CONSTRUCTION ELECTRICIAN APPRENTICESHIP PROGRAM

Level 4 — Line H: Install Electrical Equipment



LEARNING GUIDE H-8

INSTALL ALTERNATIVE POWER SYSTEMS

ita
industry training authority

THE RIGHT SKILLS ▶ A PROVEN ADVANTAGE

BRITISH COLUMBIA

Foreword

The Industry Training Authority (ITA) is pleased to release this major update of learning resources to support the delivery of the BC Electrician Apprenticeship Program. It was made possible by the dedicated efforts of the Electrical Articulation Committee of BC (EAC).

The EAC is a working group of electrical instructors from institutions across the province and is one of the key stakeholder groups that supports and strengthens industry training in BC. It was the driving force behind the update of the Electrician Apprenticeship Program Learning Guides, supplying the specialized expertise required to incorporate technological, procedural and industry-driven changes. The EAC plays an important role in the province's post-secondary public institutions. As discipline specialists the committee's members share information and engage in discussions of curriculum matters, particularly those affecting student mobility.

ITA would also like to acknowledge the Construction Industry Training Organization (CITO), which provides direction for improving industry training in the construction sector. CITO is responsible for organizing industry and instructor representatives within BC to consult and provide changes related to the BC Construction Electrician Training Program.

We are grateful to EAC for their contributions to the ongoing development of BC Construction Electrician Training Program Learning Guides (materials whose ownership and copyright are maintained by the Province of British Columbia through ITA).

Industry Training Authority
January 2011

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LEVEL 4, LEARNING GUIDE H-8:

INSTALL ALTERNATIVE POWER SYSTEMS

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Learning Objectives

Alternative power systems have unique characteristics that require an understanding of the various components used in these systems in order to install them in a safe manner. This Learning Guide outlines the various types of systems, their operating characteristics, method of installation and practices for testing and commissioning these systems.

The learner will be able to:

- describe the types of alternative power systems.
- describe the operation of alternative power systems.
- describe the characteristics of alternative power systems.
- identify the hazards associated with alternative power systems.
- describe appropriate safety procedures to be used with alternative power systems.
- select alternative power system components.
- choose optimal locations for alternative power system equipment.
- create and place required signage for alternative power systems.
- determine the proper current and voltage ratings to be applied to alternative power systems.
- select appropriate conductors for use in alternative power systems.
- select and locate protection and control equipment for alternative power systems.
- comply with supply authority requirements for grid-tie alternative power systems.
- describe appropriate methods of mounting alternative power system components.
- connect grid-tie alternative power system components.
- connect stand-alone alternative power system components.
- describe commissioning procedures for alternative power systems.
- perform maintenance on alternative power systems.
- troubleshoot alternative power systems.
- prepare records for alternative power systems.

Activities

- Read and study the topics of Learning Guide H-8: Install Alternative Power Systems.
- Complete Self-Tests 1 through 3. Check your answers with the Answer Key provided at the end of this Learning Guide.

Resources

You are encouraged to consult the following to obtain supplemental learning information:

Canadian Electrical Code, Part 1, Safety Standards for Electrical Installations, Current Edition.

Courses:

British Columbia Institute of Technology, CESA 0158: Introduction to Solar Electricity

British Columbia Institute of Technology, CESA 0159: Solar Electric Design

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Industry Training Authority
January 2011

Learning Task 1:

Describe alternative power systems

Alternative power systems are the fastest growing sector in power generation. Alternative power systems comprise a wide range of electrical generation techniques, but they all share the characteristic of not emitting greenhouse gases in the process of producing electric power. Many alternative power systems use solar energy to produce electricity. In the case of solar photovoltaic modules, the sunlight is converted directly to DC electricity. In the case of wind and hydropower, the conversion is indirect. Sunlight warms the Earth's surface and the temperature differential between different places on the Earth's surface produces wind. When sunlight warms a body of water, evaporated water is transported to land, where it falls as rain and energy can be extracted from the streams, creeks and rivers produced.

Applications for alternative power include *distributed generation* and *remote power*. Distributed generation is a rapidly growing aspect of the electrical industry. Generating power at a home or business may be less expensive than purchasing it from an electrical utility. Such systems may provide backup power if energy storage is incorporated into the system, and utilities may look favourably on distributed generation if it offsets peak power use on their system. Most distributed generation is grid-tied: the system is connected in parallel with the utility grid and excess power generation is supplied to the utility.

Remote power systems are stand-alone. Usually such systems require energy storage. Electrical energy is stored in batteries, but some systems use other methods such as pumping water to a higher elevation to store energy. Solar, wind and micro-hydropower generation is often less expensive than the operation of fossil fuel-powered generators, and many remote communities, businesses and homes are incorporating alternative power into their energy generation mix.

New technologies are being developed all the time, and the equipment used in alternative power systems is constantly changing. However, alternative power and distributed generation are part of the smart-grid concept and are becoming more common all the time.

Wind power systems

Characteristics

Wind-generated power has been around for centuries, and its use in the generation of electricity dates back to the early part of the 20th century. Wind turbines are used to capture the power in the wind by converting the kinetic energy in the wind into rotational kinetic energy that is then used to turn an electric generator. A distinction is often made between *small wind systems* and *large wind systems*. According to the Canadian Electrical Code (CEC), Section 64, small wind systems consist of one or more wind turbines with a rated output up to and including 100 kW. Large wind systems exceed 100 kW in rated output. Generally, small wind systems are installed for residential or commercial use, while large wind systems are operated for or by electrical utilities.

A wind power system includes various power and structural components. All wind power systems include a turbine and tower. Many systems include power conversion devices such as charge controllers and inverters, which change the voltage, current or frequency of the turbine's electrical output. Inverters convert DC power to AC power and are used in both stand-alone and grid-tie applications. Some wind power systems include energy storage, in which electrical energy is stored in secondary batteries such as lead acid batteries, nickel-cadmium batteries or lithium-ion batteries.

Wind turbines comprise a rotor, a generator, a frame and, usually, a tail. They can be either horizontal axis or vertical axis. Horizontal axis wind turbines, which look like a propeller, are the most familiar type. When used for producing electricity they have two or three blades. Three blades are more common on small wind turbines, as they run more smoothly. Figure 1 shows an example of a small horizontal axis wind turbine on a tubular tower. The body, shell or casing covering the generator, blade hub and other parts mounted on the top of the tower is called a *nacelle*, especially on large wind turbines.



Figure 1—Evance R9000 5 kW small domestic wind turbine

Vertical axis wind turbines are less common and are usually seen in small wind applications. A popular style of vertical axis turbine is called a *Darieus rotor*, which has an airfoil blade. Variations on this type of turbine are the H, or Giro rotor, and Gorlov rotor. Figure 2 shows an example of a large vertical axis wind turbine.



Figure 2—Darrieus wind generator Eole, Gaspe Peninsula, Quebec

Wind towers come in many different configurations, including lattice towers, Guyed tubular towers and mono-pole towers. Installation of wind turbine towers may require specialized knowledge for preparation of the footings and anchors, as well as proper use of the rigging and winches during installation. Figure 3 shows large horizontal axis wind turbines mounted on mono-pole towers.



Figure 3—Large wind turbines in Ontario

Solar photovoltaic power systems

Solar photovoltaic (PV) power is the direct conversion of sunlight into electricity. The photovoltaic effect was first observed almost two centuries ago by the French scientist Edmond Becquerel. However, it took the development of quantum theory in the early 20th century before the phenomenon could be explained and practical photovoltaic devices manufactured.

The power-generating component of solar photovoltaic power systems is a *solar module*. A solar module is a complete, environmentally protected assembly of interconnected solar cells. *Solar cells* are photodiodes that produce a voltage when exposed to sunlight.

The photovoltaic effect is the basis of photovoltaic cell technology. The key to this effect is a class of materials called *semiconductors*, the same materials used in the transistors and diodes that have replaced vacuum tubes and switches in consumer electronics.

A photovoltaic cell is made of a semiconductor material such as silicon, into which impurities, such as boron and phosphorus, are intentionally added to create two distinct "layers" within the photovoltaic cell. One layer will have a negative charge, the other a positive charge, forming a diode. The electric field, or voltage, created between these charged layers sets the stage for the photovoltaic effect.

Light energy in the form of photons excites the electrons in the photovoltaic cell, knocking them free of the crystal structure of the semiconductor. The electric field in the photovoltaic cell moves the excited electrons across the cell, where they are collected by metal contacts placed on the front and back surface of the cell. When the photovoltaic cell is connected in a circuit an electric current flows. Figure 4 shows a silicon solar cell with metal contact grid and busbars on the front surface to collect the current.

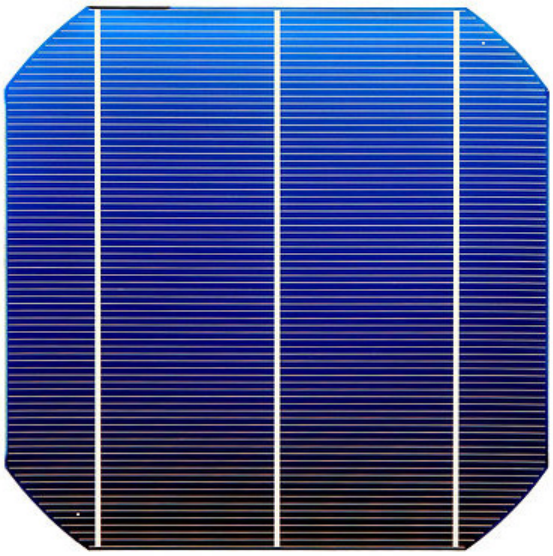


Figure 4—Example of a crystalline silicon solar photovoltaic cell

Characteristics

A typical silicon solar cell is about 10 to 15 cm across and produces approximately 0.6 volts open circuit. Useful levels of voltage are produced by connecting several solar cells in series. Most solar modules contain 60 or 72 cells connected in series.



Figure 5—Example of a solar photovoltaic module

The electrical output of a solar module is characterized by a plot of current versus voltage, known as an *IV curve*. The characteristic IV curve for a solar module changes depending on the intensity of the light striking it (irradiance), the spectral distribution of that light (which is quantified as air mass) and the temperature of the solar module. The CSA product safety standard for solar photovoltaic modules (CAN/CSA C61215-08) stipulates standard test conditions (STC) under which solar modules are rated:

- irradiance of 1000 W/m^2
- module cell temperature of 25°C
- air mass 1.5 (air mass 1.0 occurs when the sun is directly above the surface of the Earth when sunlight strikes the Earth's surface at a 90° angle)

The maximum current produced by a PV module is the *short circuit current*, abbreviated I_{sc}. The maximum current is produced when there is no load impedance and the voltage decreases to zero. The maximum voltage of a PV module is the *open circuit voltage*, abbreviated V_{oc}. Maximum voltage occurs when there is infinite impedance and no current. These two extremes in load impedance, and the whole range of conditions in between are shown on an IV curve. Figure 6 is an example of an IV curve.

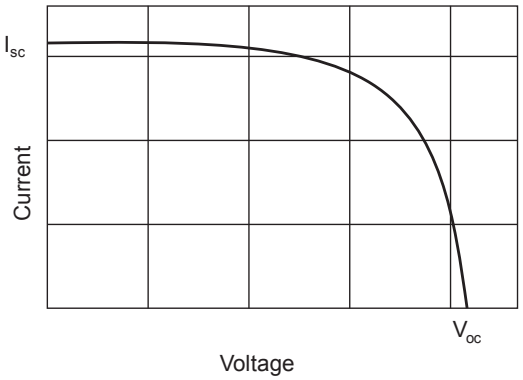


Figure 6—IV curve for a solar module (image courtesy Reid Wylde Engineering Ltd. © 2012)

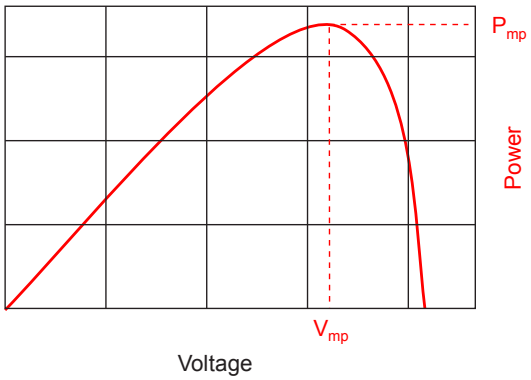


Figure 7—Power versus voltage curve for a solar module (image courtesy Reid Wylde Engineering Ltd. © 2012)

The power available from a photovoltaic module varies with the impedance of the load and is represented by the points along the IV curve. Power is calculated by multiplying the voltage and the current at any point on the curve. Figure 7 shows how power varies with voltage.

The power at the maximum power point is described as *peak power* or *maximum power*. Peak power is generally abbreviated as P_{max}, P_m or P_{mp}. The voltage that corresponds to peak power is peak voltage, abbreviated V_{mp}. Maximum power, P_{max}, is equal to the area of the largest rectangle that fits under the IV curve. Figure 8 shows how peak current, I_{mp}, is obtained from an IV curve by overlaying the power versus voltage curve. The area of the rectangle defined by where the I_{mp} and V_{mp} lines intersect is equal to the maximum power expressed in watts as shown in the equation below:

$$P_{max} = V_{mp} \times I_{mp}$$

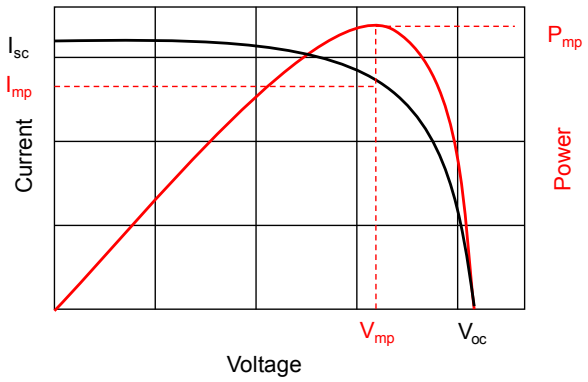


Figure 8—IV curve and power versus voltage curve showing the maximum power point values for current (I_{mp}) and voltage (V_{mp}) (image courtesy Reid Wylde Engineering Ltd. © 2012)

The electrical characteristics for a solar module at standard test conditions are provided on the nameplate of the solar module (Figure 9). These characteristics are:

- short circuit current, I_{sc}
- open circuit voltage, V_{oc}
- maximum power point voltage, V_{mp}
- maximum power point current, I_{mp}



Figure 9—Example of the CSA-required label on a solar PV module (image courtesy Eric Smiley 2015)

Micro-hydropower and hydrokinetic power systems

Hydropower or water power is harnessed from the gravitational potential energy of water at a higher elevation than the turbine, or from the kinetic energy of water that is flowing at the same elevation as the turbine. Hydropower is used for the operation of various mechanical devices, such as gristmills, sawmills, textile mills, trip hammers, dock cranes, domestic lifts and ore mills. *Hydropower* is often used today to mean *hydroelectric power*, in which a hydro turbine is connected to an electric generator.

Characteristics

Hydropower turbines can be classified according to how the energy in water is converted to rotational kinetic energy. *Impulse turbines*, which include Pelton, turgo and crossflow turbines, convert kinetic energy in a jet of water by allowing the moving water to collide with the turbine blades and impart its momentum to the turbine. The jet of water is created by placing a nozzle at the end of a pipe containing pressurized water. Figure 10 is an example of a Pelton turbine.



Figure 10—Pelton turbine

Reaction turbines, which include Francis and Kaplan turbines, convert the energy in a flow of pressurized water to rotational kinetic energy by causing a pressure drop across the turbine. Both impulse and reaction turbines require water to move from a high elevation to a low elevation so the water at the turbine is at greater than atmospheric pressure. Figure 11 shows an example of a Francis turbine.

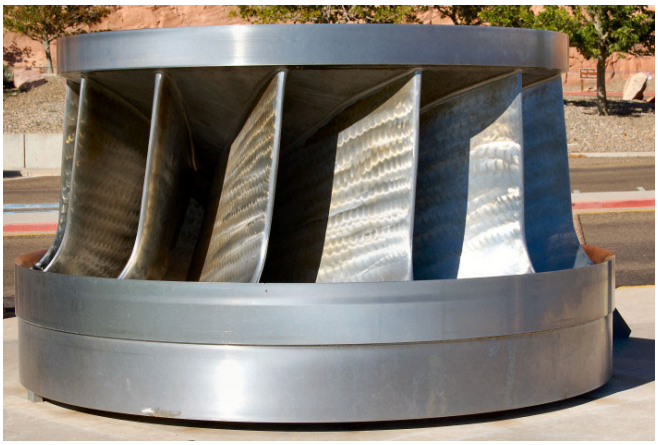
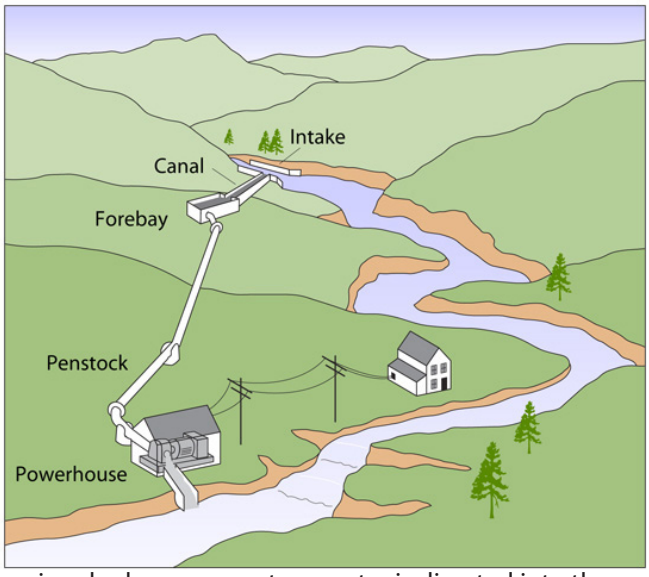


Figure 11—Francis turbine

Usually the water is conducted to the turbine in a pressurized pipe called a *penstock* and must be directed into the penstock from a creek or stream via a diversion structure such as a weir where the intake is located. Figure 12 shows the layout of a typical micro-hydro system.



In this micro-hydropower system, water is diverted into the penstock. Some generators can be placed directly into the stream.

