Electrical Tech Note — 600

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Standby Power Systems[1]

Electricity is essential to agricultural facilities, family living and business operations. An emergency source of power is essential for any farm or business with mechanically ventilated production facilities, automated electrical systems or facilities requiring constant heat or refrigeration. For a homeowner, a generator can supply power for lighting, cooking, refrigeration and pumping water in the event of a power outage due to storm damage or other problems on the power supplier's system. To protect an investment, an emergency power supply is a form of insurance that protects against potential losses.

This document offers guidelines and outlines materials and methods for designing and installing a standby power system. Be sure to check with the power supplier, local requirements, national codes and equipment instructions before making an installation and enlist the help of a licensed electrical contractor to install the electrical wiring.

Generators

A generator is an electric device that produces alternating current (ac) and is sized according to a kilowatt (kW) rating. One kW equals 1,000 watts. Watts (W) is determined by multiplying volts (E), amperes (I) and power factor (pf). Power factor is a measure of the difference in phase between voltage and current, in an electric circuit. Power factor is a number equal to or less than one. Resistance loads, such as incandescent lamps and space heaters have a power factor of one. Inductive loads such as electric motors, and ballasts for electric discharge lights have a power factor that is less than one. Some useful equations used to determine watts and kilowatts are shown in Equations 1, 2, and 3. Some generators have two kW ratings. The smaller number is the *continuous rating*, which is the generator's power output during general operation. The larger number is the *peak capacity*. Electric motors require significantly more power when starting, as compared to running. Therefore, the generator must be able to withstand short-term surges.

$$W = E \times I \times pf \qquad \textbf{Equation 1}$$
(Single-phase)

$$W = E \times I \times pf \times 1.73 \qquad \textbf{Equation 2}$$
(Three-phase)

$$kW = W / 1000 \qquad \textbf{Equation 3}$$

The generator selected must provide the same type of power at the same voltage and frequency that is delivered by the power supplier system. At a dwelling, this is usually 120/240 volt single-phase, three-wire, 60 Hz. At a business or agricultural facility, the electrical system may require a three-phase power source.

Types of Generators

Standby generators can be powered by either a tractor power-take-off (PTO) or a self-contained engine. Engine-driven generators are sold where both the generator and engine are mounted on the same frame and come as a set, Figure 1. The term *genset* is often used for the engine-driven generator and are available for

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portable placement or fixed in place. Cost is often the greatest disadvantage of this type of generator, because the original purchase price includes both the price of the engine and the generator.

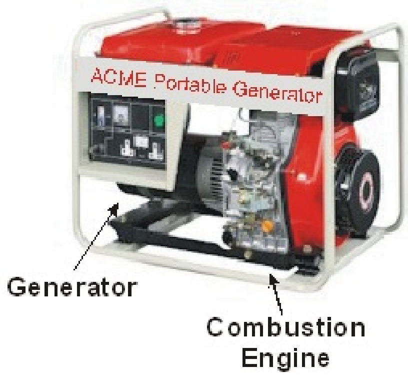

Figure 1. An engine-driven generator uses an engine to operate a generator.

A generator can also be operated from the PTO of a tractor. This has the advantage of lower cost at the time of the initial investment and it eliminates the care and maintenance of an additional engine. A PTO-driven generator is shown in Figure 2. The tractor must have the proper horsepower (hp) to power a generator. The engine or tractor should develop a minimum of 2 hp for each continuous kilowatt of electric power produced by the generator, see Equation 4. A generator with a continuous 30-kW rating would require at least a 60-hp engine.

hp = 2 hp x kW rating **Equation 4**

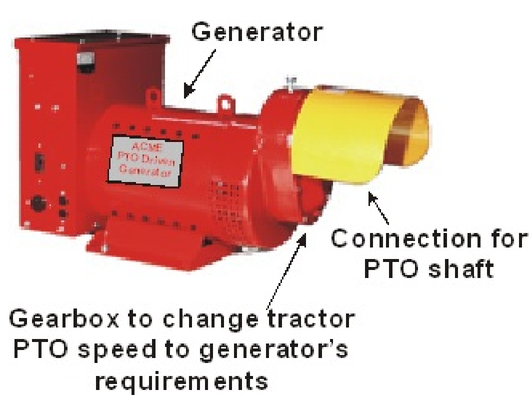

Figure 2. A PTO driven generator.

