PV and the Electrical Code

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PV and the Electrical Code

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1. Introduction

This manual has been developed for people involved in the installation of PV systems in Canada

A perusal of the Table of Contents of the Canadian Electrical Code (CEC) Part 1 will indicate that only one section (Section 50) deals with Photovoltaic Systems Installations. Rule 50-000(2), however, states that Section 50 is an amendment, which implies that all of CEC Part 1 applies to PV installations. This is indeed the case. Section 0 states “This code covers all electrical work and electrical equipment operating or intended to operate at all voltages in electrical installations for buildings, structures, and premises,…….”. There are 4 exceptions, namely; Utility Systems, Electric Railways, Aircrafts, and Marine Systems. These organizations have developed their own codes and standards and the CEC recognizes this.

Some explanation of how to interpret this manual is required. The material for this manual is based on the nineteenth edition of the Canadian Electrical Code Part 1, the 2002 CANADIAN ELECTRICAL CODE HANDBOOK and the authors’ experience.

This manual has 11 Chapters each of which deal with a specific section of the CEC. Not all sections of the CEC appear in this manual and those that do not appear have little or no relevance to PV installations. You will note that several methods have been used to quote the rules. In some cases the rule is quoted verbatim or is partially quoted, in others the rule is only referred to. The reader should have a copy of the nineteenth edition of the Canadian Electrical Code Part 1 available while reading this manual so they can read the full text of each Rule.

The question, “Why develop a manual on the electrical code when the CEC book already exists?” may be asked. The answer is the CEC has been written primarily with conventional electrical systems in mind. This means that virtually all rules assume that the electrical circuits are AC but in many cases they still apply to DC systems and circuits (a Photovoltaic Modules generates DC). This manual identifies the existing rules that are pertinent to photovoltaic systems and assists the student in interpreting them from the point of view of DC systems and photovoltaic systems in particular. Further, the CEC states, “This code is not intended as a design specification nor an instruction manual for untrained persons.” This manual is specifically for persons learning about PV systems and also does provide some design guidance.

2. The Object of the CEC Section 2 and General Information

The purpose of this chapter is to discuss the layout of the Canadian Electrical Code Book, the Object of the CEC and sections, tables and appendices of the CEC that he/she may find useful when preparing to install a Photovoltaic System.

2.1 The Layout of the CEC Book

The CEC code book consists of 43 even numbered sections. Tables, Diagrams and Appendices are used to support and explain the rules. Section 50 deals specifically with PV systems but many of the other sections have rules that must be followed when installing PV systems (these are the sections that this manual deals with). Each section has a group of persons (see pages ix to xxii) considered to be knowledgeable with respect to that subject area that regularly discuss, revise and implement rules for that section. Anyone can submit a request for an amendment to the CEC and the form for submission is on page 424.

There are approximately 65 Tables that are of use to a designer and installer of electrical equipment. The tables that the PV Industry uses most frequently are:

Table 2	Allowable Ampacity of ***copper*** conductors ***in raceways*** and ***cables***
Table 5A	Correction factors to Tables 1, 2, 3 and 4 for ambient temperature.
Table 11	Conditions of Use for Various Types of Cords.
Table 12	Allowable Ampacity of Flexible Cord and Equipment Wire
Table 16	Minimum Size of Bonding Conductors
Table 17	Minimum Size of Grounding Conductors for AC Systems
Table 19	Conditions of Use of Wires and Cables

There are 10 pages of diagrams (pages 326 to 335) for use for very special applications. Diagrams 1 and 2 (pages 326 and 327) will be of interest for installations where a PV system is installed and DC is used rather than AC for operating equipment (see rule 26-700 (3)).

There are 9 Appendices. Appendix B provides backup information for each of the rules of Sections 0 to 86. Section 50 of Appendix B (pages 399) provides several diagrams very useful to those persons in the PV Industry.

Appendix D contains several tables that the PV installer may find useful. These are:

Table D2 Page 433 This table lists the rated currents of DC motors. Of course the voltages are higher than those normally encountered in PV systems; however a ratio can be used. For example a ¼ HP 120V motor has a listed current of 2.9 amps. The rated current for a 12V motor would be 120/12 x 2.9 or 29 amps etc.