Figure 12—Micro-hydro system

A *hydrokinetic turbine* converts the kinetic energy in moving water to rotational kinetic energy of the turbine shaft in a free-flow environment. It does not need a diversion. Hydrokinetic turbines may be used in rivers, artificial channels, tidal waters or ocean currents. It is much like planting windmills in the water, and many hydrokinetic turbines resemble wind turbines, as can be seen in Figure 13.



Figure 13—Hydrokinetic Gorlov-style water turbines

Hydropower turbines may be coupled to the shaft of a synchronous generator or an asynchronous generator for AC power generation. The coupling may be direct, belt drive or other mechanism to match the rotational speed of the turbine to the generator. The optimum rotational speed of impulse and reaction turbines is directly related to the pressure driving the flow of water and the geometry of the turbine. Thus, for a given hydropower system with a fixed pressure, the rotational speed remains steady and, unlike wind turbines and hydrokinetic turbines, these systems can be designed to produce steady 60 Hz alternating current for grid-tie or off-grid applications.

Thermal systems

Thermal power generation entails the use of heat engines to drive either synchronous or asynchronous generators. The heat engines, which include internal combustion engines, steam engines, gas turbines and steam turbines, may obtain their heat energy from a variety of sources, including coal, natural gas, gasoline, diesel, wood waste, bio-diesel, alcohol, hydrogen, land-fill methane, solar thermal collectors and nuclear fission.

Operation of these plants may be highly complex due the requirements of fuel management, air supply, cooling, lubrication and control. However, the electrical installation and operation of these systems is focussed on the integration of synchronous or asynchronous electrical generators into an electrical system. The method of generating the shaft work is the study of *power engineering*.

Fuel cells

Fuel cell power-generation systems generate direct current electricity from chemical reactions. The most common reaction is the combining of hydrogen and oxygen to produce water. Although this reaction can be accomplished through combustion, a fuel cell allows the hydrogen and oxygen to combine with use of catalyst materials.

Many different configurations of fuel cell are possible, with the type of electrolyte defining the type of reaction that occurs inside the fuel cell. If the electrolyte is acidic, as in a proton exchange membrane fuel cell (PEMFC; Figure 14) or phosphoric acid fuel cell (PAFC), hydrogen molecules are split into individual atoms at the anode and the electrons are removed from the hydrogen atoms, creating hydrogen ions, or protons. The hydrogen ions then pass through the electrolyte to meet with the oxygen atoms at the cathode. Meanwhile, the electrons pass through an external circuit from the anode to the cathode, where they recombine with the hydrogen and the oxygen, forming water. The energy that would otherwise be released as heat during combustion is instead captured by harnessing the flow of electrons through the external circuit to do electrical work.

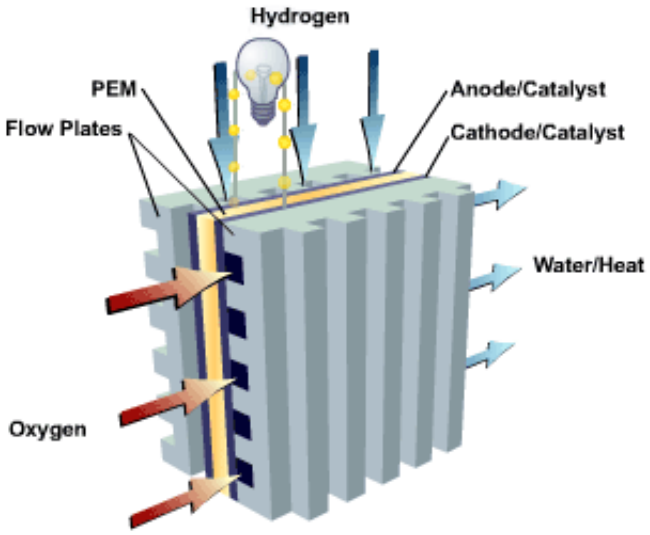


Figure 14—Diagram of a PEMFC

The voltage of a single hydrogen fuel cell can theoretically be as high as 1.2 V at open circuit, but usually operates between 0.5 V and 0.8 V during steady-state operation. In order to produce useful voltages, multiple fuel cells are assembled in series in a fuel cell *stack*. The fuel cell stack is then assembled into a fuel cell system comprising the fuel cell stack, a hydrogen supply, an oxygen supply, a cooling system, a water capturing system, a control system and the electric power circuits.

The electrical output of a fuel cell is usually supplied to a power conditioning unit, such as an inverter if AC power is required, or a charge regulator if the system is being used for battery charging. The operation of the fuel cell system is automatic and is controlled by software. As the electrical load on the system varies, the control system adjusts the fuel flow, oxygen flow and coolant flow to maintain optimal operation of the fuel cell.

As with solar photovoltaic modules, there is a characteristic voltage versus current density curve that describes the output of the fuel cell at different operating points. This is called a *polarization curve*. An example of a polarization curve for a PEMFC is shown in Figure 15. The current density is the current produced by the fuel cell divided by the surface area of the cell. As the current density rises, ohmic losses cause the voltage to decrease.

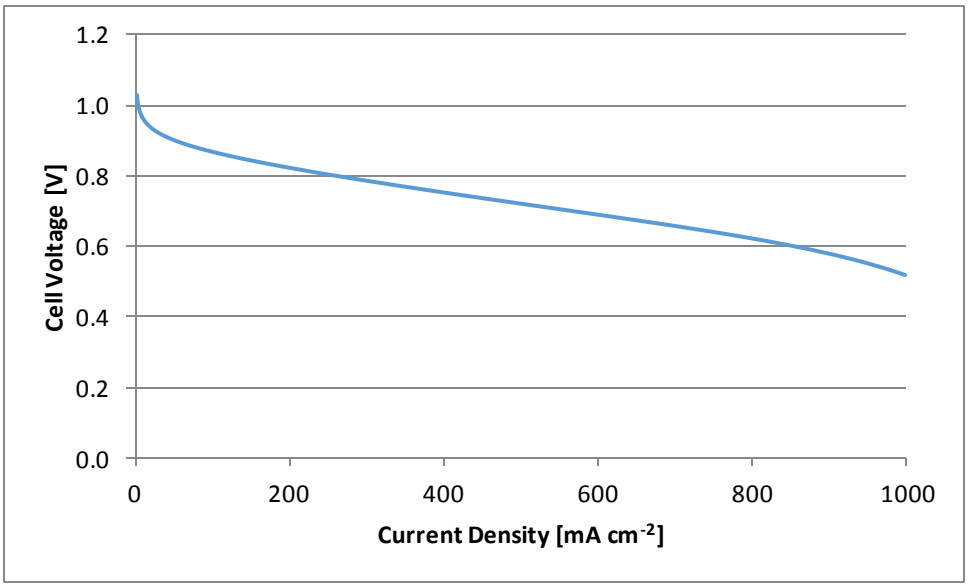


Figure 15—Fuel cell polarization curve
(image courtesy Reid Wylde Engineering Ltd. © 2015)

Power conditioning units and generators

Aside from solar photovoltaic modules, which produce DC electricity directly from sunlight, alternative power systems usually generate electricity by converting rotational kinetic energy into electrical energy with electric generators. These generators are usually either *asynchronous* (induction) generators or *synchronous* generators (alternators). In all systems, however, the electrical energy is *conditioned* or changed in various ways with power electronic equipment. This power conditioning equipment is used to change the voltage, frequency or current of the electrical power.

Power conditioning units

A *power conditioning unit* (PCU) is a piece of equipment, usually electronic, that modifies the voltage, current or waveform of electric power supplied to it. Power conditioning units perform many different functions in alternative power systems and, depending on their function, may also be called *converters*, *inverters* or *charge controllers*. Power conditioning units are most often used to:

- Regulate the charge into a battery by varying the current to the battery as the battery voltage changes. This is called a *charge controller*.
- Maximize the power produced by a solar module, wind turbine or hydro generator by varying the operating voltage of the alternative power source as the irradiance, wind speed or water pressure changes. This is called a *maximum power point tracker* (MPPT).
- Convert the direct current produced by a solar module, rectified alternator or battery into alternating current for supply to electrical loads or the electrical grid. This is called an *inverter*.

High-quality stand-alone DC to AC inverters are available with power outputs ranging from a few watts to hundreds of kilowatts, and conversion efficiencies are greater than 90%. A DC to AC inverter simplifies wiring in stand-alone systems by allowing the use of low-cost, readily available AC switches, outlets and fixtures. Stand-alone inverters supply a well-regulated 60 Hz supply of AC power and are used in 120 V single-phase, 120/240 V split-phase and 120/208 V three-phase power systems.

Grid-tie DC to AC inverters have different operating characteristics from stand-alone inverters. Grid-tie inverters do not generate their own voltage and frequency. Instead they synchronize with an external AC power source, the utility grid, and supply current. In order to meet CSA product safety standards, grid-tie inverters must qualify the AC power source and ensure that it is operating within narrow voltage and frequency parameters before supplying power to the electrical grid. A grid-tie inverter is incapable of operating in stand-alone situations. Figure 16 shows an example of a central grid-tie inverter that accepts the input of many solar modules, and Figure 17 shows an example of a grid-tie micro-inverter that converts the output of a single solar module to AC.



Figure 16—Grid-tie central inverter



Figure 17—Micro-inverter attached to racking on a roof (image courtesy Eric Smiley 2014)

Some stand-alone inverters have the capability to operate in both grid-tie and stand-alone mode. These are sometimes referred to as *hybrid* inverters and are used as backup power systems in grid-tie applications or as parallel power sources in isolated grid applications.

Stand-alone inverters are referred to as *inverter/chargers* when they also have the ability to supply DC charging current to a battery. This is important when locating disconnects and overcurrent devices, as the inverter is bidirectional and the terminals on both the DC and AC side of the inverter are both input and output terminals, depending on the mode of operation. Figure 18 shows two 6 kW inverter/chargers mounted on a wall next to a battery enclosure.

Charge controllers for batteries may be simple voltage-controlled relays, or they may incorporate more sophisticated DC to DC converters that operate solar modules, wind turbines or hydroelectric turbines at the optimum voltage for maximum power generation. The optimum voltage varies with environmental conditions such as wind speed, water pressure, temperature or solar irradiance. The controllers then step the voltage down to the battery voltage while increasing the current.



Figure 18—Stand-alone inverter/chargers and battery enclosure (image courtesy Viridian Energy Co-operative 2013)

Synchronous generators (alternators)

Synchronous generators are often used in hydro and thermal power systems, where the rotational speed of the generator can be constant without compromising the efficiency of the system. Synchronous generators are available as standard components from many manufacturers and are chosen to match with the frequency and power produced by the hydro turbine or heat engine grid-tie.

In stand-alone applications where the AC output of the generator is supplied directly to the loads, voltage is controlled by regulating the excitation of the rotor windings with an automatic voltage regulator. However, as the loads in the electrical system change, power output from these generators must be controlled. This is achieved in various ways. Some examples are:

- regulating the fuel supply to the heat engine in thermal systems
- regulating the water flow to the turbine in hydro systems
- using a diversion load controller to maintain full load on the generator

The last method, using a diversion load controller, is often much less expensive and provides better frequency regulation in small hydro systems than by regulating water flow.

In stand-alone systems with DC energy storage in batteries, permanent-magnet alternators are often used. Since the output of the alternator is rectified to DC before being supplied to the battery, these alternators are used in hydro, wind and thermal power systems without frequency regulation. The AC produced by the alternator is sometimes referred to as *wild* AC, and it varies with the speed of the turbine or engine. Generating AC offers some advantages when the alternative power source is a long distance from the point of use. In those cases the alternator can be used to generate AC at a high voltage for long-distance transmission and a transformer is used to step down the voltage before it is rectified to DC for battery charging or for input to an inverter.

Induction generators (asynchronous generators)

Three-phase induction generators are used in grid-tie and stand-alone power systems. An induction generator is much simpler and more reliable than a synchronous generator and, as a consequence, much less expensive. Often an induction motor is used as a generator, as there is no real difference in their construction. Figure 19 shows a cutaway view of an induction motor/generator.

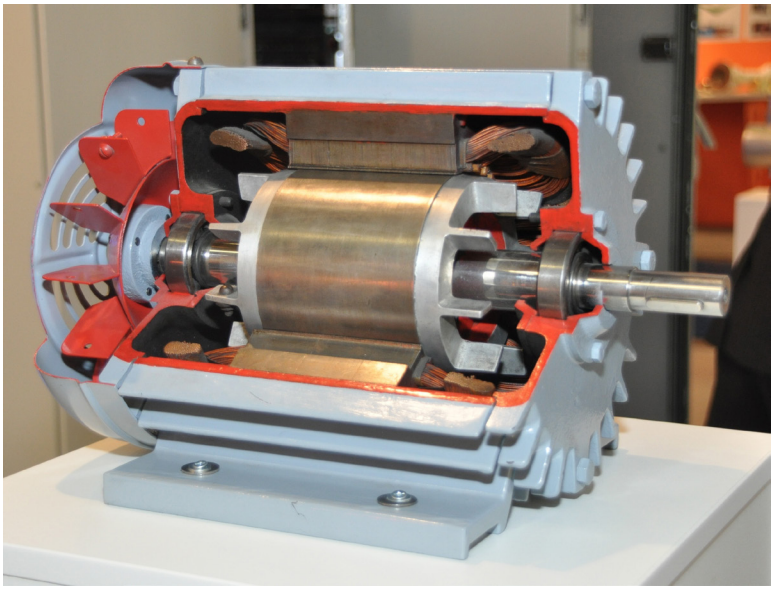


Figure 19—Induction motor/generator

When used in a grid-tie application, the output of the generator is connected to a three-phase supply—the utility grid. Initially, the generator will operate as an induction motor when power is supplied to it. If the generator is then coupled to the shaft of a wind turbine, hydro turbine or heat engine, and the shaft is made to rotate faster than the synchronous speed of the motor (e.g., 1200 rpm or 1800 rpm typically), then the slip of the motor becomes negative and power flows to the supply. The utility grid determines the frequency and voltage at which the generator operates. To ensure that the induction generator does not supply power to the grid during fault conditions, additional protective and monitoring equipment is needed to disconnect the generator and shut down the turbine if the grid voltage or frequency deviates beyond specific limits, which are usually set by the utility.

Induction generators can also be used in stand-alone applications to supply three-phase or single-phase AC power or for battery charging. In stand-alone applications capacitors are used to generate the lagging reactive magnetizing current in the stator. When properly selected, the generator produces the correct voltage and frequency when operated at full load. Specialized power conditioning units called *induction generator controllers* are used to regulate the voltage of the generator by operating as a diversion load controller to maintain a constant load on the generator as loads are added to or removed from the system.

Configuration

Stand-alone systems are defined in the CEC Section 64-002. They are systems that supply power independent of a supply authority electrical production and distribution network. Particular rules apply to stand-alone systems, such as Rule 64-104, which prescribes the wiring of inverters in stand-alone systems. Interactive systems, also called *grid-tie systems*, are also defined in Section 64-002. These systems operate in parallel with and can deliver power to a supply authority system.

Stand-alone wind power systems

Small wind turbines may be used to directly operate motor loads. Water pumping is a common application of this technology as an alternative to mechanical wind pumping systems and is relatively simple to build and operate.

A three-phase induction motor connected to a pump may be operated at variable speed directly from a three-phase synchronous alternator in a wind turbine. As wind speed varies, the frequency of the output from the turbine typically ranges from 25 Hz to 100 Hz. Thus as the power in the wind varies so does the rotational speed and power output from the pump. This arrangement means that a properly matched pump and generator will cause the wind turbine to operate very close to the optimum tip speed ratio.

Because the pump will sometimes operate at low rotational speeds, it is usually necessary to use more stages in the centrifugal pump than would be used in a conventional application. However, an "off-the-shelf" pump may be used and the pump will produce variable flow as the wind speed varies.

A direct-to-load system comprises only a few components, as shown in Figure 20. In addition to the turbine and tower, a disconnect means and/or shutdown switch is installed at the base of the tower. A controller may be used between the wind turbine and the motor load to turn the load on and off, such as when a tank is being filled by a pump. If the motor load is turned off, the controller must be able to transfer the output of the turbine to a diversion, maintaining a load on the alternator so it does not overspeed.

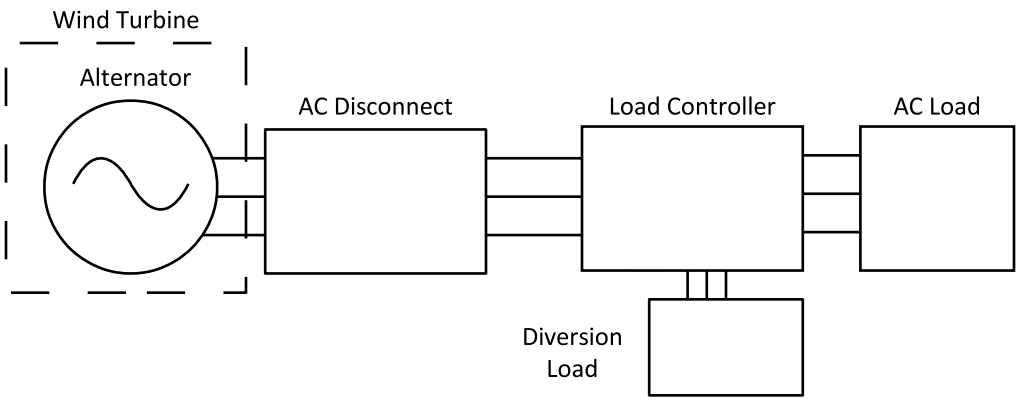


Figure 20—Wind-electric pumping system
(image courtesy Reid Wylde Engineering Ltd. © 2012)

Small wind turbines are also popular in remote power applications, where they are used to charge batteries. Due to the intermittent nature of wind power, several days of energy storage are often required. Most often batteries are used to store the electrical energy. Off-grid systems have more components than direct-to-load systems because of the energy storage, as shown in Figure 21.

In order to store energy in a battery, the output of the alternator must be rectified to DC. Some wind turbines have a rectifier built into the turbine so that DC power is supplied down the tower. Other turbines output variable-frequency three-phase AC power and a rectifier is located near the battery.

At the base of the tower, a disconnect means and/or shutdown switch is installed. A charge control or diversion charge control is installed near the battery and a disconnecting means is located on both sides of the charge control in order to isolate it for servicing. The output of the charge control is connected to a battery, and the output of a diversion charge control is connected to both the battery and a diversion load, such as a resistive heating element.