The revolutions per minute (RPM) of the PTO must be matched with the required shaft speed of the generator. The frequency of the power in the United States is 60 cycles per second (60 Hz). If the equipment is designed for 60 Hz, operating it significantly above or below this frequency could lead to premature failures. A generator which is manufactured with two-poles requires a rotational speed of 3,600 RPM's, while a four-pole generator will deliver 60 Hz at 1,800 RPM's. Because of the speed, a four-pole generator tends to have a longer rated life due to reduced wear of parts

Power Requirements for Electrical Loads

Sizing generators would be easier if electrical motors did not draw much more power when starting as when they reach running speed. Table 1 lists approximate starting and running wattages for common motors. Close examination of the table shows that the starting wattage is about four times more power to start than to run. Actual start-up power can be 3 to 8 times the operating power, depending on the motor type and load. For an agricultural facility when reliability of generator system is essential, the multiplier of four is found to be effective.

Table 1. Starting and running wattages for single-phase motors.

Approximate Wattage for 120 or 240 Volt, Induction Motors		
Motor Horsepower	**Starting Wattage**	**Running Wattage**
1/6	860	215
1/4	1,200	300
1/3	1,600	400
1/2	2,300	575
3/4	3,340	835
1	4,000	1,000
1-1/2	6,000	1,500
2	8,000	2,000
3	12,000	3,000
5	18,000	4,500
7-1/2	28,000	7,000
10	36,000	9,000

Many electrical loads are not rated in horsepower or it may be difficult to determine the horsepower of a particular motor load. Table 2 gives wattage and horsepower requirements for typical agricultural and household equipment. Table 2 is only an estimate, close examination of equipment nameplates can be useful for determining the actual power drawn.

For lights, it is necessary to determine the lamp wattage. Because of the losses in electromagnetic or the harmonic distortions caused by electronic ballasts, electric discharge lighting (fluorescent, metal halide, mercury vapor and high pressure sodium lights) must have their wattages increased by a factor of 1.2.

Generator Sizing

The generator may be sized to power the entire electrical system, but generally, only the most essential equipment and lights are considered. Even this essential equipment, in many cases, may not be operated at the same time. The ability to allow for future expansion is also a consideration. There is no single correct sizing solution. This document outlines three different generator sizing techniques, the *full-load system, sequence-load system* and *load-summation system*. The method chosen often depends upon the desired application.

A *full-load system* starts and operates either all of the loads on the system or all of the loads that are deemed to be essential. Furthermore, a full-load systems does not take load sequencing into account. For example, if a particular facility has two 5-hp motors where it is feasible that they could be starting at the same time, the starting wattage for both motors would be included. Examine Table 1, this would result in an anticipated load of 18,000 W + 18,000 W for a total of 32,000 W. The main advantage of full-load systems is that all equipment can be started at the same time.

Table 2. Approximate wattage and horsepower requirements of typical agricultural and dwelling equipment.

Approximate Wattage/Horsepower for Household Appliances		
Appliance	**Horsepower**	**Wattage**
Air Compressor	1	
Air Conditioner *(Central)*	2 - 5	
Air Conditioner *(Window)*	1/3 - 1	
Clothes Drier *(Electric)*		1,500 - 4,000
Clothes Drier *(Gas)*	1/6	
Clothes Washer	1/4 - 1/2	
Coffee Maker		1,200
Computer System		1,500
Dehumidifier	1/3	
Dishwasher	1/6	
DVD Player		100
Electric Blanket		300 - 500
Electric Fencer		7-10
Electric Skillet or Hot Plate		1,200
Fan (Ceiling)	1/6	
Freezer	1/4 - 1/2	
Furnace Blower	1/4 - 1/2	
Garage Door Opener	1/4	
Hair Dryer		1,500
Heat Pump	2 - 5	
Heater *(Space)*		500 - 1,500
Heater *(Baseboard)*		Sum of Unit Wattages
Lighting *(Electric Discharge)*		Sum of Lamp Wattages X 1.2
Lighting *(Incandescent)*		Sum of Lamp Wattages
Microwave		800 - 1,500
Radio		10 - 200
Refrigerator	1/4 - 1/2	
Smoke and CO2 Detectors		Minimal
Sump Pump	1/4 - 1/2	100 - 500
Television		200 - 600
Toaster		1,200
Toaster Oven		1,500
Range *(Per Burner)*		1,500 - 2,000
Range *(Oven)*		4,000 - 5,000
Range *(Gas)*		200
Vacuum Cleaner		500 - 700
VCR		
Water Heater		1,000 - 5,500
Well Pump	1/2 - 2	