Table D3 Page 434 This table can be used for determining conductor voltage drops. While the table is for a 1% drop on 120V systems, note 9 provides a formula to convert to any other voltage and % drop.

Table D4 Page 436 This table is similar to D3 but happens to be for 6V systems. The formulas at the bottom of the page indicate how to convert for other voltages. Both D3 and D4 are useful to a PV installer.

2.2 The Object of the CEC

Section 0 states the Object of the CEC - Which is to establish safety standards for the installation and maintenance of electrical equipment. This includes the prevention of fire and shock hazards and the operation of electrical equipment.

Section 2 of the Code sets general rules that are to be followed when undertaking an electrical installation. It is not the authors' intent to discuss all of the material in Section 2 but to disuses only those rules of every day importance to PV system installers.

2.2.1 Rule 2-004: Permits

A permit is required prior to undertaking an electrical installation. The purpose of the permit is to insure that all electrical installations are installed by qualified persons. The purpose of this is to insure that someone qualified and experienced in electrical installations will be responsible for the installation. While the method varies from Province to Province the rules in place are intended to provide assurance to the system owner of a quality and safe installation. In Alberta only a qualified Journeyman Electrician is allowed to apply for an electrical permit. In BC only an Electrical Contractor is allowed to apply for a permit. To be an Electrical Contractor in BC the firm must have a journeyman electrician on staff. In most jurisdictions there is an exception that allows a homeowner to apply for a permit to undertake electrical work in their own home only. The homeowner must be qualified to do electrical work, but one would expect that a homeowner will not put themselves in danger.

2.2.2 Rule 2-006: Application for Inspection

A permit allows the installation of electrical equipment to proceed. At various milestones during the installation an inspection is required. Upon final inspection and approval by the inspector a permit to connect to the electrical supply is issued. If the installation is not satisfactory no connection permit will be issued.

The procedure outlined above provides checks and balances during the installation. The inspector has the authority to instruct changes to be undertaken if this is necessary. If the installation is not satisfactory then no connection to the supply will be made.

The above procedure also applies to a PV installation. A permit must be secured for the installation and regular inspections must occur. Unfortunately the final step of the process – the connection/no connection cannot be enforced. Because this final step cannot be enforced, many PV installations have been undertaken without a permit being issued. Hence no inspections have taken place and, in fact, many installations have been undertaken by unqualified installers. This is one of the major reasons for CanSIA undertaking the development and delivery of the PVT courses in conjunction with Canadian Colleges. One of CanSIA's mandates is to promote safe and satisfactory PV installations.

2.2.3 Rule 2-24: Use of Approved Equipment

All equipment used in the electrical installations shall be approved for the application. This rule leads to the certification of electrical equipment. To be approved equipment must be tested for the application by a recognized testing agency and meet standards developed by the Canadian Standards Association. CSA certification is performed by a number of organizations such as, Electrical Testing Laboratories (ETL), Underwriters Limited (UL) and CSA International.

Until the early 1990's certification was an issue for PV installations, particularly with respect to inverters and to the use of circuit breakers fuses and switches for the control of PV systems. Prior to the use of PV modules for generating electricity, residential and commercial electricity was all AC. Hence most residential and commercial electrical equipment was only certified for AC applications. Standards for PV modules, inverters and charge controllers did not exist and obtaining certified equipment usually meant a special inspection was required.

All equipment must be approved for the application. Lack of approval does not mean that a piece of equipment is unsuitable for an application, but it may mean that.

You will note that the title of the code book is the Canadian Electrical Code Part 1. There is also a Part 2 of the Canadian Electrical Code. The difference is that Part 1 is for ***Installation*** of Electrical Equipment whereas Part 2 is for the testing and approval of the ***Equipment*** only. This means that a PV module will be tested under Part 2 and, if approved, will be given a label indicating CSA compliance. An inspector when inspecting an installation may ask to see equipment approvals. If a piece of equipment does not have a CSA or equivalent sticker then he/she will not allow it to be connected.

2.2.4 Rule 2-308: Working Space About Electrical Equipment

Adequate space in front of and above equipment is necessary so that maintenance can be performed on electrical systems. Similarly, adequate lighting shall be provided for the operation and maintenance of equipment. This is a matter of safety for operating personnel. The minimum space in front of electrical equipment is to be 1 metre – IN ADDITION TO THE SPACE REQUIRED TO OPEN ENCLOSURE DOORS. The minimum head space is to be 2.2 m.