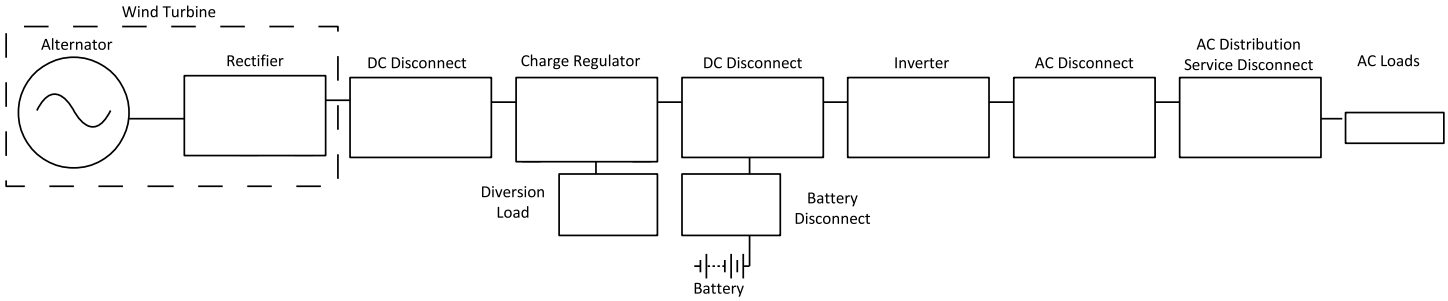


Figure 21—Off-grid wind power system
(image courtesy Reid Wylde Engineering Ltd. © 2012)

Grid-tie wind power systems

Grid-connected small wind turbines are usually connected to the supply authority with an inverter. These systems have few components, aside from a turbine, tower and inverter. A disconnect switch is required on the output of the turbine and between the inverter and the utility connection. Two examples of small grid-tie wind power systems are shown in Figure 22. The example at the top shows a wind turbine where the alternator and rectifier are housed in the nacelle and only DC circuits come from the turbine. The bottom example shows a wind turbine that produces "wild" frequency AC, which is rectified and inverted closer to the grid-interconnection point.

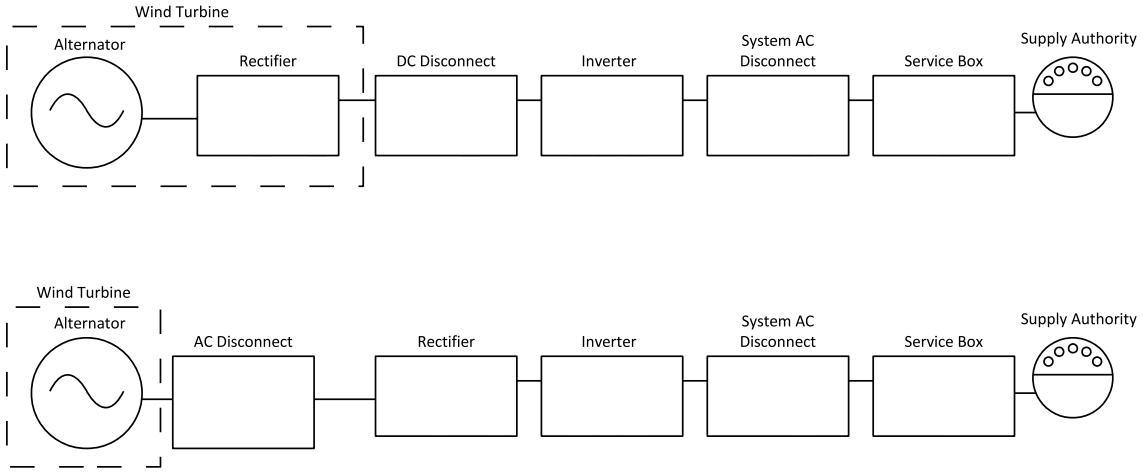


Figure 22—Small wind grid-tie systems: wind turbine with integrated rectifier (top) and wind turbine with rectifier at inverter (bottom) (image courtesy Reid Wylde Engineering Ltd. © 2012)

Figure 23 is an example of a large wind power system that uses a doubly fed induction generator (DFIG) to synchronize with the utility grid. These systems utilize a variable-frequency inverter to supply the rotor in the generator in such a way that, as the rotational speed of the rotor varies with wind speed, the output from the stator remains constant at 60 Hz. The generator and power electronics would all be housed in the nacelle at the top of the wind turbine tower.

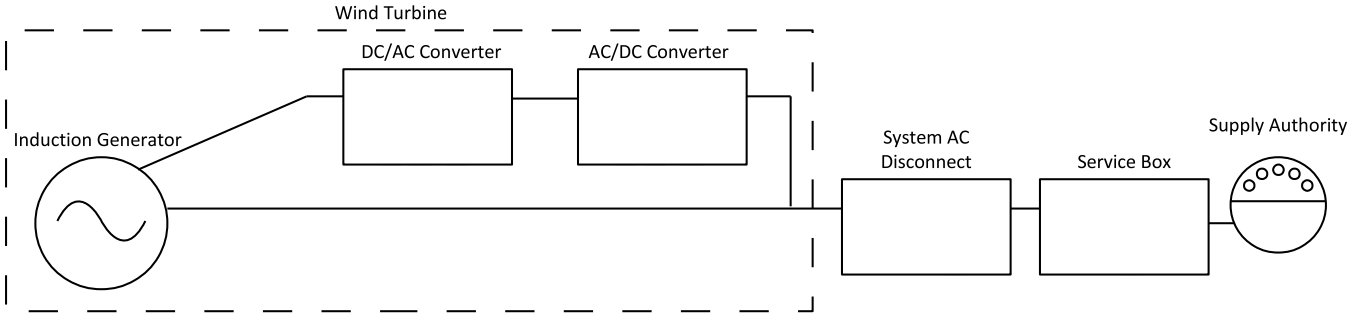


Figure 23—Large wind turbine system: wind turbine with doubly fed induction generator (image courtesy Reid Wylde Engineering Ltd. © 2012)

Stand-alone solar photovoltaic systems

Solar photovoltaic systems may be configured in many ways. As with wind turbines, the simplest systems comprise a solar photovoltaic array and a load, such as a motor. Figure 24 shows a simple direct-to-load water pumping system or ventilation system. DC loads such as pumps and fans may be operated directly from a PV module with a simple control such as a float switch, pressure switch or thermostat as a load controller. Some direct PV systems use power conditioning units such as maximum power point trackers (MPPT) and variable-frequency drives to optimize the performance of the system and operate AC loads such as submersible pumps.

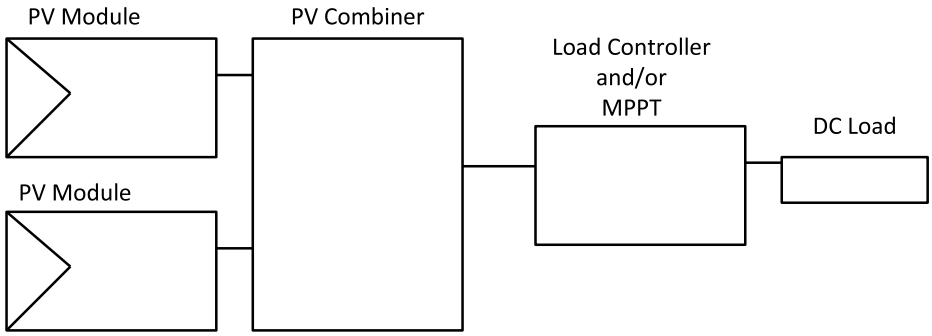


Figure 24—Direct-to-load PV system
(image courtesy Reid Wylde Engineering Ltd. © 2012)

Stand-alone solar PV power systems

Stand-alone solar PV systems often have a battery for energy storage. A stand-alone PV system with DC distribution is an excellent power source for a remote cabin, recreational vehicle or boat. Energy storage is also used in telecommunications, data monitoring and electric fencing.

The PV array charges the battery during daylight hours and the battery supplies power to the loads as needed. A charge controller regulates battery charging. The load centre may contain meters to monitor the system and fuses or breakers to protect wiring in the event of a malfunction or short circuit. Figure 25 shows an example of a stand-alone PV system with a battery that operates DC loads only.

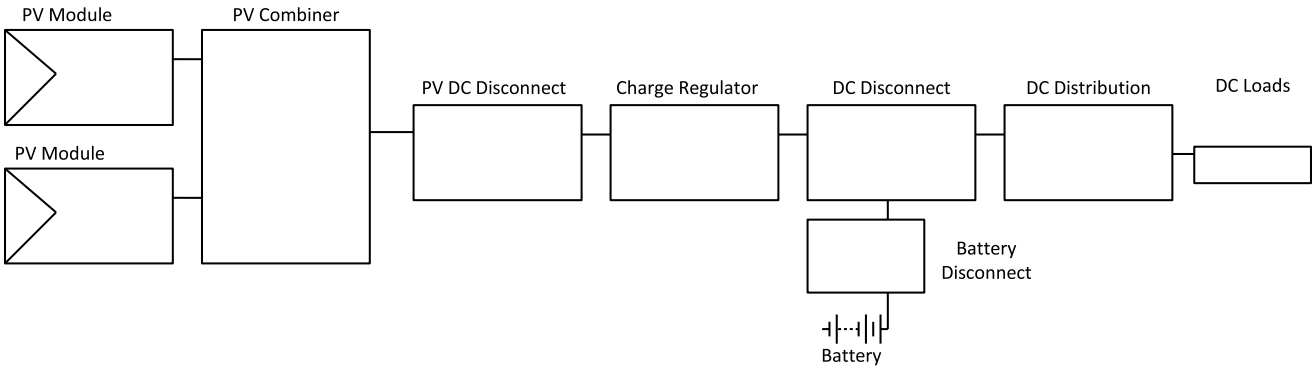


Figure 25—Stand-alone DC PV system
(image courtesy Reid Wylde Engineering Ltd. © 2012)

An inverter that converts direct current into alternating current is often used in stand-alone power systems. The inverter allows commonly available AC loads such as power tools, vacuum cleaners, washing machines and kitchen appliances to be used. Figure 26 shows an example of this type of system. This type of system is ideal for a remote residence or commercial enterprise.

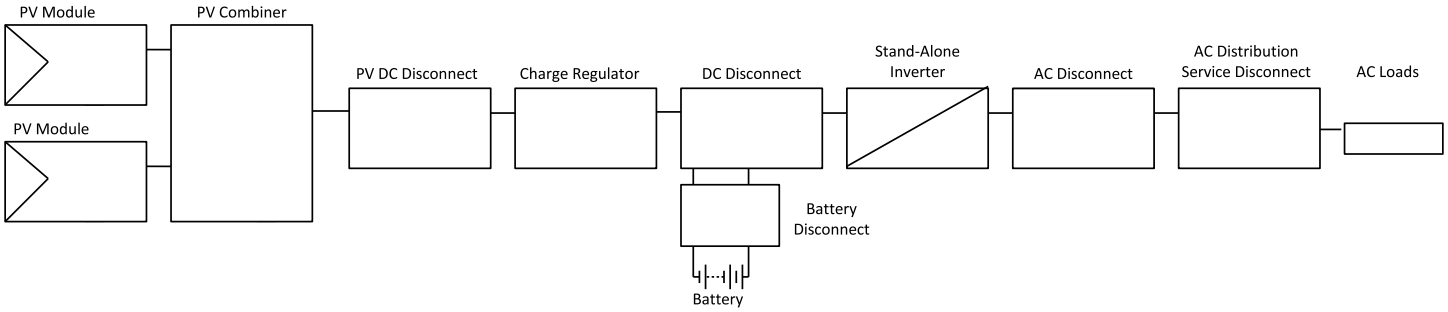


Figure 26—Stand-alone AC PV system
(image courtesy Reid Wylde Engineering Ltd. © 2012)

Some stand-alone power systems have both AC and DC loads. This may be done to conserve energy, since inverter losses are avoided and some DC equipment, such as motors, are more efficient than their AC equivalent. DC might also be used for critical loads such as refrigeration or lights.

Grid-connected solar PV systems

Utility-interactive PV systems synchronize with and supply power to the grid in addition to supplying loads on site. These systems may be operated by the utility, especially large-scale PV systems. More often, individual houses and other buildings in the grid are equipped with a PV system that feeds into the grid when excess power is generated and draws from the grid at night and in periods of low sunshine. These systems use the utility power grid as storage. Figure 27 shows a block diagram of a utility, interactive PV system.

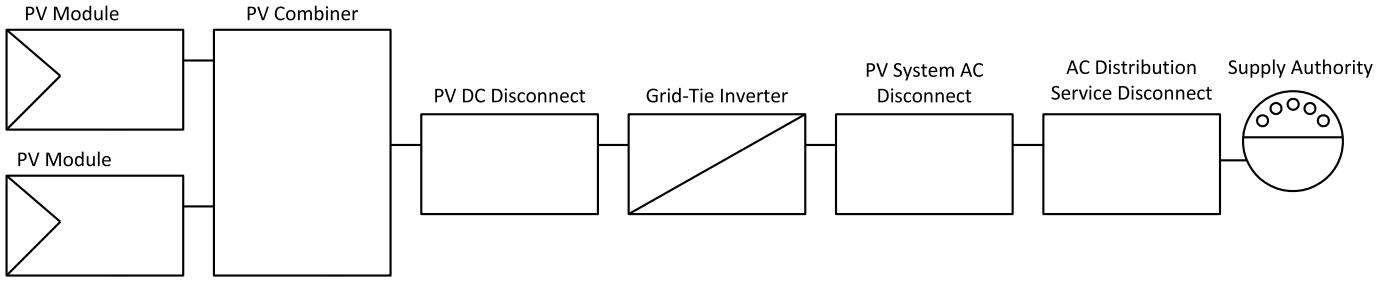


Figure 27—Utility-interactive grid-tie PV system
(image courtesy Reid Wylde Engineering Ltd. © 2012)

Utility-interactive solar PV power systems consist of an array of photovoltaic modules, an inverter, wiring and mounting structure and a means of connecting to the electric grid—typically by back-feeding the main service distribution panel. When the sun is shining, DC electricity from the photovoltaic modules is converted to AC by the inverter and fed into the

building power distribution system, where it supplies building loads. Any excess solar power is exported to the utility power grid and any shortfall is made up with grid electricity. During the night, building loads are supplied by utility power alone.

Smaller grid-tie solar photovoltaic systems may also use micro-inverters or AC modules. A *micro-inverter* is a grid-tie inverter that is designed to operate with only one or two solar modules. An *AC module* is a solar module with a mechanically integrated micro-inverter. These systems have the advantage that there are no DC circuits to install and the array can be any size, including a single module. Micro-inverters also allow maximum power point tracking of individual modules, which may improve performance in locations with where the array is intermittently in shade. Figure 28 shows a block diagram of a micro-inverter system.

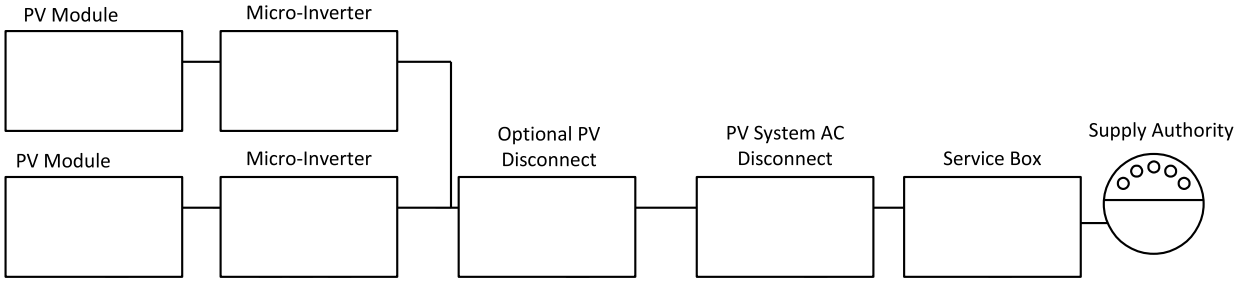


Figure 28—Grid-tie solar PV system with micro-inverters (image courtesy Reid Wylde Engineering Ltd. © 2012)

Stand-alone hydropower systems

Hydropower systems have the advantage that the rotational speed of the turbine is directly proportional to the pressure or *head* in the penstock. Since this pressure does not change, the rotational speed of the turbine and thus the frequency of the generator do not change. Hydropower system can be very simple. The simplest type of stand-alone hydropower system supplies 60 Hz AC power directly to the loads with a synchronous generator. A diversion load controller, which reacts to frequency changes, is used to maintain the frequency of the output by maintaining a constant load on the generator. Figure 29 shows a block diagram of a stand-alone hydropower system with diversion load control.

Hydropower is also used to generate DC power, which may be used for off-grid battery charging. As with wind turbines, a permanent-magnet alternator is used and the output is rectified to DC. A voltage source inverter is used to supply power to off-grid AC loads. Figure 30 shows an example of a battery charging system with a hydropower turbine. A diversion load controller is required to maintain a load on the alternator when the batteries are fully charged, but it is battery voltage that triggers the load controller.

