for these types of power sources.

Another common question is whether an on-site standby generator can be used as the normal source of power for a fire pump. An on-site standby generator does not meet the definition of an on-site power production facility and, therefore, cannot be used as a normal power source for a fire pump.

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Normal Power

When determining whether a normal power source is reliable, A.9.3.2 of NFPA 20 provides the common characteristics of a reliable power source, such as the following: the source power plant has not experienced any continuous shutdowns lasting 10 hours or more; and power outages have not routinely been experienced in the area of the protected facility as a result of failure of generation or transmission. Additionally, the normal source of power should not be supplied by overhead conductors outside of the protected facility that might need to be disconnected due to fireground operations using aerial apparatus, or that might be inadvertently disconnected by the utility to remove power from the building. If it is determined that the power source is not reliable, either an auxiliary power source would need to be provided in accordance with NFPA 20 and the *NEC* or a backup engine-driven or steam turbine–driven fire pump may be used.

Auxiliary Power

Where an auxiliary power source is required, two options exist: either an on-site standby generator may be used or an approved independent power source of the type allowed for normal power may be provided. Note that an auxiliary power source is required when installing a fire pump in a high-rise building, unless an engine-driven or a steam-driven fire pump can be provided as a backup to the electric fire pump.

OVERCURRENT PROTECTION/DISCONNECT

OCPDs serve two purposes: first, in the event of an overload (e.g., the equipment downstream of the OCPD is drawing more current than it should), the OCPD will trip in an effort to preserve the equipment; second, in the event of a ground fault or short circuit (e.g., the current is taking a path other than that intended), the OCPD will trip in an effort to preserve the conductors.

The overload protection feature of the OCPD in a fire pump installation is irrelevant, as the OCPD must be rated so high that it permits the fire pump motor to continue to run under overload conditions until it destroys itself. However, under a ground-fault or short-circuit condition the current is much higher than in an overload condition and could result in the operation of the OCPD and, therefore, a loss of power to the fire pump. Aside from this condition, the Technical Committee on Fire Pumps expects that the pump motor will continue to receive power and try to start, which is why they limit the number of OCPDs allowed in the power supply to the fire pump controller.

Two Methods of Sizing Overcurrent Protection

One option for supplying the normal power to the fire pump motor allows for the use of a transformer that is dedicated to the fire pump installation. This is necessary when the incoming utility voltage is at a level other than what the pump motors are designed to handle. However, this arrangement presents unique challenges when considering how to install this equipment in a way that meets both the intent of the *NEC* and the performance requirements of NFPA 20. For instance, the premise that the fire pump must continue to run even in the presence of an overload condition is still valid. However, because there is now an added piece of equipment in the circuit, there must be means to service and maintain this added equipment. To safely maintain and service the transformer, a disconnecting means on the line side must be installed. There must also be overcurrent protection to protect the transformer from short circuits.

This overcurrent protection is sized in a slightly different manner than other fire pump OCPDs. In installations that do not have a transformer, the overcurrent protection is sized to carry indefinitely the sum of the locked rotor currents (LRC) of the largest fire pump motor and any pressure maintenance pump motors and the full-load currents (FLC) of all other pump motors and any associated accessory equipment. This provides enough capacity for all the fire pump motors and associated equipment to come online at the same time without tripping the OCPD with what would appear to be an overload condition. However, when the same equipment is supplied through a transformer, the current on the primary side is usually much lower than the current levels on the secondary side. Because the primary side has lower current levels, the OCPD will have a lower rating, and the in-rush or start-up current will be closer to the set trip value of the device. Therefore, the OCPD must be able to carry the LRC of all fire and jockey pump motors for an indefinite period of time, as opposed to just the LRC of the largest fire pump motor and jockey pump motors for installations without a transformer.

Consider an installation where the utility supply voltage is different from the fire pump utilization voltage. In this installation, the utility supplies a voltage of 4160 V; however, the fire pump is rated to operate on 460 V. This example uses a 4160/480 V three-phase transformer to supply power to a 100 hp, 460 V, code letter G fire pump motor and a 1½ hp, 460 V, code letter H jockey pump motor. The code letter designation relates to the kVA per horsepower at locked rotor conditions and can be found in Table 430.7(B) of the *NEC*.