The *sequence-load system* operates under the assumption that the majority of the essential equipment can be started in succession. Using this type of system will result in a smaller size generator than a full-load system, and will have a significant savings in purchase price of the generator. Using the previous example of two 5-hp motors and Table 1, the sequence-load calculations would use the starting wattage for one motor and the running wattage for the other. This would result in anticipated load of 18,000 W + 4,500 for a total of 22,500 W. The draw back of this type of sizing is that most equipment must be started in a particular order to prevent overloading and stalling the engine.

The *load-summation system* is a high-bred technique of sizing a generator. The full-load system will simultaneously start all loads that were included in the calculations. Likewise, the sequence-load system will operate all of the loads desired, provided a sequence is followed. But for many locations, electrical equipment may operate automatically. Unless the units are turned off, loads such as a sump pump, refrigerators, freezers, air conditioners and furnaces operate at random intervals. The load-summation method assumes that the loads will not be starting at the same time, and furthermore, there may be times that some loads will not be operating at all. The load-summation system approach will size a generator for most realistic times and is the method most often used for residential and agricultural facilities.

Sizing a Full-Load Generator System

The rated output of the generator must be at least that of the anticipated power of the essential loads. Table 3 illustrates how to size a generator using this approach. To size the generator accurately, use the following procedure:

1. List the essential lights and equipment which must operate during an outage. It is possible that every electrical device is to be powered by the generator.

2. For each electric motor load list starting wattage. These wattages are found in Table 1. If it is impossible to determine the horsepower, use Table 2 to make an estimation.

3. For non-motor loads examine their nameplates, in some cases they give the power requirements. If the wattage of the equipment can not be determined, refer to Table 2 to estimate the wattage.

4. Examine the listed loads for two or more loads or groupings where it is extremely unlikely that they will be operating at the same time. An example of this would be a furnace and a window air conditioner. Another example is where a farmer does not run any feeding equipment during the operation of the milking equipment. When one or more loads or load groupings are found, it is only necessary to factor in the larger of the two wattage requirements.

5. Total the wattages with the exception of the loads excluded in step 4. This is the minium size of generator that would be required. This does not include any allowance for future expansion.

Table 3. Horsepower/nameplate ratings and starting wattages for equipment in the full-load electrical system example.

Equipment	Horsepower/ Nameplate Rating	Starting Wattage
Vacuum Pump	10 hp	36,000 W
Bulk Tank Cooler	5 hp	18,000 W
Silo Unloader	5 hp	18,000 W
Water Pump	3/4 hp	3,340 W
Fan 1	1/2 hp	2,300 W
Fan 2	1/3 hp	1,600 W
Electric Heater	4,000 W	4,000 W
Incandescent Lights	800 W	800 W
Fluorescent Lights	1,200 W x 1.2	1,440 W
TOTAL:		**85,480 W**

This example would result in a generator size equivalent to 85,480 watts or 85.5-kW. If a 85.5-kW generator is selected, it would have the capacity to start all the loads simultaneously. If it is determined that there would never be a chance that the silo unloader and the milking system will be operated at the same time, it would be possible to disregard the lower wattage of the two loads. Under this scenario the 18,000 watts of the silo unloader would not be included in the calculations, resulting in 67,480 watts.

Sizing a Sequence-Load Generator System

The sequence-load generator system relies upon an orderly starting of most loads allowing the use of running wattages for some motors rather than the starting wattage. To size the generator using the sequence-load method, use the following procedure:

1. List the essential lights and equipment which must operate during a power outage.

2. Using the list of equipment, Table 1 and Table 2, list the running and start up wattages for all motors in order of highest start-up to lowest start-up.

3. The running wattages of the non-motor operated appliances and lighting equipment should be included last. For these appliances there is no distinction between running and starting.

4. Take the first motor to be operated and determine what it takes to start it. Then add the running wattage of that motor to the starting wattage of the second motor to be started, and determine what wattage it takes to run the first motor and start the second. Continue this process until all motors are started. Then add on the remainder of the non-motor loads.