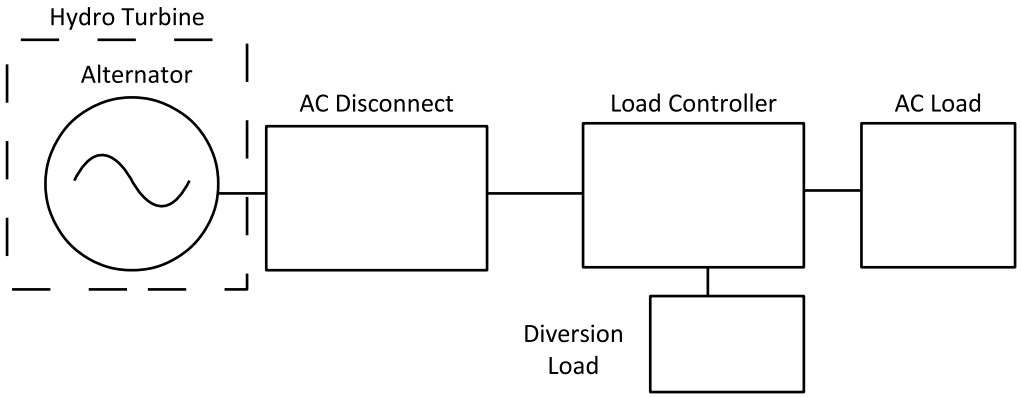


Figure 29—Stand-alone AC hydropower system
(image courtesy Reid Wylde Engineering Ltd. © 2012)

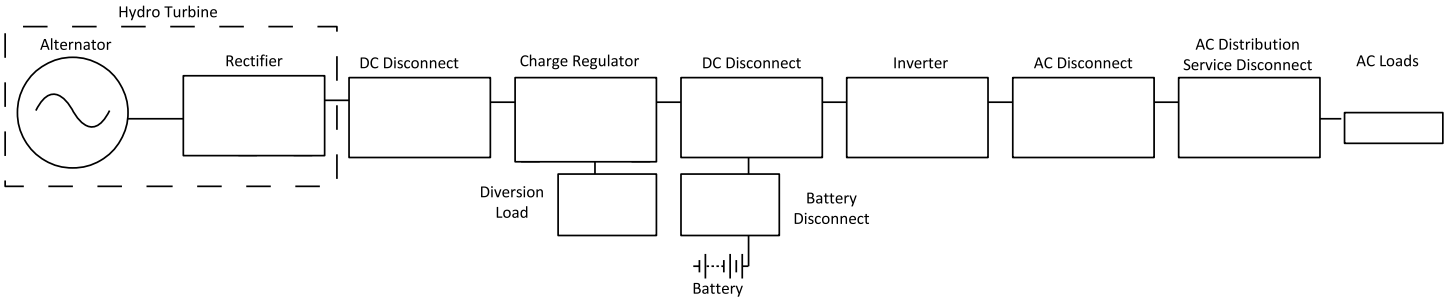


Figure 30—Stand-alone hydropower system for battery charging
(image courtesy Reid Wylde Engineering Ltd. © 2012)

Grid-tie hydropower systems

In grid-tie applications an induction generator is used to generate AC power. The induction generator synchronizes automatically with the electrical grid, and these types of systems have the least number of components. The supply authority requires additional protective equipment to prevent islanding and ensure the output of the system is within specified voltage and frequency limits, but no load governor is required as the utility grid maintains a constant load on the turbine. Figure 31 illustrates the configuration of a grid-tie hydropower system using an induction generator.

Some smaller grid-tie hydropower systems use a permanent-magnet alternator, and the output is rectified to DC. A current source inverter, like the ones used in wind power systems, is used to supply AC power. This is often a more cost-effective method of grid-tie, since the inverter has the required anti-islanding and protective functions built into it. Often provision must be made, such as the use of a diversion load, to ensure the generator does not operate in a no-load condition when the utility fails.

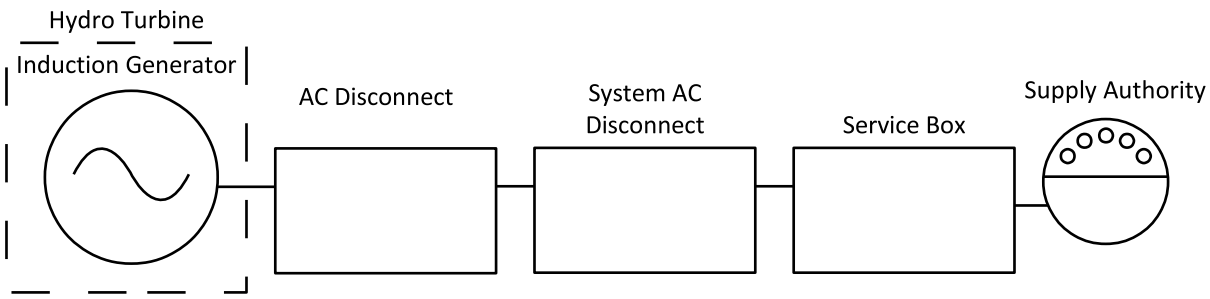


Figure 31—Grid-tie hydropower system with induction generator (image courtesy Reid Wylde Engineering Ltd. © 2012)

Now do Self-Test 1 and check your answers.

Self-Test 1

1. For each of the questions below indicate whether the system is a stand-alone system (SA) or a grid-tie system (GT).

   a. Energy storage to operate loads when the renewable power source is unavailable

      SA GT _____

   b. An inverter to synchronize with an external source of voltage and frequency

      SA GT _____

   c. An inverter that creates its own voltage and frequency

      SA GT _____

   d. A charge controller to avoid overcharging batteries

      SA GT _____

   e. An AC system disconnect to isolate the inverter output from the AC distribution system

      SA GT _____

2. In a stand-alone system Energy storage allows operation of loads whose power is greater than the output of the renewable power source.

   a. True

   b. False _____

3. A grid-tie power system is designed to supply power to the electrical grid whether utility power is available or not.

   a. True

   b. False

4. Refer to the image on the next page to answer this question. Fill in the blanks for each component in the list with the letter of the appropriate component from the drawings.

   Battery disconnect _____

   PV disconnect _____

   Load controller _____

   Stand-alone inverter _____

   Charge controller _____

   Combiner _____

   AC load distribution _____

   DC power distribution panel _____

   PV system AC disconnect _____

   Grid-tie inverter _____

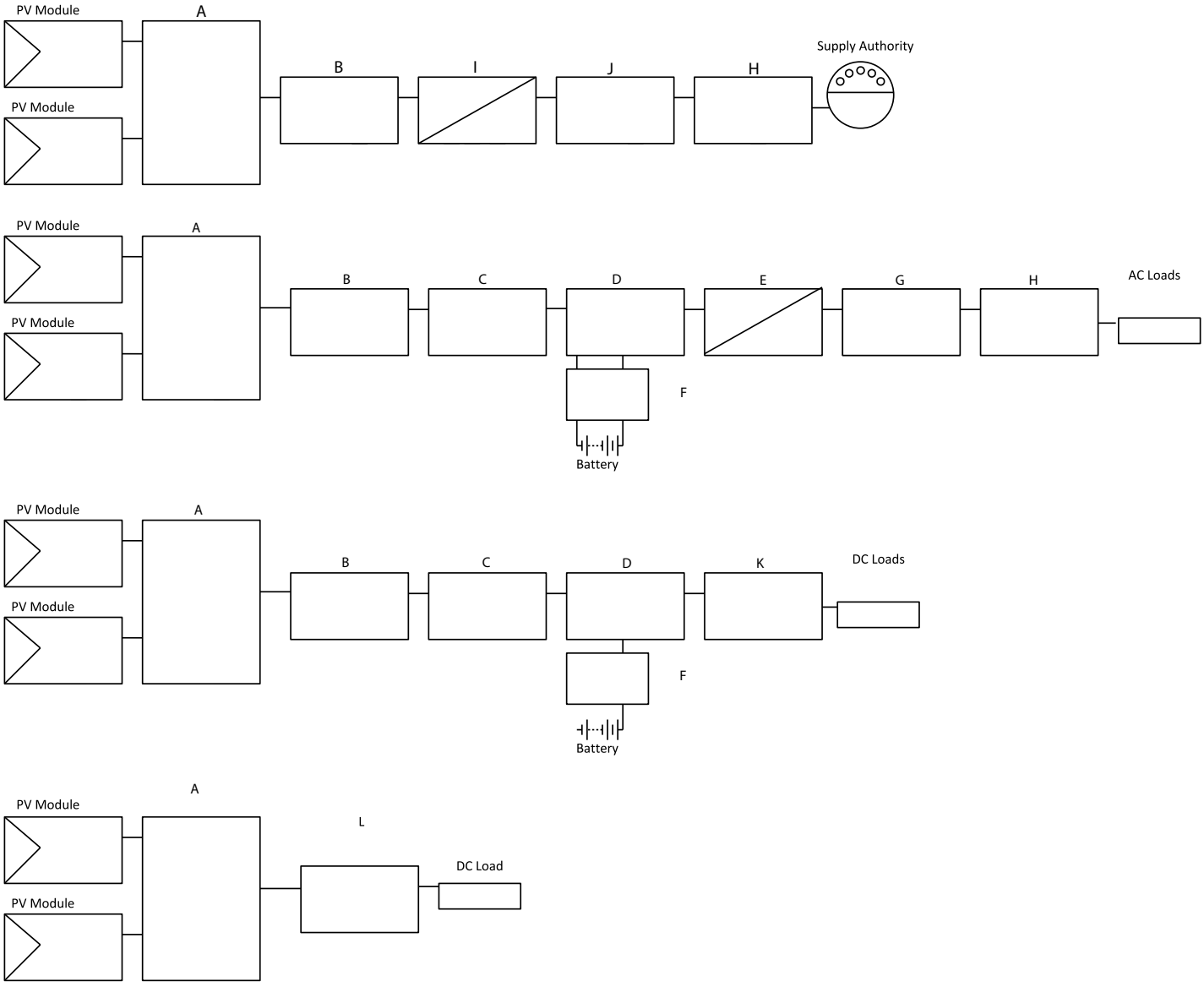


Image for question 4

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 2:

Install alternative power systems

Safety

Working safely with alternative power systems requires taking precautions to avoid electrical shock. High DC voltages are often present in solar photovoltaic systems, especially when several solar modules are connected in series. Photovoltaic systems may have DC open circuit voltages over 500 volts. The power levels in alternative power systems also create a significant arc-flash hazard. Appropriate protective gear must be worn when working on combiners and other enclosures that may contain live circuits.

Solar photovoltaic and wind turbine hazards

Good practice is to only make the final connections on series strings of solar PV modules once all the other wiring is complete and correct voltage and polarity have been verified. Photovoltaic source circuits can only be de-energized by placing an opaque covering over the array. Appendix B for Rule 64-060 states that an opaque covering is an acceptable means of disabling the array.

Wind turbines present an electrical hazard when turning. Installation should not be attempted when even moderate winds are present. Wind turbines can produce very high voltages when turning under no-load conditions. Whenever possible electrical connections for the wind turbine should be made before the turbine is raised on the tower.

Utility supplied AC in grid-tie systems presents hazards as well. Installers must be aware at all times that grid-tie systems have at least two sources of supply. Lock-out and tag-out procedures should be implemented before wiring is installed between the combiner boxes and the source (PV) disconnect at the inverter and before grid power is connected to the service meter.

Solar photovoltaic systems and wind turbines are often installed on roofs or elevated mounting structures where there is a significant fall hazard. Fall hazards are further compounded by the possibility of slips, trips and falls, as does exposure to hot or cold environments and potential injuries caused by lifting or moving heavy components.

A further hazard is also identified in *SPE-900-13—Solar photovoltaic rooftop-installation best practices guideline*, CSA Group, June 2013:

> *Solar photovoltaic modules and arrays require occasional maintenance and inspection to ensure that they are performing as intended. Maintenance and inspection personnel should note that the underside of solar arrays are ideal locations for wasp and bee nests. This can be particularly hazardous when working on a roof or ladder, where egress options are limited.*

CAUTION! NEARLY FULL VOLTAGE IS ALWAYS PRESENT AT THE TERMINALS OF A PV MODULE, EVEN AT LOW LIGHT LEVELS.

Workplace safety training for alternative power system installers should include:

- fundamentals of electrical hazards
- fall protection requirements and the use of fall protection equipment
- the safe handling, use and transport of materials
- the safe use of ladders
- hazards and controls while working on sloped roofing
- hazards and controls while working at the edge of the roof
- hazards and controls while working around covered skylights and roof openings
- pre-installation checks, emergency plan and first aid

Battery hazards

Batteries present their own special hazards. Unlike other electrical power sources, batteries can never be turned off. Although most batteries in alternative power systems are less than 50 V, they may still present a shock hazard. In addition arc-flash presents a serious hazard, as the available fault current at the battery terminals can be very high. Insulated tools are recommended for working within the battery enclosure.

Many batteries also present a chemical hazard. Lead-acid batteries contain sulphuric acid, which is highly corrosive. A neutralizing solution of baking soda mixed with water should be readily available, as should an eye wash station. Personal protective equipment for working with batteries includes eye protection and gloves.

PPE

Depending on work-site conditions, proper personal protective equipment for alternative power system installers may include:

- hard hat
- steel-toed boots
- eye protection
- gloves
- fall protection safety harness and lanyard
- hearing protection

In addition, if workers are involved in commissioning or performing maintenance on live systems, they may be required to use:

- arc-flash protection
- Insulated tools

PV combiner boxes, PV output circuit disconnects and battery disconnecting means are key locations where live circuits and arc-flash hazards may be present. Proper warning signs should be in place.

Procedures

Safety procedures for working with alternative power systems must take into account the presence of two or more power sources. Grid-tie systems have, at minimum, utility grid-supplied power and the alternative power-generating equipment itself. Stand-alone systems will often have batteries and will have one or more types of alternative power-generating equipment, such as wind turbines and solar photovoltaic modules.

Safe working procedures must include:

- Lock-out tag-out protocols that lock out all sources of supply.
- Polarity testing to ensure that DC circuits are not connected in reverse. Not only can reverse polarity cause equipment damage, but when DC circuits are connected in parallel, as in a solar combiner, a reverse polarity connection will create a hazardous situation because the voltage will be doubled at the connection. This is illustrated in Figure 1.
- Awareness of live circuits connected to equipment that cannot be turned off, such as batteries
- Ensuring that disconnect devices that are not load-break rated, such as attachment plugs and pull-out fuses, are not operated under load. NEVER disconnect a PV module connector under load. An electrical arc can occur.
- Using a current clamp meter to check for hazardous energy prior to working on photovoltaic circuits.

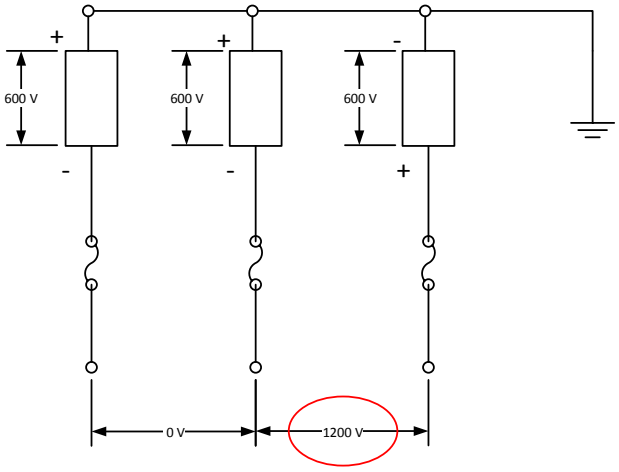


Figure 1—Hazardous voltage due to reverse polarity in a solar combiner (image courtesy Reid Wylde Engineering Ltd. © 2012)

Warning signs should be located at all disconnecting means where more than one source of power is present. These warning signs are required by Rules 64-060(10) and 64-112(4)(b)(i). Most power conditioning units have more than one source of supply as well. In order to ensure that disconnecting means and other devices are completely de-energized, maintenance personal must lock out the disconnect means for all sources that supply the device.

An additional hazard is present in ungrounded renewable energy power systems. These systems must have a ground fault protection system. However, the ground fault protection system is usually located at the charge regulator or inverter, and if the disconnecting means between the array and the ground fault protection system is open, a ground fault can be present with no warning or indication. Warning labels will be located at all junction boxes, disconnecting means and devices where ungrounded circuits can be accessed, as prescribed by Rule 64-066(1(c). Test continuity between ground and all ungrounded conductors before commencing service. There should be no continuity.

General work-site hazards

Other general hazards that are encountered at alternative power work sites include:

- working with ladders
- working in very hot weather

When working with ladders, proper lifting and carrying procedures should be developed and used in addition to the proper procedures for positioning, securing, climbing and working from ladders.

Overhead power lines present a particular hazard when working on roofs and positioning ladders. Be aware of this hazard and maintain required clearances. Do not use metal ladders.

The effects of hot weather are exacerbated when working on rooftops or in attic spaces. Hazards include burns, sunburns, dehydration, heat exhaustion, heatstroke and death. Be aware of the high temperatures of roof materials and other surfaces in the hot sun and wear appropriate clothing. This can include knee pads and gloves. Avoid heat exhaustion hazards by working during the cooler portion of the day. Develop proper hydration practices and be aware of the warning signs of heat exhaustion and heatstroke.

Selection and installation of components

Section 64 of the CEC governs the installation of alternative energy equipment. It is worth reading Rule 64-002, which contains the special terminology used in this section. The definition of photovoltaic module includes the application classes of photovoltaic modules. They are:

- Application Class A photovoltaic module—an unrestricted access module approved and marked for use in solar photovoltaic systems operating in excess of 50 V DC or in excess of 240 W
- Application Class B photovoltaic module—a restricted-access module approved and marked for use in solar photovoltaic systems where the module is inaccessible to the public
- Application Class C photovoltaic module—a limited-voltage, unrestricted-access module, approved and marked for use in photovoltaic systems operating at 50 V DC or less and 240 W or less

Overcurrent protection

Rules 64-058, 64-214, 64-308, 64-404, 64-506, 64-606 and 64-704 prescribe overcurrent protection for alternative power systems. Overcurrent protection must be provided to protect circuits from all electrical sources. Overcurrent devices such as breakers, if back-fed, must be suitable for the purpose.

Except for large wind systems, overcurrent protection is not required where the available short circuit current is not greater than the rated ampacity of the equipment. Special attention must be paid when multiple renewable energy sources are connected in parallel, such as in a solar array. The short circuit current of a solar module is so close to the operating current and frequently no overcurrent protection is required when only one or two photovoltaic source circuits are connected in parallel. This is described in Rule 64-214(1) and Appendix B. Additionally, overcurrent devices must be accessible and, when installed in photovoltaic source circuits, grouped together.

Small wind conductors

Rule 64-304 prescribes the ampacity and temperature rating of the conductors supplied by a small wind turbine. The ampacity of the conductors must be not less than the maximum rated current of the generator multiplied by 125%, and the conductors must be rated not less than 90°C.

The maximum rated current of the generator must be obtained from the manufacturer's specifications. Depending on the type of wind-generator, the output may be rectified DC, wild-frequency three-phase AC from a permanent-magnet alternator, or 60 Hz AC from a built-in inverter. In the latter case, the inverter specifications will state the continuous output current. Wind turbines without a built-in inverter will usually not state the maximum rated current in the specifications. There may be a nameplate on the turbine generator, but more often it will be necessary to calculate the current based on the maximum rated power output of the turbine and the lowest voltage it will be connected to, as in the equation below:

$$I_{max} = \frac{P_{max}}{V_{min}}$$

The output voltage of the generator in stand-alone systems will be determined by either the battery voltage, if an on/off controller or pulse-width modulated controller is used, or the minimum operating input voltage of the charge controller if a maximum power point tracking charge controller is used. Grid-connected systems will have a maximum power point tracking inverter with a minimum operating input voltage.