3. CEC Section 50 – Solar Photovoltaic Systems

3.1 Scope

As described in Rule 50-000(1), Section 50 applies to all photovoltaic systems except for those that meet the requirements for Class 2 circuits. Class 2 circuits are described in Rule 16-200(1)(a) and (b). These are circuits where current, voltage and power are limited so that they do not present as great a shock and fire hazard as those available from power circuits. [CEC Handbook]

Photovoltaic modules are current, voltage and power limited so there are many situations where a photovoltaic module may be part of a Class 2 circuit and the exception of Rule 50-000(1) would apply.

EXAMPLE:

A single photovoltaic module is directly connected to a small DC pump. The PV module has the following specifications:

P_{mp}	50 Watts
V_{oc}	21.5V
V_{mp}	16.7V
I_{sc}	3.1A
I_{mp}	3.0A

Is this a Class 2 circuit?

Solution: Yes.

Rule 16-200(1)(b)(iii) applies since the open circuit voltage is over 20 V but does not exceed 30 V and the current is supplied from, *"A device having characteristics which will limit the current under normal operating conditions or under fault conditions to a value not exceeding 100/ V amperes, where V is the open circuit voltage; …"*. In other words both the operating current (I_{mp} = 3.0A) and the fault current (I_{sc} = 3.1A) does not exceed, 100 divided by 21.5V = 4.65A.

It is also important to note that Rule 50-000(2) states that Section 50 is supplementary to, or amendatory of, the general requirements of the Canadian Electrical Code. In other words, all photovoltaic systems must adhere to the general requirements of the Canadian Electrical Code including Sections 2 through 16 and Section 26.

A note in Appendix B places additional requirements on all solar photovoltaic systems, regardless of voltage and current ratings. If installed in hazardous locations, the requirements of Section 18 must be applied to these systems. See ***Chapter 10*** for a discussion of Hazardous Locations.

3.2 Terminology

There are special terms used to describe the components and circuits within a solar photovoltaic system. These terms are defined in Rule 50-002 and are supplemented by a diagram in Appendix B. These definitions are specific to photovoltaic systems. Read Rule 50-002 and Appendix B and become familiar with the terms used to describe photovoltaic systems. Pay careful attention to the difference between the **photovoltaic source circuit** and the **photovoltaic output circuit**. The **photovoltaic source circuit** refers to only those conductors between modules and from the modules to the common connection point or *combiner*. The term **Power conditioning unit** is not a common term, but it refers to inverters and charge controllers.

Throughout this Chapter terms that are defined in Rule 50-002 and Section 0 will be used and highlighted in bold. Figure 1 identifies the main components and circuits of a **stand-alone solar photovoltaic system**.