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First, determine the FLC for both motors in order to size the transformer in accordance with 695.5(A). In the *NEC,* there are two current values associated with motor loads the FLC and the nameplate value. As stated in 430.6, the FLC values can be found in Tables 430.247 through 430.250, depending on the circuit characteristics. For this example, the FLCs in Table 430.250 give are 124 amps for the fire pump and 3 amps for the jockey pump for a total of 127 amperes. As required by 695.5(A), the transformer must be sized at 125 percent of the total full-load current:

$$127 \text{ A} * 1.25 = 158.75 \text{ A}$$

Using the following formula to convert this to Volt-Amperes for a 480 V, three-phase system, it is determined that the minimum rating for the transformer is 131.98 kVA:

$$158.75 \text{ A} * 480 \text{ V} * \sqrt{3} = 131.98 \text{ kVA}$$

The next largest standard size for transformers is 150 kVA, but any rating above the minimum is permitted to be used.

Next, determine the minimum ampere rating for the primary OCPD. As required by 695.5(B), the minimum size OCPD must allow the secondary of the transformer to supply the LRC of all fire pump motors as well as the jockey pump. If there were any fire pump accessory equipment present, this could be supplied simply at the FLC value. If the LRC is not provided on the nameplate of the motors, it must be calculated based on the code letters provided on the nameplate and in Table 430.7(B). In this example, the LRC for the fire pump motor is calculated as follows:

From Table 430.7(B), code letter G requires 6.29 kVA/hp. Therefore:

$$\text{LRC} = 6.29 \text{ kVA/hp} * 100 \text{ hp} = 629 \text{ kVA}$$

$$\text{Convert kVA to Amps} = 629 \text{ kVA}/0.48 \text{ kV} * \sqrt{3} = 756.59 \text{ A}$$

Note: 480 V = 0.48 kV

The LRC for the jockey pump motor is calculated as follows:
From Table 430.7(B), code letter H requires 7.09 kVA/hp. Therefore:

$$\text{LRC} = 7.09 \text{ kVA/hp} * 1.5 \text{ hp} = 10.64 \text{ kVA}$$

$$\text{Convert kVA to Amps} = 10.64 \text{ kVA}/0.48 \text{ kV} * \sqrt{3} = 12.8 \text{ A}$$

Combining the calculated LRC values for the fire pump motor and jockey pump motor gives a total of 769.39 A. To determine how much current this translates to on the primary, multiply the total current by the secondary to primary voltage ratio, as follows:

$$769.38 \text{ A} * \frac{480 \text{ V}}{4160 \text{ V}} = 88.77 \text{ A}$$

This gives a total of about 89 A on the primary side of the transformer; therefore, the primary OCPD must be larger than 89 A. The next largest standard size OCPD is 90 A and would have enough capacity to allow the LRC of the fire pump motor and the jockey pump simultaneously.

Now consider a scenario where there is no transformer involved. NFPA 20, 9.2.3.4, requires that for this arrangement, the OCPD must be sized for the largest fire pump motor LRC and the FLCs of other pump motors and accessory equipment. Assume two 100 hp fire pump motors and two 1.5 hp jockey pump motors. The LRC and FLC values, calculated in the previous example, are as follows:

LRC of fire pump 1 = 756.59 A
FLC of fire pump 2 = 124 A
FLC of jockey pump 1 = 3 A
FLC of jockey pump 2 = 3 A

The total current follows:

$$\text{Total current} = 756.59+124+3+3 = 886.59 \text{ A}$$

The next highest standard size OCPD is 1000 A, in accordance with 240.6 of the *NEC*. This is a difference of roughly 736 A between the rating of the OCPD and the FLC of the motors, calculated as follows:

$$\text{Difference calculation} = 1000 \text{ A}-124 \text{ A}-124 \text{ A}-3 \text{ A}-3 \text{ A} = 736 \text{ A}$$

This allows adequate room for less than ideal operating conditions for the fire pumps without exceeding the rating of the OCPD. This relationship can be better understood when examining the OCPD time-current curve, which will be discussed later.

As can be seen in the previous examples, the rules for sizing the OCPD are different depending on whether or not the installation uses a transformer. For installations without a transformer, the OCPD must be rated for the sum of the largest LRC and the FLCs of the remaining motors. For installations with a transformer, the primary OCPD must be able to supply the LRCs of all the fire pump and jockey pump motors. This means that the primary OCPD rating is much closer to what the actual current might be upon startup when all pump motors come online simultaneously.