Example for Rule 64-304

A wind turbine rated 3.5 kW is connected to an MPPT inverter with a minimum input voltage of 200 V DC. The maximum rated current of the generator would be calculated as:

$$\frac{3500\ \text{W}}{200\ \text{V}} = 17.5\ \text{A}$$

The ampacity of the conductors from the generator to the inverter must be not less than:

$$17.5 \text{ A} \times 125\% = 21.875 \text{ A}$$

Rule 64-306 Wiring Methods prescribes the acceptable conductor types, methods of installation and methods of support for the conductors installed in or on the wind turbine tower. Rules 12-120, 12-100, 12-1010, 12-1114 and 12-1308 may also need to be referred to, depending on the type of installation.

Generally, conductors on the outside of a tower must be:

- in flexible or rigid conduit;
- mineral insulated cable; or
- armoured cable

Conductors on the inside of the tower may be:

- flexible cord suitable for extra-hard usage (e.g., SOW);
- armoured cable; or
- conductors suitable for raceways, if installed in a raceway

In all cases the conductors must be supported properly as described in Rule 12-120 and Table 21. Furthermore, Rules 12-1010, 12-1114 and 12-1308 describe methods of support for rigid and flexible metal conduit, rigid PVC conduit and liquid-tight flexible conduit, respectively.

Small wind disconnect

Rule 64-310 Disconnecting Means prescribes the type and location of the disconnecting means on the output of a small wind system. According to Rule 64-310(1), a disconnecting means shall be located on each load circuit of the wind turbine. There is an exception in Subrule (2) when the turbine output circuit is used to regulate the turbine speed. This exception is to avoid potentially hazardous situations when the output of the wind turbine requires a load to limit its speed and thus its voltage. In such a situation it is common to use a shorting switch to prevent the turbine from overspeed. Figure 2 illustrates the disconnecting means described by these rules. It is labelled *AC Disconnect* and is located next to the wind turbine.

When a disconnecting means is installed, Subrules 64-310(5) and (7) prescribe the location of the switch. If it is not located within sight of the base of the wind turbine, it must be capable of being locked in the open position. Furthermore, Subrule (8) states the switch shall be installed:

a. At a readily accessible location, either on or adjacent to the turbine tower;

b. On the outside of a building or structure or as close as practicable to the point of entrance of the system conductors; and

c. Not more than 9.0 m from the base of the turbine tower.

This rule is contradictory and most likely was intended to say "or" in Subrule (8)(b) rather than "and."

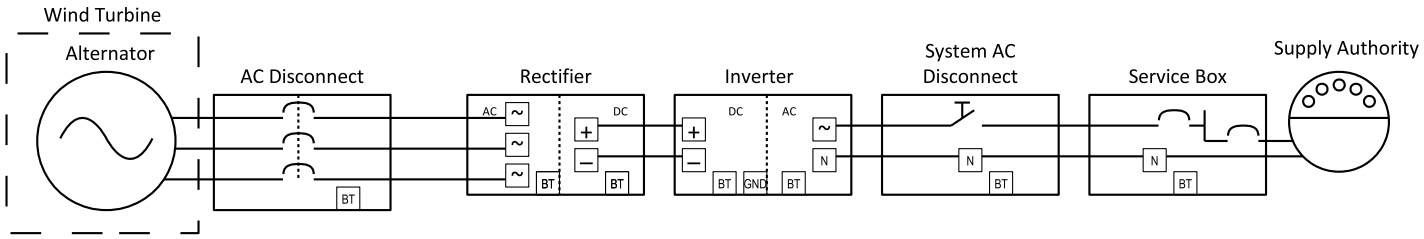


Figure 2—Location of disconnect in small wind system (image courtesy Reid Wylde Engineering Ltd. © 2012)

Rule 64-310(4) directs that the disconnecting means be in accordance with Rule 84-024. Although Section 84 is limited in scope to interconnected systems—and by inference the AC portion of an interconnected system—the provisions in this rule should be used to prescribe the disconnecting means in stand-alone systems and in systems where the output of the turbine is DC. Figure 3 shows a disconnect switch that meets the requirements of Rule 84-024 and is mounted on the outside of a building.



Figure 3—DC disconnecting means (image courtesy Eric Smiley 2014)

Large wind, micro-hydropower and hydrokinetic disconnect

Rules 64-406, 64-508 and 64-610 refer to large wind, micro-hydropower and hydro kinetic systems, respectively. They all prescribe the type and location of the disconnecting means for their respective systems. The disconnecting means shall comply with Rule 64-060 and be labelled in a conspicuous, legible and permanent manner as per Rule 64-074 Subrule (1).

PV source circuit series connections

Rules 64-210 Wiring Methods and 64-220 Attachment Plugs and Similar Wiring Devices prescribe the types of conductors, method of installation and method of connection of the series connections between solar modules. Figure 4 depicts an example of the attachment plugs used on solar module leads. These leads are supplied as part of the approved solar module and are the primary method of connecting solar modules in series. This is allowed by Rule 64-220(2), so long as the array either operates below 30 V or is not installed in a readily accessible location.



Figure 4—MC4 connector

Rule 64-210(1) allows for the use of flexible cords suitable for extra-hard usage (e.g., SOW) for interconnection of solar modules, but this is rarely done and is a provision originally intended to allow for more flexible conductors to be used in arrays mounted on movable trackers. Generally, conductors are selected in accordance with Rule 4-008(1) and would be selected from Table 19. Suitable conductors from Table 19 must meet the requirements of use.

Subrules (2) and (3) of Rule 64-210 provide exceptions to Rule 12-204 for open wiring. Solar modules are permitted to be interconnected with the conductors supplied as part of an approved solar module. Type RPVU may also be field installed for interconnection of modules. However, there are constraints on the use of these conductors. Rule 64-210(4) prescribes protecting the conductors from mechanical damage, supporting them within 300 mm of every box or connector and supporting them at intervals of not more than 1 m. Mechanical protection against damage from rodents also must be provided unless DC arc-fault protection is provided at the module.

PV source circuit home-run conductors

Type RPV and RPVU conductors were introduced in the 2012 Code and have restrictions on their method of installation. These conductors are typically used as "home-run" wiring in solar arrays going from the first and last modules in a series-connected string to the combiner or junction box. Section 64 of the Canadian Electrical Code defines these as *photovoltaic source circuit conductors*. They are connected to the leads on the solar modules with attachment plugs that comply with Rule 64-220. Type RPVU conductors are permitted so long as they are mechanically protected where subject to damage, are serviced only by qualified personnel and are inaccessible to the public. The note to Rule 64-210 in Appendix B clarifies that wire screening, elevation or fencing is an acceptable method of rendering the circuits not readily accessible.

Installation	RPV	RPVU
Raceway (except cable tray) in dry/damp location	Table 19	Table 19 (note 5)
Raceway (except cable tray) in wet location	Table 19	Table 19
Inside building or structure in a raceway	64-210(9)	64-210(9)
Cable tray for interconnection of PV system	Only if marked (TC) or equivalent	64-210(6)
Exposed to weather for interconnection of modules within an array without raceway*	-	64-210(3)
Direct Earth burial	-	Table 19

*Provided conductors are mechanically protected, serviced by a qualified person, and inaccessible to the public

Figure 5—Conditions of use for RPV and RPVU conductors

Conductors used in photovoltaic source and output circuits shall be marked or colour-coded according to Rule 64-212. There either must be permanent surface markings on the conductors or the conductors must be coloured red for positive and black for negative. It is worth noting that this is notwithstanding Rule 4-038, which would require the identified (grounded) conductor in a grounded system to be white.

Photovoltaic combiner and overcurrent protection

Combiners, aside from providing a point for the connection of solar modules in parallel, are where overcurrent protection for the photovoltaic source circuits are usually located, when required. Overcurrent protection is not required where the sum of the available short circuit current from all photovoltaic source circuits is not greater than the ampacity of the apparatus or conductors. If there is no possible back-feed of current from the battery, inverter or charge controller, the maximum available short circuit current, $I_{sc\text{-}max}$, is calculated by using the "n – 1" rule, where n is the number of parallel solar photovoltaic source circuits (series strings) connected to the combiner and I_{sc} is the short circuit current of the solar modules in the series string. The rule is explained in Rule 64-214(1) and can be described by the equation:

$$I_{sc\text{-}max} = (n-1) \times I_{sc}$$

Example

A combiner has three strings of solar modules with a short circuit current of 9.45 A. The maximum available short circuit current is:

$$I_{sc\text{-}max} = (3-1) \times 9.45\ A = 18.9\ A$$

This value must be compared to the maximum series fuse size of the photovoltaic modules, which is essentially the ampacity of the conductors within the modules. It must also be compared to the ampacity of the conductors in the photovoltaic source circuit—the home run wiring and the leads on the modules.

If the modules have a maximum series fuse size of 15 A and 12 AWG leads, overcurrent protection would still be required in the combiner, since 18.9 A exceeds the 15 A "ampacity" of the solar module.

Even when overcurrent protection is not required, Rule 60-060 requires a disconnecting means for the photovoltaic modules, and if quick-connect devices, as described in 64-020, are not used on the photovoltaic source circuits, the combiner would be the location of the photovoltaic source circuit disconnecting means. Furthermore, when a combiner is used, a single disconnecting means is required for the photovoltaic output circuit that is either integral with the combiner or within 2 m of the combiner.

PV output circuit conductors

The DC conductors from the combiner to the main photovoltaic disconnect must be selected to handle the continuous load on that circuit. The continuous load is calculated according to Rule 64-206(b). Note that although the 2015 Electrical Code no longer stipulates that the load on a photovoltaic source or output circuit is continuous, it is industry practice to treat such currents as continuous.

$$I_{continuous} = I_{sc} \times 125\%$$

The conductors in the PV output circuit will usually be in cable or a raceway, and the gauge of wire is determined from Table 2 or 4. In addition, the PV output circuit is often located on a roof, so it may be exposed to temperatures greater than 30°C and de-rating factors from Table 5A must be applied. It is not unusual for the conductors to reach 50°C or even 60°C if exposed to direct sunlight above a black roof surface. The temperature rating of the terminals in the combiner, or other devices to which the PV output circuit conductors are connected, must also be taken into account, as per Rule 4-006, and the appropriate column from Table 2 or 4 must be used when selecting the wire gauge.

Example

The PV output circuit of a combiner carries the current from three strings of solar modules with a short circuit current of 9.45 A. The continuous load on the circuit is:

$$I_{continuous} = (3 \times 9.45\ A) \times 125\% = 35.44\ A$$

The combiner terminals are rated 90°C but the lugs in the PV disconnect are only rated 75°C.

Therefore, assuming no more than three 90°C copper conductors in a raceway comprise the circuit and it is exposed to 50°C ambient temperatures, Table 5A prescribes a 0.82 correction factor (CfT), and thus Table 2 requires a minimum 8 AWG conductor to be selected:

$$I_{ampacity} = \frac{I_{continuous}}{CfT} = \frac{35.44\ A}{0.82} = 43.2\ A$$

Once the conductor size is selected it must be evaluated against the overcurrent protection provided in the PV disconnect if fault current is available from other sources such as batteries or parallel photovoltaic arrays.

If the PV output circuit conductors are installed inside a building, they must be contained in a metallic raceway, metal enclosures or cables with metal armour or metal sheaths from the point of penetration to the first readily available accessible disconnecting means, as described in Rule 64-062(2). Rule 64-210(9) also applies if type RPV or RPVU conductors are used.

PV output circuit disconnect

In addition to disconnecting means located at the combiner, Rule 64-060(4) requires a disconnecting means to disconnect the power conditioning unit downstream from the solar array, which may be a charge controller or inverter. It is standard practice to install a disconnecting means near the inverter or charge controller to facilitate maintenance and service. Since inverters and charge controllers are supplied from more than one source, Rules 14-414 and 14-700 apply and this requires a disconnecting means adjacent to the inverter or charge controller. Both disconnects must be selected to handle the continuous load available from the photovoltaic source circuit as calculated above, as well as being rated for the voltage of the circuit.

Example

Continuing the last example: a 60 A heavy duty disconnect must be selected (general duty disconnects are not typically rated for DC) and the next smallest size, 30 A, is too small. If overcurrent protection is required, the overcurrent protection must be selected according to Rule 8-104 using the continuous load. The heavy duty disconnect is only 80% rated if it is fused. Therefore:

$$I_{minimum\ fuse} = \frac{I_{continuous}}{0.80} = \frac{35.44\ A}{0.80} = 44.3\ A$$

So a 50 A fuse may be used in a 60 A heavy duty disconnect. Now compare the PV output circuit conductor size to the overcurrent protection to check if 8 AWG at 50°C is still sufficient.

Application of Rule 64-060 to this disconnect is ambiguous and the local authority should be consulted to determine if this disconnect must comply with Rule 84-024. It is not obvious that the rules in Section 84, which address interconnection with the utility grid, should be applied to the DC circuits of a photovoltaic array.

Rule 64-218 prescribes further system protection in the form of a rapid shutdown device that limits the photovoltaic source or output circuits to not more than 30 V and 240 VA, within

10 seconds. This device must be provided on buildings or structures where the photovoltaic source or output circuit conductors installed on or in buildings are more than 1.5 m in length or more than 3 m from the photovoltaic array.

PCU disconnect

The input and output of an inverter or charge controller must have a disconnecting means, according to Rule 64-060(4). Furthermore, since most power conditioning units are connected to more than one supply source, the disconnecting means on the input and the output must be grouped as per Rule 14-414 and a warning sign must be placed on or adjacent to the disconnecting means so that all disconnecting means are opened to ensure complete de-energization of the inverter or charge controller.

There are limitations on grouping the disconnecting means on many power conditioning units because the voltages at the input and output may be very different. An example is a charge controller that accepts DC input from the solar array with a maximum voltage of 600 V DC and has a nominal output voltage of 48 V DC. It may not be practical to locate the disconnecting means for these in the same enclosure, but they would have to be located in close proximity and labelled appropriately. Figure 6 illustrates the location of the DC and AC disconnects for the charge regulator and inverter in a stand-alone system. Note that the DC disconnect in the middle has three potential sources of supply: the output of the charge regulator, the battery and the inverter, which may have battery-charging capability.

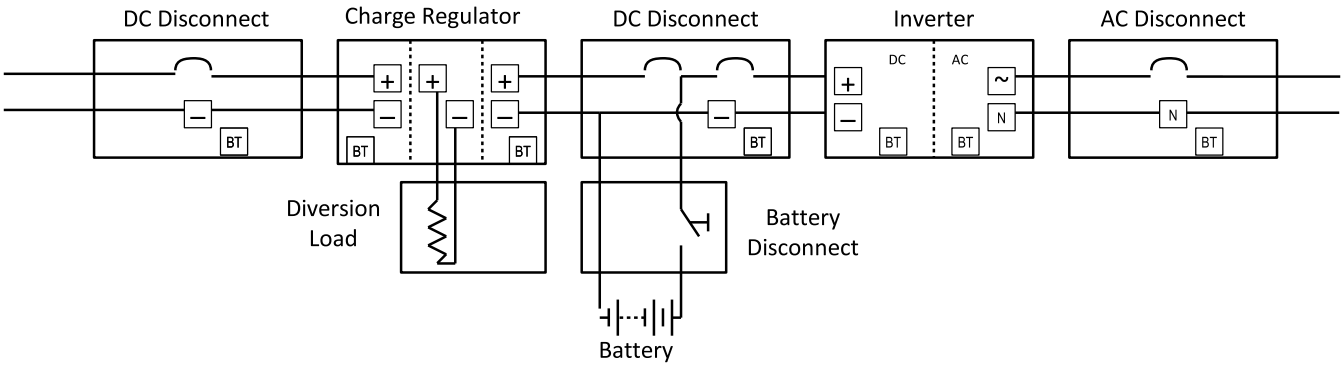


Figure 6—Location of disconnects for PCU and battery in a stand-alone system (image courtesy Reid Wylde Engineering Ltd. © 2012)

Battery disconnect

As with the PCU, a disconnecting means is required for the battery, in accordance with Rule 64-060(4). An overcurrent device is also required in the conductors connected to the battery, in accordance with Rule 64-802, and this overcurrent device would require a disconnecting means that isolated it from all sources of supply, as per Rule 14-402. This means a disconnecting means is required on the supply from the battery and the supply from the power conditioning unit. A touch-safe fuse holder or a pull-out fused disconnect is one method of complying with this requirement. The location of the battery disconnect can be seen in Figure 6.

Battery interconnections

According Rule 64-810, flexible cables may be installed between batteries and from the battery enclosure to a nearby junction box. The cables must be suitable for hard service and be moisture resistant. Such cables can be identified in Table 11. There are a series of footnotes to Table 11 that make it confusing as to which cables might be used. Single-conductor cables are necessarily used for battery interconnections, and DLO and PPC are often chosen. It would appear that cables with the designation DLO (diesel locomotive cable) are acceptable, but footnote 13 implies that PPC is only for temporary installations and it is not clear that Rule 64-810 takes precedence over the footnote. The ampacity for these cables is referenced in Table 12A.

The note for Rule 64-810 in Appendix B specifically excludes welding cable for this application.

PCU to battery conductors

The conductors between the battery and the power conditioning unit must be approved for the conditions of use. Generally these conductors run in a raceway and must be selected from Table 19. Often extra-flexible conductors are preferred for connection to the battery terminals, and there are finely stranded conductors that are marked RW90 or R90. Often these are dual-rated cables that are also marked DLO and can be used as the battery interconnects.

The continuous load on the battery conductors is calculated from the continuous power output of the inverter, $P_{inverter}$, the efficiency of the inverter at full power, $\eta_{inverter}$ and the lowest battery voltage $V_{battery\text{-}min}$.

$$I_{continuous} = \frac{P_{inverter}}{\eta_{inverter} \times V_{battery\text{-}min}}$$

Example

An inverter rated 6000 watts continuous has an efficiency of 90% at that power and will operate at a minimum battery voltage of 44 V on a nominal 48 volt battery.

$$I_{continuous} = \frac{6000\ W}{0.90 \times 44\ V} = 151\ A$$

The disconnecting means, overcurrent device and conductors between the battery and inverter must all be sized based on this continuous load. If the overcurrent device is 80% rated, this would require a 200 A fuse and a 200 A disconnect. The battery interconnects, if chosen from Table 11, would be 1 AWG or greater based on Table 12A. The conductors to the inverter, if copper, run in a raceway and chosen from Table 19, would be 3/0 or greater.