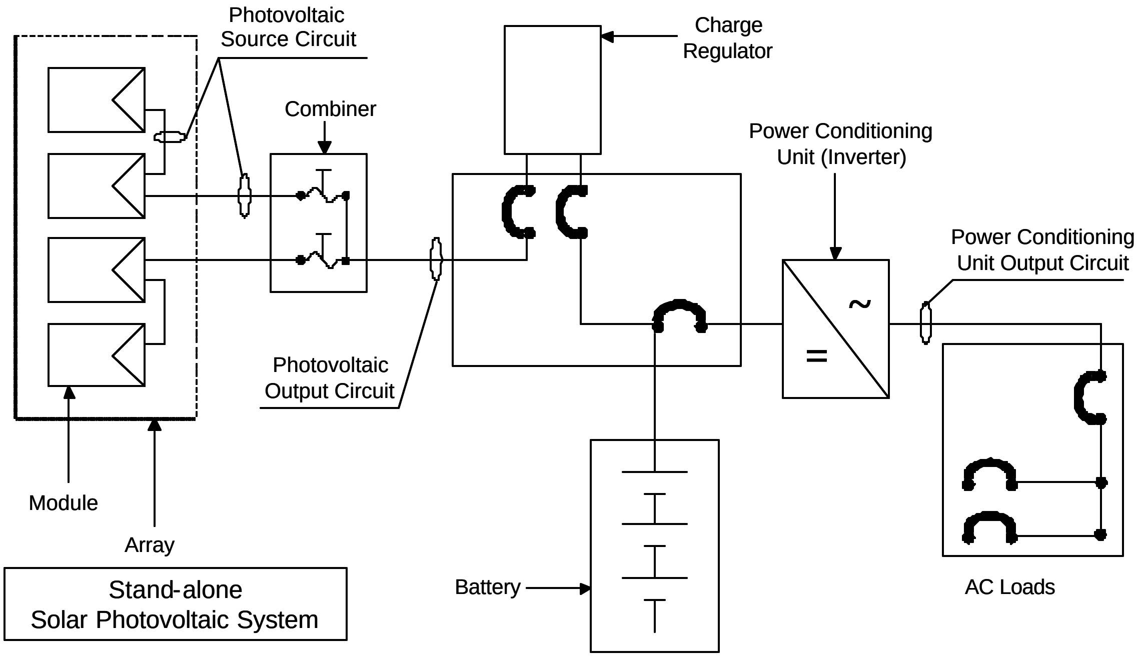

Figure 1: Diagram for Identifying PV System Components

3.3 Marking

A permanent label shall be placed at the disconnect switch for the **photovoltaic output circuit**. Rule 50-004(1) states that the label must show the following information:

- Rated operating current and voltage; and
- Rated open-circuit voltage; and
- Rated short-circuit current.

This marking should be a permanent sign or label which is affixed to the enclosure which contains the disconnect for the PV **array**. In **stand-alone systems** a single enclosure, or Control Centre, often contains all the disconnects for the DC portion of the system. **Interconnected systems** may have a disconnect for the **photovoltaic output circuit** located in the inverter. The information on the label allows the inspector to verify proper conductor ampacity and overcurrent device ratings. The label also enables the user, designer or installer to install the system, assess the performance of the system and make changes to the system.

In addition to specifying the operating voltage and current, this rule also requires that the rated open-circuit voltage rated short circuit current be specified. Both the rated open-circuit voltage and short circuit current are higher than the operating voltage and current and therefore may present a hazard to operating personnel.

EXAMPLE:

A PV system contains a single **module** with the following specifications:

P_{mp}	50 Watts
V_{oc}	21.5V
V_{mp}	16.7V
I_{sc}	3.1A
I_{mp}	3.0A

Write out a label for this system.

Solution:

Solar Photovoltaic System

Operating Current	3.0 A
Operating Voltage	16.7 V
Rated Open Circuit Voltage	21.5 V
Rated Short Circuit Current	3.1 A

Figure 2: Label for Solar Photovoltaic System

3.4 Voltage Rating

Photovoltaic **modules** are rated at Standard Test Conditions (STC) which stipulate a **module** temperature of 25°C. The open-circuit voltage of a PV module is affected by temperature such that the open circuit voltage increases as temperature decreases. Thus if a PV array is operating at temperatures below 25°C, the electrical equipment in a PV system will be exposed to voltages greater than the open circuit voltage obtained at Standard Test Conditions. Rule 50-006 increases the voltage rating of the **photovoltaic source circuit** by 25% above the STC rated open circuit voltage. This ensures that the components of a photovoltaic system are chosen so they are not exposed to voltages exceeding their voltage rating when the photovoltaic **modules** are operating at temperatures below 25°C. Since there is nothing to prevent the voltages present in the **photovoltaic source circuits** from being present in the **photovoltaic output circuits**, the rated voltages for the photovoltaic source circuits should also be applied to the **photovoltaic output circuit**.

EXAMPLE:

Two PV modules, each rated 21 V open circuit at 25°C are connected in series before being connected to the *combiner*.

What is the rated open circuit voltage of the **photovoltaic source circuit**?

Solution:

2 modules in series x 21 V = 42 V

42 V x 125% = 52.5 V

<u>Rated open circuit voltage is 52.5 V</u>

3.5 Current Rating

Photovoltaic **modules** are current limited. The maximum current produced by a photovoltaic **module**, or its short circuit current, depends on the intensity of sunlight striking the **module** and the surface area exposed to the sunlight. The short circuit current of a photovoltaic **module** is typically 10 to 15 percent higher than its operating current.