If it is determined that two or more motors may start at random intervals (such as refrigeration and well pumps) record only starting wattage.

5. Choose the largest wattage value from all of the steps for sizing the generator.

Table 4 lists equipment and the starting and running wattages for each device that will be used for an example of the sequence-load system. Note that this is the same list of equipment used in the full-load example. For this example, it will be assumed that the water pump is a load that will start randomly after it is turned on, therefore, only start-up wattages are used. Table 5 illustrates how to size a generator using the sequence-load system.

Table 4. Start-up and running wattages for the equipment in the sequence-load generator system example.

Equipment	Horsepower/ Nameplate Rating	Running Wattage	Starting Wattage
Vacuum Pump	10 hp	9,000 W	36,000 W
Bulk Tank Cooler	5 hp	4,500 W	18,000 W
Silo Unloader	5 hp	4,500 W	18,000 W
Water Pump	3/4 hp	835 W	3,340 W
Fan 1	1/2 hp	575 W	2,300 W
Fan 2	1/3 hp	400 W	1,600 W
Electric Heater	4,000 W	4,000 W	4,000 W
Incandescent Lights	800 W	800 W	800 W
Fluorescent Lights	1,200 W x 1.2	1,440 W	1,440 W

Table 5. Electrical loads, shown in Table 4, are started in a sequence. Shaded boxes indicate starting wattages of motors.

Equipment	Step 1 (W)	Step 2 (W)	Step 3 (W)	Step 4 (W)	Step 5 (W)	Step 6 (W)	Step 7 (W)
Vacuum Pump	36,000 W	9,000 W	9,000 W	9,000 W	9,000 W	9,000 W	9,000 W
Bulk Tank Cooler		18,000 W	4,500 W	4,500 W	4,500 W	4,500 W	4,500 W
Silo Unloader			18,000 W	4,500 W	4,500 W	4,500 W	4,500 W
Water Pump[1]				3,340 W	3,340 W	3,340 W	3,340 W
Fan 1					2,300 W	575 W	575 W
Fan 2						1,600 W	400 W
Electric Heater							4,000 W
Incandescent Lights							800 W
Fluorescent Lights							1,440 W
Peak Load	**36,000 W**	**27,000 W**	**31,500 W**	**21,340 W**	**23, 640 W**	**23,515 W**	**28,555 W**

1. The water pump in this example is considered to be a random starting load.

Careful examination of the above example shows that the peak power usage is at step number 1, therefore, it would be necessary that at least a 36-kW generator be selected. Note that the peak load placed on the generator occurred in the first step in this example. This is not always necessarily the case.

Load-Summation Method for Sizing a Generator

In many facilities, it can be difficult to predict the starting sequence of starting sequence of motor loads. For example, unless the units are turned off, loads such as a sump pump, refrigerators, freezers, air conditioners and furnaces are motor loads that operate automatically. Since the starting and stopping times of such automatic loads are not predictable, it is highly unlikely that these loads will start at the same time. It is also possible that no motor load may be in operation at a given time. The full-load method would require the use of starting wattages, likewise, the automatically starting loads used in the sequence-load method would also cause the starting wattage to be used. This would result in a generator that is sized large enough for any condition, but for the majority of the time, it would be oversized.

Table 6 provides an example for sizing a generator using the load-summation method. To size a generator using the load-summation method use the following procedure:

1. List the essential lights and equipment which must operate during an outage.

2. Using Table 1 and Table 2 list the running wattages for all loads except for the largest motor. For the largest motor record only the starting wattage. If there are two or more motors of the same size, list the starting wattage of only one.

3. Examine the listed loads, for two or more loads or groupings where it is extremely unlikely that they will be operating at the same time. An example of this would be a furnace and a window air conditioner. Another example is where a farmer does not run any feeding equipment during the operation of the milking equipment. When one or more loads or load groupings are found, it is only necessary to factor in the larger of the two wattage requirements.

4. To determine generator size, add up the starting wattage of the largest motor to the running wattages of other motor and non-motor equipment.

Table 6. Horsepower/nameplate ratings and wattages for equipment in the load-summation method for sizing a generator.