Equipment bonding

The exposed, non-current-carrying metal parts of alternative power systems must be bonded to ground, regardless of system voltage and system grounding method. This includes the solar module frames, solar module racking structure, wind turbine nacelle, wind turbine tower, micro-hydro turbine enclosure and any other metallic fittings, enclosures or parts. Rules 10-400, 10-402, 64-312, 64-408 and 64-512 address this requirement. Section 10 provides specific rules as to proper equipment bonding methods.

In many cases a 6 AWG copper conductor is used for equipment bonding in these systems due to the equipment bonding conductors not being installed in the same manner as the circuit conductors. Rule 60-070 addresses the need for equipment bonding methods to be done in such a way that removal of the equipment does not interrupt bonding continuity. This is re-iterated in Rule 64-222 for solar modules, which can often be removed from a solar array without causing the array to be shut down. Lay-in lugs, as shown in Figure 7, are often used so that a continuous bonding conductor can be attached to the equipment or solar modules that may be removed during servicing.

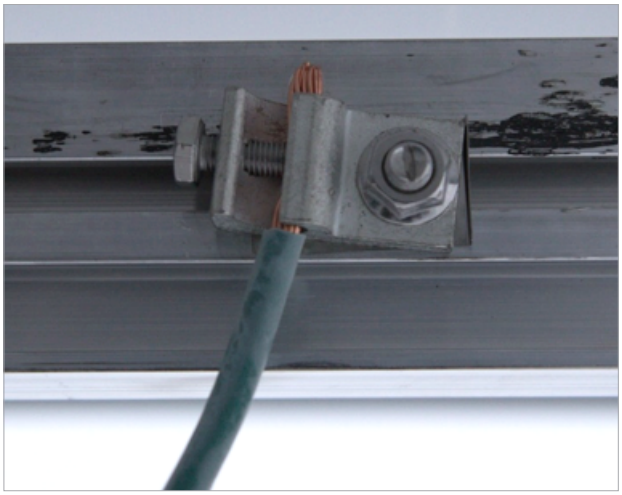


Figure 7—Lay-in lug attached to module racking
(image courtesy Reid Wylde Engineering Ltd. © 2014)

Another method of bonding solar modules is to use a special washer on the mechanical connections of the solar modules. These washers provide continuity between the solar module frame and the racking structure and eliminate the need for a bonding conductor connected to each solar module. Figure 8 shows an example of such a bonding washer between two solar modules.

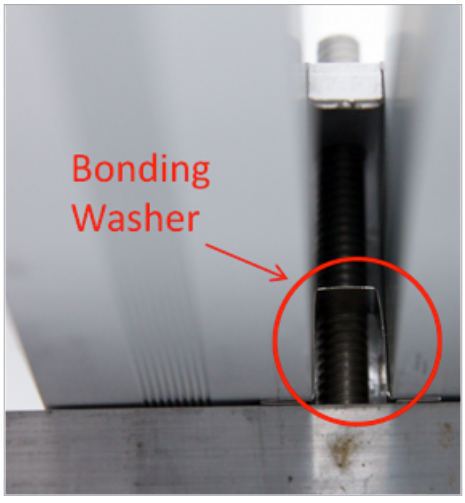


Figure 8—Bonding washer installed on a solar array
(images courtesy Reid Wylde Engineering Ltd. © 2014)

System grounding

Solar photovoltaic systems and alternative power systems may be grounded or ungrounded (see Rules 64-056, 64-064, 64-066, 64-068, 64-312 and 10-810). As with any power system, system grounding must occur in only one place. Ungrounded systems must meet additional requirements, including but not limited to:

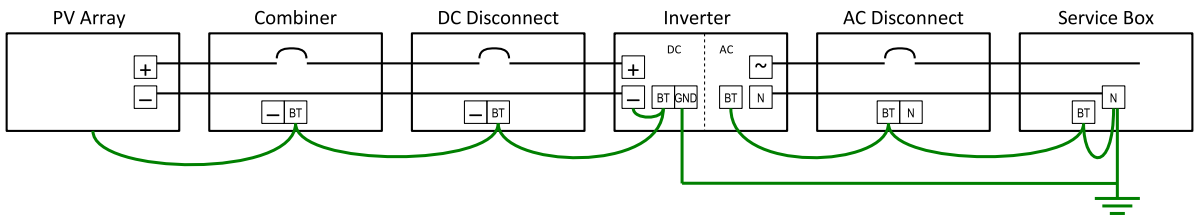
- Overcurrent protection is required on all circuit conductors.
- All source supply circuits must be protected in metallic sheathed cable or a metallic raceway.
- A ground fault protection device must be installed.
- Suitable warning labels must be placed wherever ungrounded circuits can be exposed during service.

DC supply circuits in both grounded and ungrounded systems are required to have a ground fault protection device or system as prescribed by Rules 64-064(4) and 64-066(1)(e). Most grid-tie inverters and many charge controllers have this capability built into them.

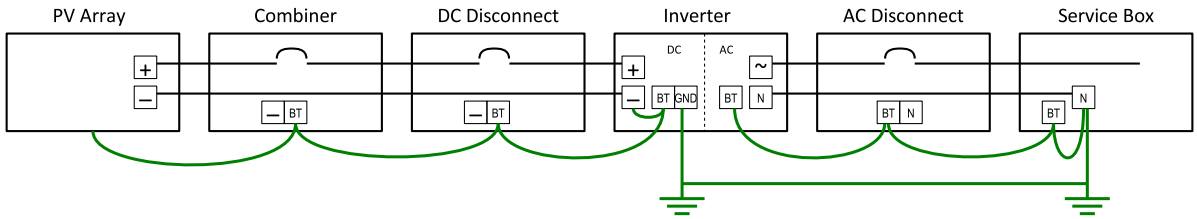
Grounding conductor

Rule 60-068 and Appendix B describe three alternative methods of providing proper connection to the grounding conductor. These methods are illustrated in Figure 9. The top figure shows a separate grounding conductor for the DC side of the system from the inverter to the grounding electrode. The grounding electrode is a shared with both the DC and AC sides of the systems as well as the equipment bonding system as per Rule 60-068(a). The middle figure shows a separate grounding electrode installed as per Rule 64-068(b) with a 6 AWG conductor joining the two ground electrodes as per Rule 10-702. The bottom figure shows a combined DC grounding conductor and AC equipment bonding conductor, which is allowed by Rule 64-068(c). It must be un-spliced from the inverter to the grounding electrode as per Rule 10-806. Often a bonding bridge, as shown in Figure 10, with a lay-in lug is installed outside the service box to allow the un-spliced conductor to pass through and provide a place for the neutral of the AC system to be bonded to ground.

a)



b)



c)

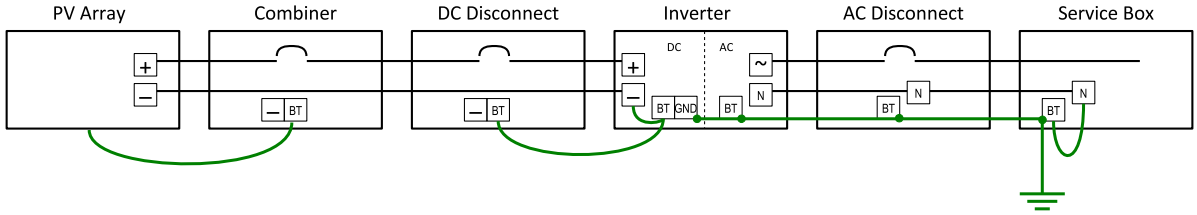


Figure 9—Grounding conductor configurations
(image courtesy Reid Wylde Engineering Ltd. © 2012)



Figure 10—Example of a bonding or grounding bridge
(copyright Arlington Industries http://www.aifittings.com)

Location for maximum efficiency

Locating solar modules and wind turbines for optimal performance is relatively easy. If there is sufficient wind in a particular geographic location, wind turbines should be located at least 10 metres above any obstacles within 100 metres in the prevailing wind direction (Figure 11). In addition, if located on a hill, they should not be installed on the slope of the hill but at the top, or if that isn't possible, at the bottom. In addition, it is inadvisable to install wind turbines on buildings. Not only is there turbulence around buildings, which impacts performance, but wind turbines vibrate and that vibration will pass into the building, disturbing the occupants.

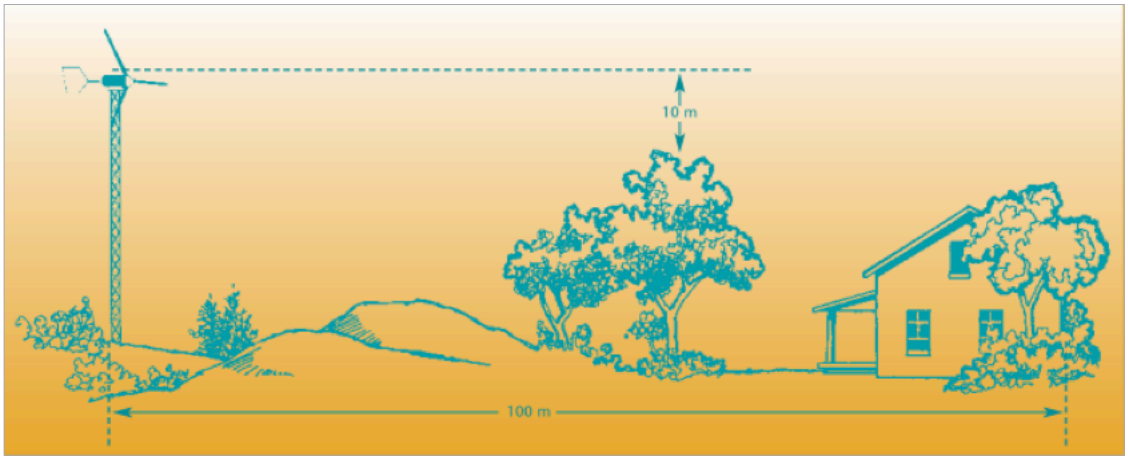


Figure 11—Wind turbine location

Solar modules, on the other hand, are often installed on buildings since using the readily available mounting surface of the roof can reduce installation costs. Solar modules require direct sunlight to operate effectively, so shadows from trees, other building, chimneys and ventilating pipes on roofs should be avoided. Generally, solar modules should have, at minimum, an unobstructed view of the sun from about 9 a.m. to 3 p.m. Figure 12 shows an example of a shading analysis. The path of the sun is shown as horizontal arcs passing from one side of the page to the other. Shadows created by objects on the horizon block the sunlight at different times of the day.

Any unavoidable shadows from nearby objects such as chimneys or power poles must be evaluated on a case-by-case basis and alternative array layouts or wiring configurations may be employed to mitigate the performance impact.

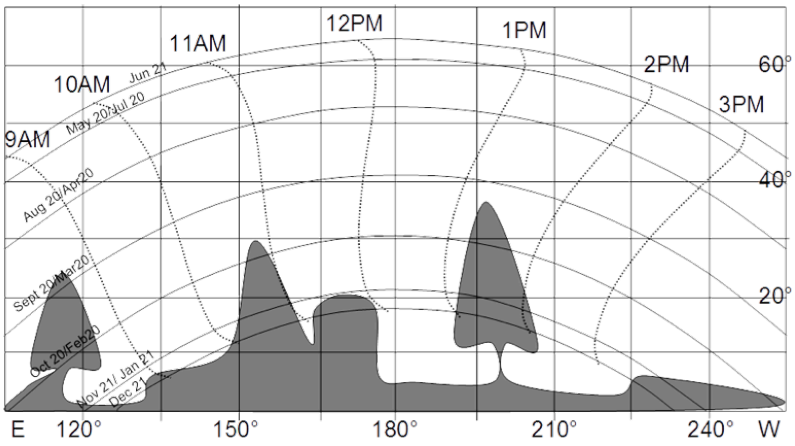


Figure 12—Example of a shading analysis
(image courtesy Reid Wylde Engineering Ltd. © 2012)

The location of hydro turbines and the design of those systems is a much more complex topic and not really within the scope of work of an electrician. Similarly, heavy-duty mechanics generally take responsibility for installation of thermal power plants.

Additional code requirements

Signage

Rule 64-200 requires a permanent marking at the disconnecting means for the photovoltaic output circuit. Figure 13 shows an example of the sign to be placed on the photovoltaic disconnecting means. In addition to specifying the rated operating voltage and current and the rated short circuit current, which are readily obtained from the solar PV module nameplate and either multiplying by the number of modules in series to obtain voltage or the number of modules in parallel to obtain current, this rule requires a calculation of the maximum photovoltaic source circuit voltage, as per Rule 64-202, using either:

- the open circuit voltage, V_{OC}, multiplied by 125%; or
- a calculated voltage, V_{MPC}, based on the lowest expected daily minimum temperature, T_M, and the voltage-temperature coefficient of the PV module, T_K.

This latter calculation is described in appendix B as:

$$V_{MPC} = V_{OC} \times \left(1 + \left(T_M - 25°C\right) \times T_K\right)$$

A warning sign for a photovoltaic system must be in capital letters with a minimum height of 9.5 mm, in white on a red background.

Example

Ten modules with a rated open circuit voltage of 42.0 volts are installed in a location with an extreme minimum temperature, as obtained from the Canadian Climate Normals database, of –12°C. The module has a voltage temperature coefficient of –0.36%/°C.

$$V_{MPC} = 10 \times 42.0\ V \times \left(1 + \left(-10°C - 25°C\right) \times -0.0036\right) = 473\ V$$

This is considerably lower than what would be obtained by simply multiplying by 125%, which would give 525 V. Many system designers prefer using the calculation approach from Appendix B because it allows them to configure the array with more solar modules in series without exceeding the voltage limits of the equipment as described in Rule 64-202(3).

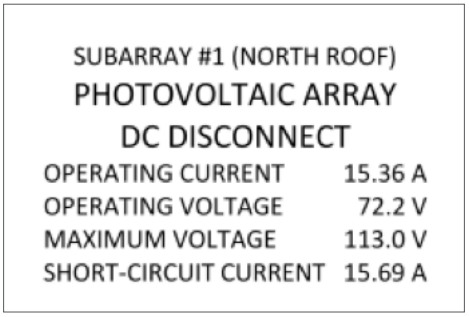


Figure 13—Example of the label affixed to the PV output circuit disconnect (image courtesy Reid Wylde Engineering Ltd. © 2014)

Further signage, warning labels and plaques are required by Rules 64-060(10), 64-072, 64-074, 64-104(c), 64-102(c)(iv), 64-112(4)(b)(i) and 84-030(2). Figure 14 illustrates some of the signs and labels required for a grid-tie system.

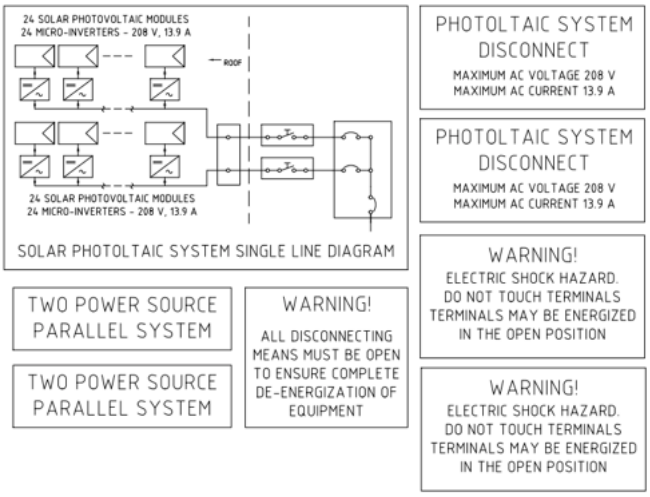


Figure 14—Example of the labels and plaques required for a grid-tie system using micro-inverters (image courtesy Reid Wylde Engineering Ltd. © 2014)

Rules 64-310, 64-406, 64-508 and 64-610 require a label at the disconnecting means for small wind, large wind, micro-hydropower and hydrokinetic systems indicating that it is the means of disconnect for the system. Appendix B provides examples of the wording on such labels, such as, "WIND TURBINE GENERATOR SYSTEM DISCONNECT SWITCH."

Rules 64-300, 64-400, 64-500 and 64-600 prescribe a label that describes the system either at the base of the wind turbine tower or at the system disconnect switch and, in the case of a wind turbine, the overcurrent protection ratings.

Supply authority

BC Hydro has an interconnection standard for alternative power systems less than 100 kW entitled *Distributed Generation Technical Interconnection Requirements 100 kW and Below (DGTIR-100)*. This standard is for distribution-connected customers to connect a small energy source to the BC Hydro distribution system to offset their load and participate in the net metering program (RS1289) or other energy procurement offers.

BC Hydro distinguishes between simple and complex interconnected systems. A simple distributed generator (DG) system shall meet all of the following:

- be an inverter-based system installed in accordance with Canadian Electrical Code (CEC) Part I and certified to the requirements of CSA C22.2 No. 107.1-01 for utility interconnection; and
- have an aggregate nameplate rating of 27 kW or less (30 kVA at 0.9 power factor) at the point of common coupling (or point of delivery); and
- have self-contained revenue metering (services 200 A or less, and not 600 V, 3-phase, 3-wire, Delta services).

Simple systems can often be completed by an electrical contractor with only proof of an electrical inspection required by BC Hydro. Complex interconnected systems are reviewed in more depth by BC Hydro and may require design by an electrical engineer.

Systems larger than 100 kW must comply with BC Hydro's standard, *35 kV and Below Interconnection Requirements for Power Generators*.

Mounting components

Solar module support structure

The structures that support solar modules are designed to support the weight of the solar modules and to withstand wind and snow loads on those modules. When the mounting structure is located on a roof it may be necessary to evaluate the ability of the roof to support those same loads. However, often when a solar photovoltaic array is mounted parallel to the roof surface and no more than 100 mm from the roof surface according to the mounting structure manufacturer's directions, the installation of the array is unlikely to generate or transmit any loads greater than those for which the roof was originally designed. Under such circumstances the installer may only be responsible for ensuring:

- The attachments are secured to structural members in the roof;
- The attachments do not create a pathway for water to enter the roof; and
- The solar modules are secured properly to the mounting structure.