Photovoltaic **modules** are rated by manufactures at Standard Test Conditions which stipulate that the **modules** are exposed to sunlight at 1000 W/m^2. 1000 W/m^2 is a typical irradiance at sea level when the sun is directly overhead. However, reflected light from grass, snow, water or cloud formations can cause irradiance to exceed 1000 W/m^2. Additionally, PV **modules** installed at higher elevations may experience higher irradiance due to less atmosphere between the module and the sun.

If overcurrent protection is not provided, Rule 50-008 states that the current rating of a photovoltaic source circuit shall be the rated short circuit current of all available photovoltaic power sources multiplied by 125%.

Often, several **photovoltaic source circuits** are connected in parallel at a common connection point or *combiner*. The output from the combiner is called the **photovoltaic output circuit** . If a fault occurs in one of the **photovoltaic source circuits** connected to a *combiner*, all the parallel **photovoltaic source circuits** can feed the fault through the *combiner*. For this reason, if no overcurrent protection is provided, the current rating of any one **photovoltaic source circuit** must be calculated based on all of the available **photovoltaic power sources**. The current rating for each **photovoltaic source circuit** is, therefore, the sum of the rated short-circuit currents of all the **photovoltaic source circuits** multiplied by 125%, and is the same as the current rating of the **photovoltaic output circuit**. The conductors in the p**hotovoltaic source circuits** are selected based on this current rating.

If overcurrent protection is installed in the **photovoltaic source circuit**, Rule 50-008 doesn't specify what the current rating should be. However, Rule 8-104(1) states that the ampere rating of a circuit shall be the ampere rating of the overcurrent device protecting the circuit or the ampacity of the conductors, whichever is less. Therefore the current rating of the **photovoltaic source circuit** is usually based on the overcurrent protection in that circuit.

How does one choose the overcurrent protection in the **photovoltaic source circuit**? Good design practice dictates that the overcurrent protection for the **photovoltaic source circuit** should be at least 125% of the rated short-circuit current of the photovoltaic **module** in that circuit. Doing so will avoid nuisance tripping of breakers or nuisance blowing of fuses during periods of increased irradiance, while still protecting the circuit in the event of a fault.

In some situations the 125% factor, which we have borrowed from Rule 50-008, is not adequate to prevent blowing of fuses when no fault is present. A combination of reflected light off snow and fog in parts of Canada has been reported to cause as much as an 80% increase in irradiance above Standard Test Conditions. In order to ensure reliable system operation, overcurrent protection, conductors and *charge regulators* may need to be chosen for operation under this extreme condition.

Refer to ***Chapter 6*** and Rules 8-104(4), (5) and (6), which apply to the selection of equipment in the photovoltaic source and output circuits since the rated current, as calculated in Rule 50-008, should be considered a continuous load on the **photovoltaic source circuit**.

EXAMPLE:

A photovoltaic **array** comprised of three photovoltaic **modules** is connected via wire in raceway to a *combiner*, where the modules are connected in parallel. The module specifications are:

P_{mp}	50 Watts
V_{oc}	21.5V
V_{mp}	16.7V
I_{sc}	3.1A
I_{mp}	3.0A

1. If no overcurrent protection is provided, what is the current rating of the **photovoltaic source circuit**?

Solution:

3 modules in parallel x 3.1A = 9.3A

9.3A x 125% = 11.6 A

The current rating of the **photovoltaic source circuit** is 11.6 Amps

2. If overcurrent protection is provided in the form of fuses sized to operate at 125% of the rated short-circuit current, what is the current rating of the **photovoltaic source circuit**?

Solution:

First the size of the fuse must be determined.
1 module in parallel x 3.1A = 3.1 A
3.1A x 125% = 3.875A

The load on the photovoltaic source circuit must be considered continuous and Rule 8-104(5)(a) applies (See ***Chapter 6***). The fuse size should be:
3.875A / 80% = 4.84A (rounded up to 5 Amps)

The current rating of the **photovoltaic source circuit** is 5 Amps

There is a Maximum Fuse Size stated in the specifications for any UL listed photovoltaic **module**. This Maximum Fuse Size takes into account both the 125% factor of Rule 50-008 and the requirements of Rule 8-104. Although this Maximum fuse size is based on the National Electrical Code, using the maximum fuse size recommended by the manufacturer as protection for the photovoltaic source circuit should enable one to meet the requirements of the Canadian Electrical Code.