Assume two 100 hp fire pump motors and two 1.5 hp jockey pump motors in an installation where a transformer is necessary. If sized correctly, the following values would be used to calculate the total current:

LRC of fire pump 1 = 756.59 A
LRC of fire pump 2 = 756.59 A
LRC of jockey pump 1 = 12.8 A
LRC of jockey pump 2 = 12.8 A

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The total current would then be as follows:

Total current = 756.59+756.59+12.8+12.8 = 1538.78 A

The primary current is, therefore, as follows:

$$\text{Primary current} = 1538.78\ \text{A} * \frac{480\ \text{V}}{4160\ \text{V}} = 177.55\ \text{A}$$

The next largest standard size OCPD is 200 A. It is important to note that if the incorrect method of sizing the OCPD is used, the 177.55 A load might exceed the OCPD and possibly trip the circuit. If the OCPD in this example were sized as though a transformer were not present, the total current would be 886.59 A, as calculated in the previous example. This means that the primary current would then be as follows:

$$\text{Primary current} = 886.59\ \text{A} * \frac{480\ \text{V}}{4160\ \text{V}} = 102.3\ \text{A}$$

The next largest standard size OCPD is 110 amperes.

Comparing the preceding two OCPD calculations, it is clear that if the OCPD is sized correctly, it is required to be 200 A. However, if the OCPD were incorrectly sized using the nontransformer method, it would only be required to be 110 A. If an OCPD of 110 A were installed and the motors of all pumps were to start, the 177.55 A load would exceed the 110 A OCPD rating and possibly trip the circuit. Instead, when the proper sizing method is used, the result is a minimum standard size of 200 A and enough capacity to allow all pumps to start simultaneously with no issues.

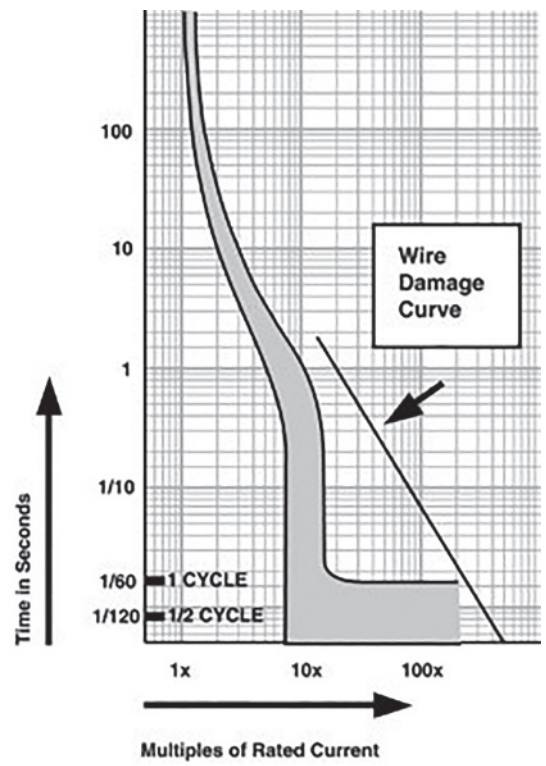
Time-Current Curve

The protection characteristics of overcurrent devices can be viewed in what is called a time-current curve, which is available from the manufacturer of the equipment. These graphs show the range of currents and the amount of time it will take to open the device. Typically, the greater the current value is over the trip setting, the faster the device will operate. Curve 1 is an example of a typical time-current curve.

The solid shaded portion of the time-current curve represents the current values and the time it will take for the OCPD to trip. The graph shows that as the current increases, the time to trip decreases. On motor and transformer startup, the circuit is essentially a short circuit until the windings have time to build up enough impedance to limit the current to the FLC levels. Startup currents can be very high and run the risk of getting into the "instantaneous trip" zone of the overcurrent device.

MULTIBUILDING CAMPUS-STYLE ARRANGEMENT

NFPA 20 does not provide requirements for power arrangement in a multibuilding campus-style system; however, the *NEC* provides



CURVE 1 *Time-Current Curve.*

requirements in 695.3(C). This option is applied when the sources in 695.3(A) are not practicable. It is important to note that under this arrangement only, additional disconnecting means and the associated OCPDs are permitted. See Exhibit S4.4 in Part 4, Supplement 4, of this handbook. Under the multibuilding campus-style system, where 695.3(A) cannot be used, two options are available:

1) Two or more feeders from separate utility services
2) A feeder from a utility service and an alternate source of power such as a generator

If multiple disconnects and OCPDs in series are used in this arrangement, as permitted by 695.4(B)(1)(b), selective coordination must be applied. Selective coordination is accomplished during the design process by selecting OCPDs based on their time/current characteristics. This ensures that in the event of an overcurrent condition, the device closest to the fault will open before the next device upstream. The main goal of selective coordination is to isolate the faulted portion of the electrical circuit quickly while at the same time maintaining power to the remainder of the electrical system.