Nonetheless, the installer should consult an appropriate design professional if unsure of the structural requirements of the solar module support structure. If the mounting structure is tilted, greater wind or snow loads may be created on the roof and a design professional must be consulted.

Wind turbine towers

Wind turbine towers should be installed by qualified personnel. Skills in rigging are often required, and the footings and anchors must be designed to withstand considerable forces. Small wind turbines can be installed on tilt-up towers with winches and hand tools. Larger wind turbines may require a crane.

Combiners

Combiners are often mounted on roofs and must be appropriate for installation in wet conditions. Rain-tight connectors must be used for all wires and cables entering the combiner. In addition, it is important to verify suitable mounting orientations for the combiner. In order to maintain their rain-proof rating many combiners must be installed vertically.

Power conditioning unit (PCU)

Charge controllers, diversion load controllers and stand-alone inverters are usually only intended to be installed in dry locations. As with any other piece of electrical equipment they must be securely attached to the surface on which they are installed. Stand-alone inverters are often quite heavy; some weigh over 50 kg. If they are to be mounted on a wall, it may be necessary to reinforce the wall before mounting the inverter.

Many utility interactive inverters are designed for outdoor installation and are generally lighter than stand-alone inverters. However, depending on the geographic location, outdoor temperatures may be lower than the specifications for the inverter allow. Some inverters are rated to –40°C, while others are only rated to –25°C.

Grid connection

Rule 64-112 prescribes a supply-side grid interconnection. Figure 15 shows a connection to the supply side of the service with the disconnecting means required by Rule 84-024 supplying a dual lug meter base. Other points where a supply-side connection may be made are at a splice in the feeder or on the main lugs of the distribution panel if dual lugs are present. A tap connection on the supply conductors may be made if there is sufficient space, or if the panel has dual lugs on the main disconnect, the connection may be made there. In many cases a splitter must be installed between the meter and the distribution panel because there is insufficient room for the wiring and connections, as shown in Figure 16. However, supply-side connections are usually only required on very large alternative power installations, which are more common in commercial and industrial situations where the main service already incorporates a splitter.

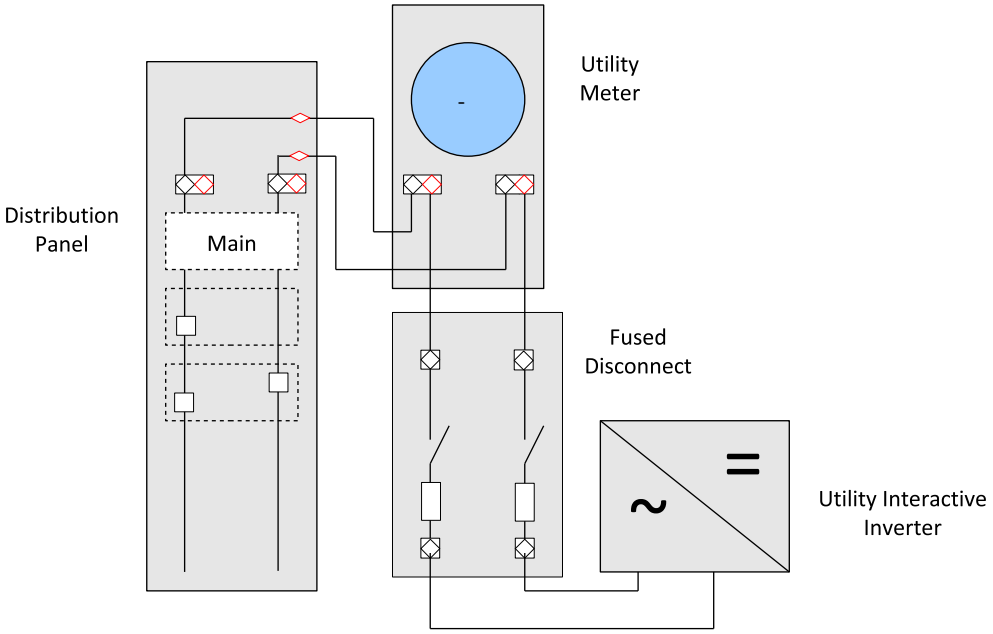


Figure 15—Supply-side connection to a dual lug in the meter base before the main disconnect in the distribution panel (image courtesy Reid Wylde Engineering Ltd. © 2012)

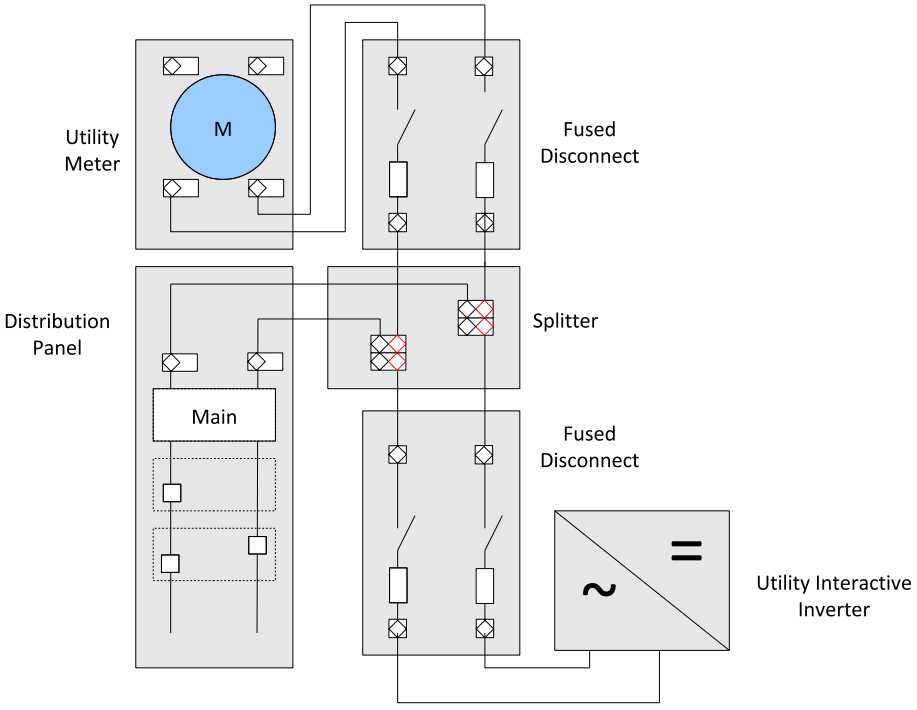


Figure 16—Supply-side connection to a splitter before the main disconnect in the distribution panel (image courtesy Reid Wylde Engineering Ltd. © 2012)

Load-side connection are permitted, as per Rule 64-112(2). A load-side connection is shown in Figure 17. In this case a breaker in the distribution panel is supplied by the disconnecting means required by Rule 84-024. Rule 64-114(3) sets out the manner by which a load-side connection may be made. If the dedicated breaker supplied by the alternative power system is located at the opposite end of the busbar, as required by Rule 64-114(3)(b)(ii), the sum of the ampere ratings of the overcurrent devices supplying power to the busbar are permitted to exceed the busbar rating.

If the panel supplies a dwelling, the sum of the overcurrent devices may be a maximum of 125% of the busbar ratings, otherwise they may be no greater than 120% of the busbar rating.

Example 1

A 200 A main panel in a dwelling is permitted to be supplied by a maximum of:

$$I_{max} = 200\ A \times 125\% = 250\ A$$

If the main breaker is 200 A, the breaker connected to the alternative power system may be a maximum of 50 A. If that breaker is 80% rated, then the maximum output from the alternative power system would be 40 A.

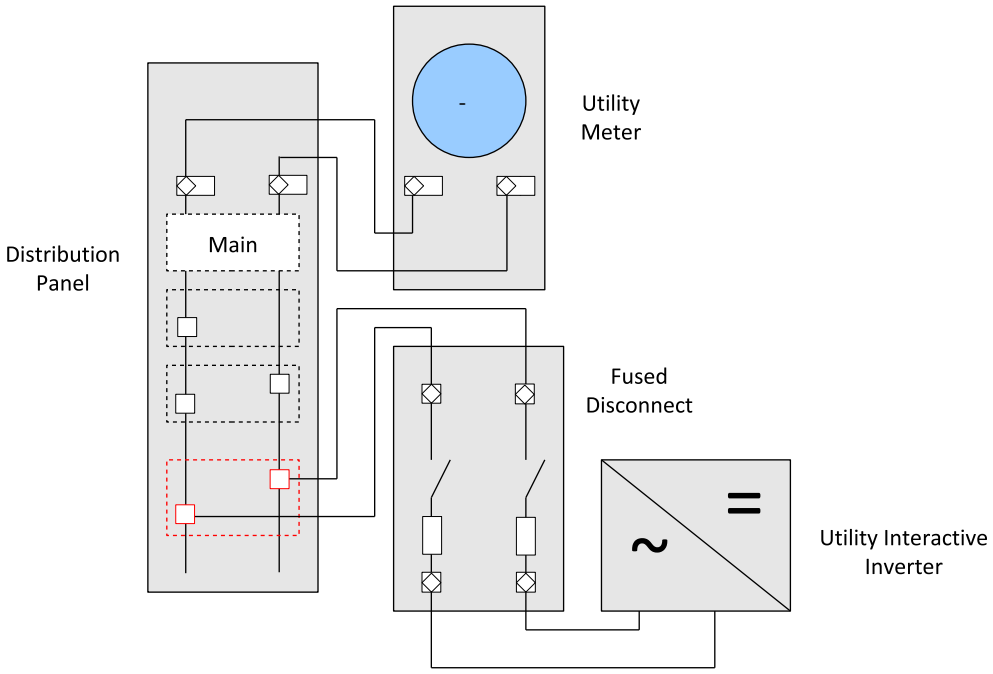


Figure 17—Load-side connection to a back-fed breaker in the distribution panel (image courtesy Reid Wylde Engineering Ltd. © 2012)

Example 2

A 125 A panel in a commercial building is permitted to be supplied by a maximum of:

$$I_{max} = 125\ A \times 120\% = 150\ A$$

If the breaker supplying the panel is rated 100 A, the breaker connected to the alternative power system may be a maximum of 50 A. If that breaker is 80% rated, then the maximum output from the alternative power system would be 40 A.

 Now do Self-Test 2 and check your answers.

Self-Test 2

Answer the following questions and cite the rule(s) that apply.

1. Identify the allowable flexible cord types that can be installed inside a small wind turbine tower.

2. At what maximum distance must a 4 AWG copper flexible cord be supported inside a wind turbine tower?

3. Identify allowable armoured cables that shall be installed up the centre of a small wind turbine tower.

4. At what maximum distance must a 00 AWG armoured cable containing copper conductors be supported when installed inside a small wind turbine tower?

5. What are the conditions of use if conductors are installed in a raceway on the inside or outside of a small wind turbine tower?

6. What type of raceway may be installed on the outside of a small wind turbine tower?

7. What is maximum value of overcurrent protection allowed for a wind turbine described as having a peak output of 2.6 kW that is configured to supply a nominal 48 V battery?

8. If the maximum current of a wind turbine is less than 12 A, what is the maximum overcurrent device allowed?

9. If the maximum steady-state I_{sc} for a wind generator is 10 A, and a 10 AWG copper conductor is used in the circuit, what size overcurrent device is required?

10. What is the minimum ampere rating of the disconnect on the output circuit of a wind turbine that has a rated continuous output of 4.8 kW at 240 V AC.

11. An inverter output circuit is protected by a 30 A circuit breaker supplying a 10 AWG copper wire. What size copper bonding conductor is required in this circuit?

12. A stand-alone inverter is supplied by a nominal 48 V battery and is connected with 2/0 AWG cables protected by a 150 A breaker. What size grounding conductor is required to ground the DC portion of this system to a grounding electrode?

13. A PV electric power system uses separate ground electrodes for the DC portion of the system and the AC portion of the system. What size conductor must be used to connect these ground electrodes?

14. The 150 V DC, PV output circuit of a combiner carries the current from five strings of solar modules with a short circuit current of 9.45 A each. The combiner terminals are rated 90°C and the lugs in the PV disconnect are rated 75°C. Assuming no more than three 90°C copper conductors in a raceway comprise the PV output circuit and it is exposed to 50°C ambient temperature:
    a. What is the minimum size conductor to be installed in this circuit?

    b. What is the minimum rating of the fused disconnect to be installed in this circuit if it is rated 80% continuous?

For the following questions, choose the best answer and cite the appropriate rule.

15. What is the maximum nominal battery voltage allowed in a dwelling?
    a. 24 V
    b. 48 V
    c. 50 V
    d. 100 V
    e. 120 V

16. The conductor between a charge regulator and a battery must have overcurrent protection located:
    a. at the charge regulator
    b. at the battery
    c. in the middle of the circuit between the charge regulator and the battery
    d. at both the charge regulator and the battery

17. Which of the following cable types are suitable for battery interconnection? (Choose all that match.)

    a. SJ

    b. W

    c. DLO

    d. PPC

    e. TEW

---

18. Welding cables are allowed for battery interconnection.

    a. True

    b. False

---

19. A 125 A panel in a commercial building is supplied by a 60 A breaker. What is the maximum size of breaker, to be supplied by an alternative power system, that can be installed at the opposite end of the panel busbar?

    a. 125 A

    b. 90 A

    c. 60 A

    d. 50 A

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 3:

Test and maintain alternative power systems

Solar module performance

In order to evaluate the performance of a solar array it is important to understand the how its operating characteristics change under different environmental conditions. Electrical characteristics of solar modules are reported standard test conditions (STC). However, actual operating conditions seldom correspond to standard test conditions.

PV module performance varies with the module operating temperature. Maximum power decreases by approximately –0.5% per degree Celsius increase in cell temperature.

$$P_T = P_{STC} \times \left(1 + \left(T_{module} - 25°C\right) \times T_{PK}\right)$$

Where:

P_T = the power at the module temperature

P_{STC} = the power at standard test conditions

T_{module} = the module temperature

T_{PK} = the power-temperature coefficient in percent per degree Celsius

This decrease in power is mainly caused by a decrease in the open circuit voltage of the module. A typical value is –0.36%/°C. The decrease in open circuit voltage can be calculated by:

$$V_{OC\text{-}T} = V_{OC\text{-}STC} \times \left(1 + \left(T_{module} - 25°C\right) \times T_K\right)$$

Where:

$V_{OC\text{-}T}$ = the open circuit voltage at the module temperature

$V_{OC\text{-}STC}$ = the open circuit voltage at standard test conditions

T_{module} = the module temperature

T_K = the voltage-temperature coefficient in percent per degree Celsius

PV modules always operate above the ambient temperature. In full sunlight a module with good air flow around it will be about 25°C to 30°C above the ambient temperature.

For example, if $T_{ambient}$ = 25°C, then under full sunlight, T_{module} = 50°C, approximately.

Figure 1 shows the open circuit voltage increasing as the temperature decreases and decreasing as the temperature increases. The impact of temperature on current is negligible and is usually ignored.

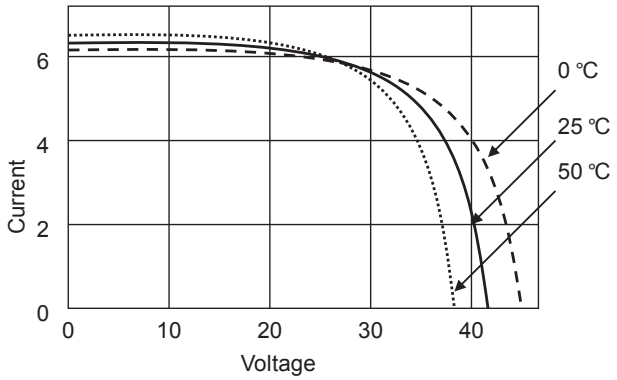


Figure 1—The effect of temperature on the IV curve of a photovoltaic module (image courtesy Reid Wylde Engineering Ltd. © 2012)

An increase in irradiance directly increases the current output of a PV module. Figure 2 shows how the IV curve is affected by irradiance. Open-circuit voltage is not significantly affected by the irradiance level and remains nearly constant until very low light levels.

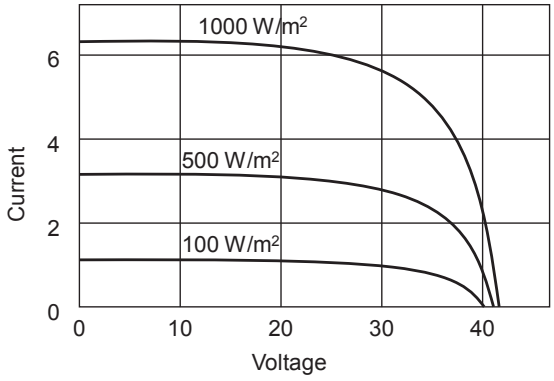


Figure 2—The effect of irradiance on the IV curve of a photovoltaic module (image courtesy Reid Wylde Engineering Ltd. © 2012)

The short circuit current output of a solar module is directly proportional to the irradiance and can be calculated by:

$$I_{SC-H} = I_{SC-STC} \times \left(\frac{H}{1000\ W/m^2} \right)$$

Where:

I_{SC-H} = short circuit current at the irradiance

I_{SC-STC} = short circuit current at standard test conditions

H = the irradiance

Note that the power produced by a solar array is also directly proportional to the irradiance.

Manufacturers rate their modules according to standard testing procedures and supply this information with the modules. Figure 3 shows typical specifications for a photovoltaic module.

Generic PV 300 Solar Module	
Maximum Power, P_m	300 W
Operating Voltage, V_{mp}	34.0 V
Operating Current, I_{mp}	8.70 A
Open Circuit Voltage, V_{oc}	42.0 V
Short Circuit Current, I_{sc}	9.45 A
Maximum System Voltage	600 V
Maximum Series Fuse Size	15 A
NOCT	45°C
Voltage Temperature Coefficient	-0.36%/°C

Irradiance 1000 W/m², Air Mass 1.5, and module temperature 25°C.