Rule 50-008 should not be interpreted to mean that overcurrent protection is not required in the **photovoltaic source circuit**. **Stand-alone systems** often have a battery. A fault in the **photovoltaic source circuit** could occur such that the battery supplies fault current to the **photovoltaic source circuit** which exceeds the rated ampacity of the components and conductors in the circuit. Read Rule 50-010, which addresses whether overcurrent protection is required.

3.6 Overcurrent Protection

The requirements of Section 14 apply to the overcurrent protection for photovoltaic conductors and apparatus. Rule 50-010(1) states that when the available short-circuit current does not exceed the rated ampacity of the electrical apparatus or conductors in the circuit, overcurrent protection is not required. If the available short circuit current is less than the ampacity of the conductors or apparatus, then a hazardous condition should not exist in the event of a fault.

However, the total of the current ratings of all **photovoltaic source circuits** and the fault current available from the battery must be taken into account when applying this rule. Overcurrent protection will be required between the battery and the **photovoltaic source circuits** since batteries are a source of very high fault currents.

According to Rule 50-010(2), if overcurrent devices are installed for the photovoltaic source circuits, they shall be **accessible** and grouped where practicable. If a *combiner* is used, this is the appropriate place for the overcurrent devices, but this may pose a problem if the *combiner* is located near a photovoltaic array located on the roof of a building. According to the definitions in Section 0, **Accessible** means the equipment is not guarded by locked doors, elevation or other effective means. Therefore Rule 50-010(2) may preclude installing a *combiner* with overcurrent protection near a roof mounted photovoltaic array since access to most roofs is either locked or requires a ladder. Photovoltaic system installations are still a relatively new practice in Canada and this rule illustrates why it is a good idea to contact the electrical inspector before commencing work so that difficulties in interpreting the rules of the CEC may be worked out ahead of time.

3.7 Disconnecting Means

Photovoltaic **modules** are energized whenever exposed to light and a battery is always energized. Thus it is important in a photovoltaic system that a means is provided to disconnect all equipment from all ungrounded conductors of all sources as describe din Rule 50-012(1). This will allow safe servicing of equipment in the photovoltaic system. Figure 3 illustrates the placement of disconnecting means in a photovoltaic system. Pull out fuses are often used in the *combiner* and these can serve as the disconnect means if they are listed for operation under load. Some types of attachment plugs, as described in Rule 50-016, may also be suitable as a disconnect means if properly rated for disconnection under load.

Note that simply disabling a photovoltaic **array** by placing an opaque covering over the modules does not satisfy the requirements of 50-012. An opaque covering does not isolate the equipment. Furthermore, read Rule 14-700 which specifically states that diodes, transistors and other solid state devices are not suitable for disconnecting or isolating equipment.