Equipment	Horsepower/ Nameplate Rating	Notes	Wattage
Refrigerator	1/3 hp	Running Wattage	400 W
Sump Pump	1/4 hp	Running Wattage	300 W
Furnace Blower	1/4 hp	Not Included[1]	------------
Window AC Unit	1/3 hp	Running Wattage	400 W
Well Pump	1/2 hp	Starting wattage[2]	2,300 W
Television	400 W	Using Table 2	400 W
Electric Skillet	1,200 W	Using Table 2	1,200 W
Microwave	1,500 W	Using Table 2	1,500 W
Radio	100 W	Using Table 2	100 W
Incandescent Lighting	800 W	No Adjustment Needed	800 W
Fluorescent Lighting	400 W	400 W x 1.2	480 W
TOTAL:			**7, 880 W**

1. When comparing loads, it is determined that the furnace blower and the air conditioning unit will not be operating at the same time. Therefore for calculation purposes, only the larger load is included.

2. For this example, the well motor was the largest motor load.

Using the load-summation, the example would result in a minimum size generator of 7,880 watts. In some cases ,not all the essential equipment will need to be operated at the same time. In the previous example, if the electric skillet and the microwave are not operated at the same time as the well pump and the TV, the load demands on the generator would be lowered. Table 7 utilizes the optional method for sizing a generator where predetermined loads will be switched off at certain times.

When comparing the two totals in Table 7, the largest demand on the generator occurs when the microwave and the electric skillet are operating. This grouping of loads would require that the generator be at least 6,380 watts. As was demonstrated in this example, a reduction in generator size may occur if it can be guaranteed that two or more loads will not operate at the same time.

Other Load Considerations

Variable frequency drives (VFD) are non-linear loads, which are used to control the speed of some induction motors. Through their operation they can induce a harmonic distortion in the sine wave. The result of this harmonic distortion is overheating of the internal windings of the generator. Some generator manufactures suggest that to prevent the likelihood of generator damage that the total VFD load not be greater then 50% of the rated generator capacity.

A generator voltage regulator must have a sufficient response time to minimize voltage sags and swells that result from loads being turned on and off. In general, motors are forgiving of these momentary fluctuations in voltages. Lights may flicker as the loads are changed. However, electronic equipment such as computers may be adversely affected. For expensive electronic equipment, it may be desirable to have it connected to an uninterruptible power supply (UPS). A UPS would filter out potential power quality problems, thus protecting sensitive equipment.

Table 7. Horsepower/nameplate ratings and wattages for equipment in the load-summation for sizing a generator with the assumption that certain loads will not operate at given time periods.

All Equipment in operation except for Microwave and Electric Skillet			
Equipment	**Horsepower/ Nameplate Rating**	**Notes**	**Wattage**
Refrigerator	1/3 hp	Running Wattage	400 W
Sump Pump	1/4 hp	Running Wattage	300 W
Furnace Blower	1/4 hp	Not Included[1]	------------
Window AC Unit	1/3 hp	Running Wattage	400 W
Well Pump	1/2 hp	Starting wattage[2]	2,300 W
Television	400 W	Using Table 2	400 W
Radio	100 W	Using Table 2	100 W
Incandescent Lighting	800 W	No Adjustment Needed	800 W
Fluorescent Lighting	400 W	400 W x 1.2	480 W
TOTAL:			**5,180 W**
All Equipment operating Except for Well Pump and the TV			
Equipment	**Horsepower/ Nameplate Rating**	**Notes**	**Wattage**
Refrigerator	1/3 hp	Starting Wattage	1,600
Sump Pump	1/4 hp	Running Wattage	300 W
Furnace Blower	1/4 hp	Not Included[1]	------------
Window AC Unit	1/3 hp	Running Wattage	400 W
Electric Skillet	1,200 W	Using Table 2	1,200 W
Microwave	1,500 W	Using Table 2	1,500 W
Radio	100 W	Using Table 2	100 W
Incandescent Lighting	800 W	No Adjustment Needed	800 W
Fluorescent Lighting	400 W	400 W x 1.2	480 W
TOTAL:			**6, 380 W**

Transfer Switches

Installing a standby electrical system requires compliance with the *National Electrical Code*, local regulations and power supplier requirements. Making the connection from the generator to the electrical system in a safe manner is essential. If connected improperly, the generator can be a shock hazard to occupants of the building or to works servicing the power lines.