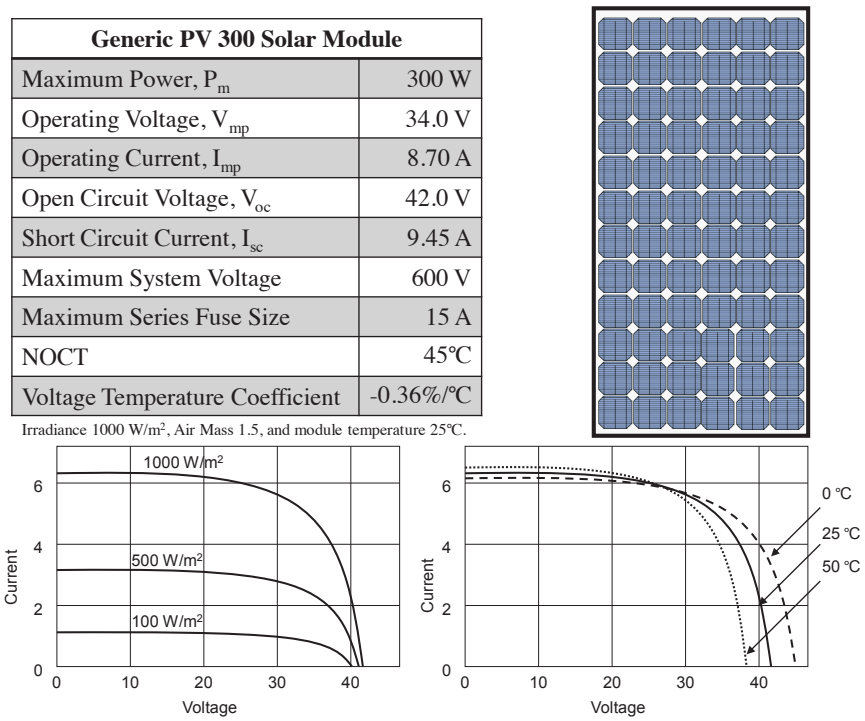


Figure 3—Photovoltaic module specifications
(image courtesy Reid Wylde Engineering Ltd. © 2012)

To verify the operation and performance of a solar array, measurements of open circuit voltage, short circuit current and the operating voltage, current and power are made. The actual operating conditions must be taken into account when making these measurements. These measurements can be taken with the following instruments:

- A standard multimeter can be used for most measurements on a solar array. However, care must be taken when measuring short circuit current, and the probes on the meter should not be used to short out the solar module or array.
- Module temperature can be measured with a thermocouple, thermistor or infrared thermometer.
- Irradiance measurements can be made with a hand-held irradiance meter or a small PV module with a calibrated short circuit current.
- A megohmmeter is also required for verifying the insulation resistance of the components.

Wind turbine performance

Although the design of the rotor influences the operating characteristics of the wind turbine, in all cases the rotor is connected either directly or via a gearbox to an electric generator. The electrical output of a wind turbine depends on the type of electrical generator used and the rotational speed of the turbine.

Most small wind turbines use permanent-magnet alternators that produce variable-frequency three-phase alternating current. The output from the alternator either is rectified to DC for battery charging or is supplied to an inverter for interconnection to an AC electrical grid. Small wind turbines use low-speed, direct-drive generators to increase reliability.

Larger wind turbines use induction generators, which are used to supply power directly to an AC electrical grid.

The electrical output from the generator depends on the wind speed and the characteristics of the load placed on the output from the generator. Voltage varies with the frequency or rotor speed of the turbine, and the current varies with the torque applied to the shaft of the alternator by the blades of the turbine. A key concern for optimizing the output of a wind turbine is that for a particular turbine blade design, there is a single value of the *tip speed ratio*, the ratio between the blade tip speed and the wind speed, at which the conversion of power is maximized (Figure 4). Thus, if an optimum tip speed ratio is to be maintained, the rotational speed of the turbine must vary as the wind changes.

There are two ways the output of a small wind turbine with a permanent-magnet alternator is managed:

1. A load that maintains a constant voltage, such as a battery, is connected directly to the rectified output of a wind turbine with a PM alternator. The frequency of the alternator output changes only a small amount, since the battery voltage changes a relatively small amount. When the wind speed increases, the current produced by the alternator increases, placing a greater load on the alternator. A disadvantage of this configuration is that the wind turbine is most efficient at only one wind speed since the blade speed is essentially fixed.

2. The frequency and voltage of the alternator are allowed to vary such that the ratio between the tip speed of the blades and the wind speed remains constant. This means that as the wind speed increases, the rotational speed of the alternator increases proportionally and the power output is maximized (Figure 5). Power conditioning units such as DC to DC converters and DC to AC inverters are used to track the maximum power of the wind turbine as the wind speed changes and then convert the output of the alternator to a voltage and frequency that are compatible with the load being supplied. The load can be DC loads such as batteries or AC loads such as a utility grid.

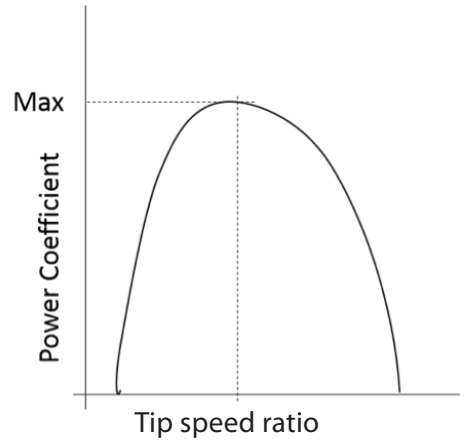


Figure 4—Tip speed ratio at which the power coefficient of a wind turbine is maximized (image courtesy Eric Smiley)

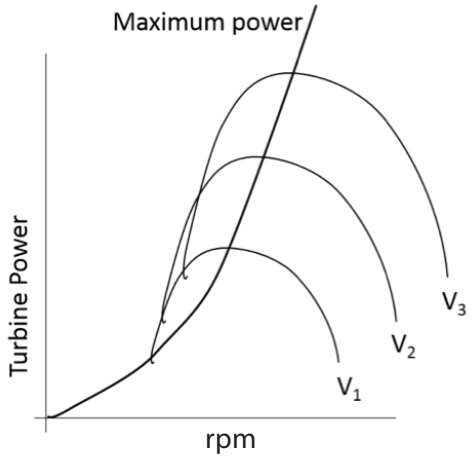


Figure 5—Wind turbine power versus rpm at different wind speeds, V, where $V_1 < V_2 < V_3$ (image courtesy Eric Smiley)

If the load on the alternator is removed, the rotor speed increases, as does the voltage. This can result in damage to the alternator due to the centripetal forces on the alternator at high rotor speed or due to high voltages exceeding the insulation ratings of the windings. For this reason diversion load controllers are used with wind turbines in battery-charging systems. A diversion load controller diverts or shunts excess power to a "dump" load when the batteries are full. The dump load is usually a resistive load such as a water or air heating element that is always available.

Induction generators, used in larger wind turbines, are usually connected directly to the utility grid. In order to maintain the efficiency of the turbine as wind speed changes:

- The blade geometry is adjusted to account for the varying tip speed ratio;
- Gearboxes are used to adjust the tip speed ratio at different wind speeds while maintaining a constant rotational speed in the generator;

- A doubly fed induction generator (DFIG) is used whereby the frequency of the current supplied to the rotor is varied as the wind speed changes in such a way as to maintain a constant voltage and frequency in the stator winding of the induction generator; or
- The output of a three-phase synchronous generator is allowed to vary in frequency and voltage with wind speed and the output is converted to DC and then back to AC, as with a grid-connected small wind turbine.

Testing of alternative power systems

Before installing fuses in combiners, closing disconnects or turning on power conditioning equipment, the following tests should be performed:

- Test AC circuits for continuity, phasing and voltage.
- Test DC circuits for continuity.
- Test bonding conductors for continuity.
- Verify DC polarity of PV source circuits and output circuits.
- Test insulation resistance for source and output circuits.

Solar photovoltaic systems

In addition to the tests described above, additional measurements to verify performance can be made

- Test string open-circuit voltage and compare to specifications and module temperature.
- Test string short circuit current and compare to specifications and module temperature.
- Evaluate system performance.

Example

A 4.8 kW solar photovoltaic system is operating at 45°C and 850 W/m^2. The power delivered to the inverter or charge controller at this temperature is:

$$P_T = P_{STC} \times \left(1 + \left(T_{module} - 25°C\right) T_{PK}\right) = 4800\ W \times \left(1 + \left(45°C - 25°C\right)\left(-0.005°C^{-1}\right)\right) = 4320\ W$$

where the percentage per degree Celsius has been converted to degrees Celsius to the negative one.

The decreased irradiance further reduces this value by:

$$\left(\frac{H}{1000\ W/m^2}\right) = \left(\frac{850\ W/m^2}{1000\ W/m^2}\right) = 0.85$$

Therefore the total available power is:

4320 W × 0.85 = 3672 W

Voltage drop in the wires and mismatch between modules will further reduce this value by approximately 5%, and the total power delivered is:

3672 W × 0.95 = 3488 W

Documentation of alternative power systems

General information about the alternative power system should be collected and presented to the client. This information may also be required by the inspection authority and the utility, if a grid-tie system is being installed. The documentation may include:

- DC and AC power ratings of equipment
- manufacturer, model and quantity of each major component
- site layout diagram showing the location of major components and disconnects
- single line diagram
- warranty details
- permits, inspection certificates and interconnection agreements

Maintenance of alternative power systems

PV array maintenance

Basic maintenance for a solar PV array may only be required once a year. It includes:

- debris removal—removing leaves and debris that can pose a fire risk or impede water drainage
- shading control—such as trimming nearby trees
- module soiling—removing dirt, dust and other soil from the array may be required
- structural attachment and conduit entry weather sealing inspection

Before performing, cleaning inspection or maintenance of the array, the system should be checked for indication of a ground fault and a fall safety program should be in place. A visual inspection should be performed after cleaning to identify defects or damage to the modules, damage or corrosion on structural elements, abrasion or other damage to wiring.

Battery maintenance

Proper battery maintenance must be performed every one to three months and requires:

- DC voltmeter
- DC ammeter (clamp-on type is recommended to measure large battery currents)
- yydrometer for measuring electrolyte specific gravity
- a load tester may be used to evaluate battery age

Proper personal protective equipment and safety gear should be in place before:

- inspecting and cleaning battery enclosures, trays and terminations
- inspecting disconnects and wiring
- checking torques on terminations
- measuring specific gravity
- performing equalization or other procedures
- adding de-ionized or distilled water to flooded lead acid batteries



Now do Self-Test 3 and check your answers.

Self-Test 3

1. A wind turbine with a permanent-magnet alternator is connected directly to a battery after rectifying the output to DC. The output will be maximized at all wind speeds.
   a. True
   b. False

2. A diversion load is used in wind power systems (choose one):
   a. To maintain a constant tip speed ratio
   b. To prevent alternator overspeed
   c. To increase the battery voltage

3. A wind turbine produces 60 Hz at a wind speed of 4 m/s. If a constant tip speed ratio is maintained and the wind speed increases to 6 m/s, what is the output frequency?

   _____

4. A solar module is rated to produce a maximum power point current, I_{mp}, of 7.0 amps at standard test conditions and a voltage of 30.0 V.
   a. What is the maximum power the module is rated for?

      _____

   b. What size of resistive load would operate this module at the maximum power point?

      _____

5. A solar module is rated to produce a maximum power point current, I_{mp}, of 7.0 amps at standard test conditions. At an irradiance of 500 W/m^2, what maximum power current would it produce?

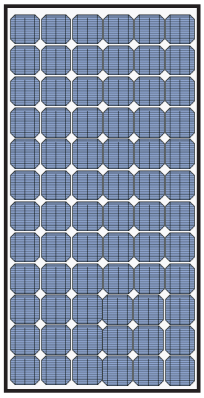
   _____

6. A crystalline silicon solar module is rated to produce an open circuit voltage of 42.0 V. At a module temperature of –25°C, what is its open circuit voltage?

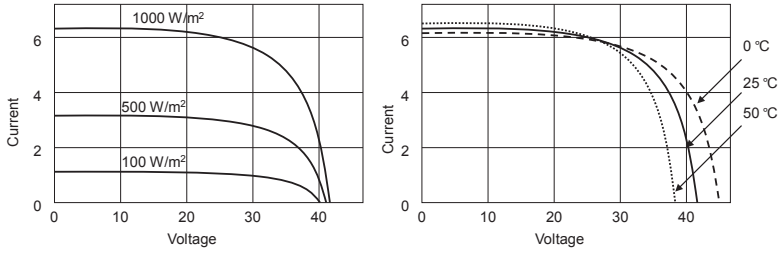
   _____

7. A solar array comprising two solar modules in series and three parallel series strings has what I_{mp} and V_{mp} values at STC, if the modules are rated to produce a maximum power point current, I_{mp}, of 7.0 amps at standard test conditions and a voltage of 30.0 V?

Generic PV 300 Solar Module	
Maximum Power, P_m	300 W
Operating Voltage, V_{mp}	34.0 V
Operating Current, I_{mp}	8.70 A
Open Circuit Voltage, V_{oc}	42.0 V
Short Circuit Current, I_{sc}	9.45 A
Maximum System Voltage	600 V
Maximum Series Fuse Size	15 A
NOCT	45°C
Voltage Temperature Coefficient	-0.36%/°C



Irradiance 1000 W/m², Air Mass 1.5, and module temperature 25°C.



8. In the space below draw an IV curve for the PV module described in the specifications shown above at –40 degrees Celsius and irradiance of 1000 W/m².

Go to the Answer Key at the end of the Learning Guide to check your answers.

Answer Key

Self-Test 1

1. a. SA
   b. GT
   c. SA
   d. SA
   e. GT
2. a. True
3. b. False
4. a. Battery disconnect F
   b. PV disconnect B
   c. Load controller L
   d. Stand-alone inverter E
   e. Charge controller C
   f. Combiner A
   g. AC load distribution H
   h. DC power distribution panel D
   i. PV system AC disconnect G
   j. Grid-tie inverter I

Self-Test 2

1. SOW, SOOW, STW, STOW and STOOW, from Rule 64-306(3)(b) & Table 11.
   Feedback: S, SO, SOO, ST, STO, STOO are now recognized only as components of equipment
2. 30 metres. Rules 64-306(5), 12-120(2) and Table 21
3. TECK 90, ACWU90 and ACGWU90, Rule 64-306(3)(c) and Table 19
   Feedback: Must be suitable for concealed wiring in wet locations.
4. 24 metres. Rules 64-306(4), 12-120(4) and Table 21
5. Suitable for raceway in wet locations. From Rules 64-306(1), 64-306(2), 64-306(3) and Table 19. Also 4-008.
6. Rigid or liquid tight flexible conduit. From Rule 64-306(2)(a)
7. 70 A. Rule 64-308(2)
   Feedback: $125\% \times I_{max} = 125\% \times (2600\ W/48\ V) = 67.7\ A$

8. 15A. Rule 64-308(4)

   Feedback: Rule: 4-002 requires conductors of not less than 14 AWG, which may be protected by a maximum 15 A overcurrent device according to Rule 14-104.

9. None. Rule 64-308(1)

10. 25 A. Rule 64-310(3)

11. 12 AWG. Rule 10-814 and Table 16A

12. 6 AWG. Rules 10-810(2) and 10-812

13. 6 AWG. Rule 10-702(b)

14. a. 4 AWG

    b. 80 A fuse in a 100 A disconnect

15. c. 50 V. Rule 64-800(3)

16. d. at both the charge regulator and the battery. Rules 64-010(1), 64-702 and 14-100

17. c. DLO, d. PPC, Rule 64-810

18. False. Rule 64-810 Appendix B

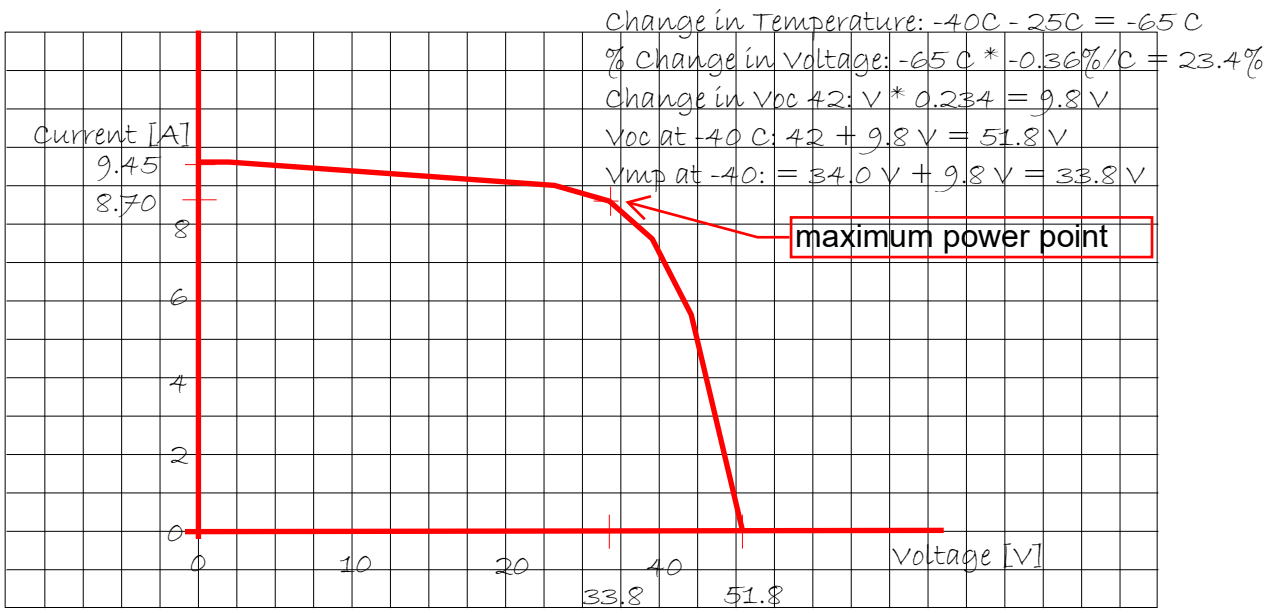
19. b. 90 A. Rule 64-112(4)(c)

Self-Test 3

1. b. False
2. b. To prevent alternator overspeed
3. 90 Hz
4. a. 210 W

   b. 4.3 ohms
5. 3.5 A
6. 49.6 V
7. I_{mp} = 21 A, V_{mp} = 60.0 V.

8.


Change in Temperature: -40C - 25C = -65 C
% Change in Voltage: -65 C * -0.36%/C = 23.4%
Change in Voc 42: V * 0.234 = 9.8 V
Voc at -40 C: 42 + 9.8 V = 51.8 V
Vmp at -40: = 34.0 V + 9.8 V = 33.8 V
Current [A]
9.45
8.70
8
6
4
2
0
0
10
20
40
Voltage [V]
33.8
51.8
maximum power point



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