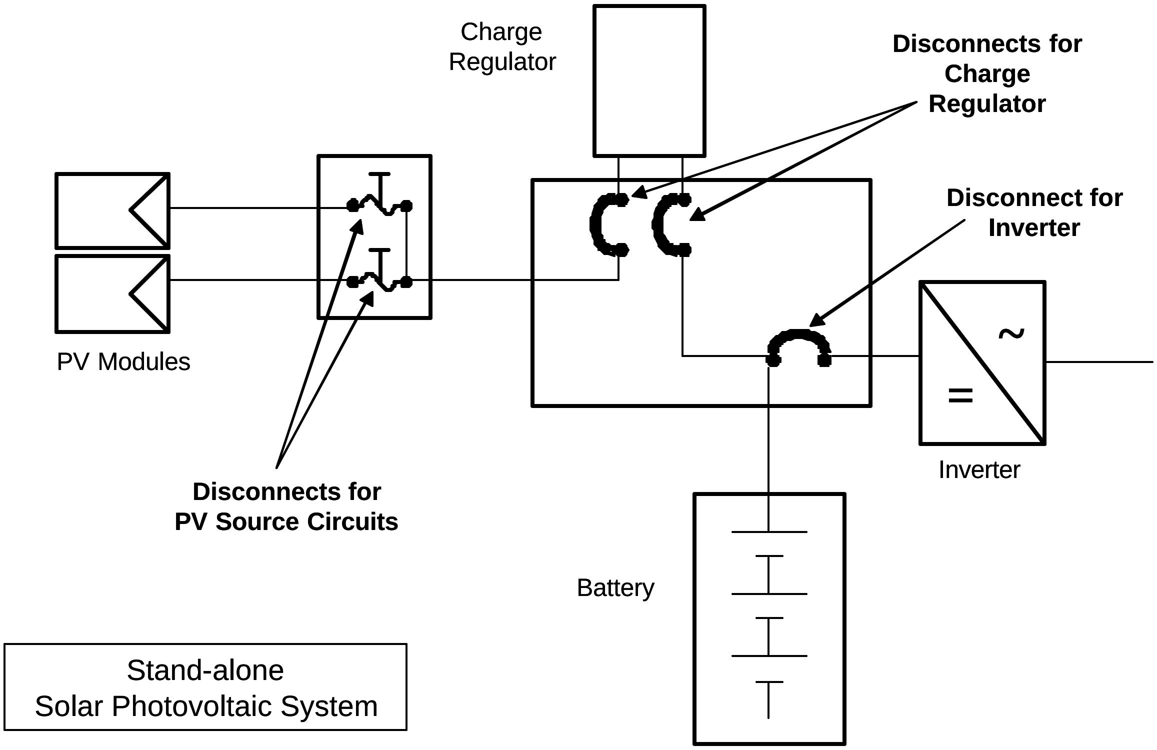

Figure 3 Placement of Disconnect means in a Stand-alone PV System

Typically the *charge regulator* in a photovoltaic system is supplied by two energy sources and requires a disconnect means for each source of energy. This is also shown in Figure 3.

Modules, **panels** and **arrays** may be connected in parallel with other **modules**, batteries and even power sources such as wind generators. Thus the equipment in a photovoltaic system is often energized from more than one source. If this is the case, Rule 50-012(2) states that the installation must comply with Rule 14-414.

3.8 Wiring

Rule 50-014 makes an exception from the general rules for the interconnection of PV modules. In most PV installations, Section 12 allows photovoltaic **modules** to be interconnected with wires and cables in accordance with Table 19 of the CEC. Read ***Chapter 4*** for more information on wire types and conductors. The most common wire types used for PV module interconnection are single conductor RW90 in raceway, Tray Cable (where properly supported), NMWU and TECK90.

However, Rule 50-014 also allows flexible cords of a type specified in Table 11 of the CEC for extra-hard usage to be used. For example, SOW meets this requirement and is often used to interconnect the modules in PV arrays that actively track the motion of the sun. Stranded or flexible wire is preferred for making **module** interconnections.

3.9 Module Interconnection

Attachment Plugs and Similar Wiring Devices shall be permitted for the connection of flexible cord between photovoltaic **modules** or **panels**. Rules 50-016 states that these devices must have the following characteristics:

- No exposed parts
- Polarized
- Non-interchangeable
- Locking
- Properly rated
- Provide strain relief

The **bonding conductor** plays an important safety function and safe working procedures require the presence of this conductor so that all equipment is bonded to ground. According to Rule 50-018, removal of a photovoltaic **module** or **panel** shall not interrupt the **bonding conductor** to other photovoltaic **modules**. This Rule requires that modules not be bonded in a daisy chain such that removing a **module** during service or maintenance would leave remaining modules without a bond to ground. Read ***Chapter 7*** for more information on Grounding and Bonding.

Although Rule 50-018 requires module connections to be arranged so that the bonding conductor is not interrupted when a module is removed, there is no specific rule that requires the installation of photovoltaic modules so that removal of a module or panel from a photovoltaic source circuit does not interrupt the **identified** conductor. However, Rule 4-034 requires that devices installed in multi-wire branch circuits shall be installed such that they may be disconnected without interrupting the continuity of the **identified** conductor. Further more, Rule 4-026(d) stipulates that a neutral conductor be installed so that any neutral conductor may be disconnected without disconnecting any other neutral conductor. If the same logic is applied to photovoltaic systems in which the negative is grouned, a negative bus arrangement such as provided in a *combiner* should be used so that PV modules may be removed from a PV array without interrupting the **identified** conductor in the other **photovoltaic source circuits**. Figure 4 illustrates the proper connection of the bonding and negative (**identified**) conductors in a *combiner*. Note that the bonding conductors are between the frame of the photovoltaic modules and the enclosure of the *combiner*. A bonding conductor also runs from the *combiner* to the main DC disconnect along with the **photovoltaic output circuit**.