Generator connections must prevent the accidental connection between a generator and the power supplier system. A transfer switch, which is a double-pole, double-throw is used on generator systems for safety. The action of the switch prevents accidentally feeding power back onto the power supplier's lines. Figure 3 shows a transfer switch as well as the electrical symbol which is used on blueprints. A transfer switch can be either manual or automatic. The standby generator must be connected in such a way that the circuits can receive their power from either the power supplier lines or the generator. There are three common methods of installing the transfer switch.

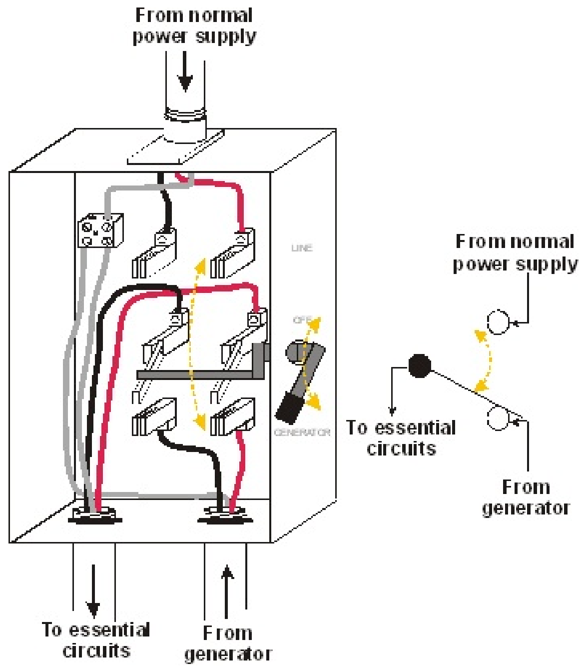

Figure 3. A double-pole, double-throw transfer switch.

Method 1: A transfer switch can be installed in the electrical service entrance to a building ahead of the service panel. This connection is shown in Figure 4. Usually a flexible core extends from the transfer switch to the generator. With this method, any circuit can be operated as long as the generator kW rating is sufficient to supply the load.

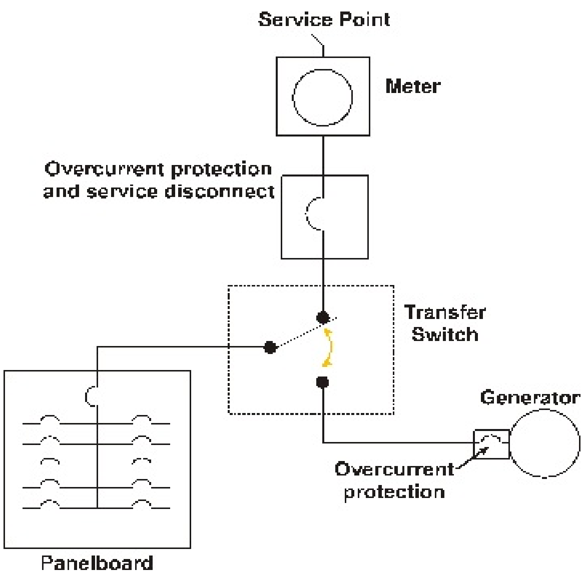

Figure 4. A transfer switch is connected for the entire service panel.

Method 2: A transfer switch is placed between an adjacent separate essential circuit panel and the main service panel, Figure 5. The essential circuit panel receives power from the utility supply or from the standby generator. By using this method, it is not necessary to modifying an existing service entrance to a building. With this method only circuits in the essential circuit panel can receive power from the standby generator.

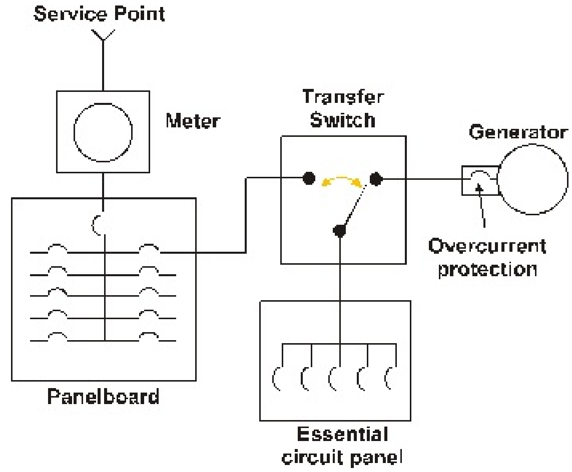

Figure 5. The transfer switch is connected to supply power to an essential circuit panel.

Method 3: The double-pole switch is on selected individual circuits. An approved panel containing several double-pole switches is attached to the service panel. These panels are pre-wired and ready for connection. The wire of an essential circuit is removed from the circuit breaker or fuse and connected to the double-pole switch input wire. The output wire from the double-pole switch is connected to the circuit wire that was removed from the circuit breaker or fuse. This device is shown in Figure 6.

Connecting to a Standby Generator

Appliances can be directly plugged into the portable generator by using an extension cord. This method of connection will not require the use of a transfer switch because the appliance is unplugged from the building's electrical system. Some appliances are not cord and plug connected such as the furnace, well-pump, and other similar pieces of equipment. Therefore, one of the previously mentioned uses of double-pole switches may be required.

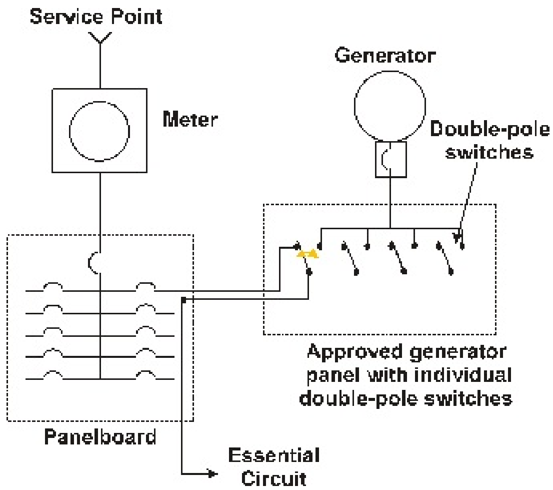

Figure 6. Selected circuits connected to an approved panel containing individual transfer switches.

Depending on the generator, different connections are found. Most portable generators have receptacles where an attachment plug may be installed. A twist-lock receptacle will normally give good reliability. These types of receptacles tend not to vibrate loose as easily as a straight-bladed receptacle. Special plugs with weatherproof enclosures can be installed on the outside of the building ready for connection to a portable generator. Never use an extension cord with a male cord cap on each end. If this type of cord is used, a potential electrocution hazard exists if the plug is removed accidentally or on purpose when the generator is operating.

If an extension cord is used, it must be a type that is heavy-duty and outdoor rated. The flexible cord leading from the generator must have an ampere rating of not less than the rating of the circuit protector on the generator, Table 7. Another factor is the length of the cord. Electrical conductors have resistance and the longer the length of cord the greater the resistance. This resistance will cause a voltage drop, reducing the voltage at the load end of the cord. For electrical motors, this can lead to premature equipment failure. To compensate for long cords, it may be necessary to increase the wire size of the cord, this will cause a reduction in the voltage drop. Stationary generators are permanently mounted onto a concrete pad. These generators are hard-wired to the transfer switch using an approved raceway system that protects the conductors from the environment and sunlight.

Table 7. Minium suggested flexible cord size assuming the maximum length of cord is 30 feet.

Overcurrent Protection Size on Generator	Conductor Size (AWG)
15 Amperes	14
20 Amperes	12
30 Amperes	10
40 Amperes	8
50 Amperes	6
70 Amperes	4

Locating the Standby Generator

The standby generator must be placed outside in a well ventilated space and not near any opening (window, door or vent) in the wall where exhaust may be allowed to accumulate in an occupied area. In addition, the location of the generator must be clear of combustible materials. Noise produced by the generator should also be taken into account.

Solving Problems

Some portable standby generators are intended for use an stand-alone systems to power portable equipment and have a ground-fault circuit interrupter (GFCI) protecting the output circuit. The purpose of this device is to sense when a person may be receiving a shock and automatically disconnect the power to the receptacle. This same device can interfere with the operation of the generator when it is connected to a building wiring system.

The equipment grounding wire and the neutral wire are connected together at the main service disconnecting means and inside the generator. The equipment grounding conductor and the neutral conductor will act as parallel conductors between the service panel and the generator. This signals a false ground-fault to the generator and the GFCI will trip. In this situation the main bonding jumper inside the generator must be removed, preferably by the equipment manufacturer or a licensed electrical contractor. *NOTE:* After this modification, the generator will no longer pass OSHA inspection on job sites.