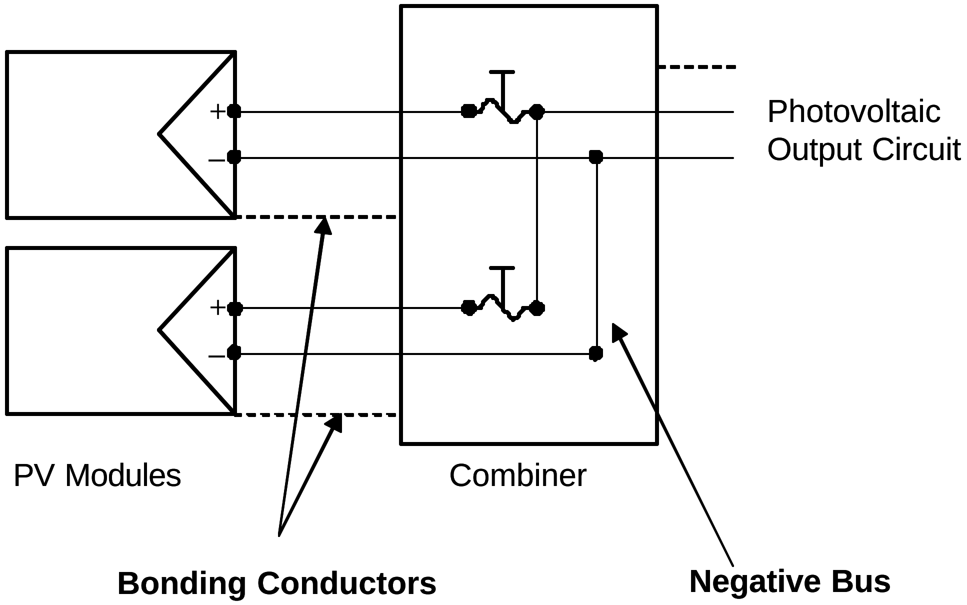

Figure 4 Arrangement of Bonding and Negative Conductors in a Grounded System

3.10 Interconnected systems

Rule 50-020 applies to photovoltaic systems that are interconnected with the utility or **supply authority**. Rule 50-020(1) states that the equipment in an interconnected system must be connected in compliance with Section 84. Section 84 applies to the installation of consumer-owned electric power generation equipment connected and operating in parallel with another **supply authority** system.

Take note of Rule 84-002 which states, “interconnection arrangements shall be in accordance with the requirements of the supply authority.” The utility that owns the distribution system (the **supply authority**) which a photovoltaic system is to be interconnected with has the last word on how that interconnection is to be made. Utilities that allow the interconnection of photovoltaic systems will publish their own document outlining such requirements. Typically this document will reference documents from organizations such as CSA, IEEE and/or the IEC and explicitly state the parameters that such systems must operate within and the applicable equipment standards. For example, CSA C22.2 No 107.1-01 is the applicable standard for inverters used in **interconnected systems**.

Rule 84-026 is also of particular importance. This rule lists the requirements of the disconnecting means for a parallel generation system. Since Rule 84-026(1)(c) states the disconnecting means shall, “have contact operation verifiable by direct visible means…”, molded case switches or circuit breakers are not acceptable. Safety Switches with visible blades are most often used for this application.

50-020(2) allows either a dedicated branch circuit breaker or a fused disconnect on the load side of the service box to be used as the point where the photovoltaic system ties into the building electrical distribution system. No electrical loads may be connected to the branch circuit breaker or fused disconnect and it should be labeled as being the **power conditioning output circuit**.

4. CEC Section 4 – Conductors

4.1 Scope

Rules 4-000 and Rule 4-002 define the scope Section 4 and the minimum wire size for electrical circuits covered by the CEC Part 1. PV source circuits, output circuits, etc. are power supply circuits and thus Section 4 applies to photovoltaic installations.

4.2 Ampacity of Wires and Cable

Rule 4-004 describes the tables that must be referred to when determining if a conductor has the required ampacity for a circuit. Conductors carrying current produce heat due to the resistance of the wire. This Rule and the Tables it refers to, are designed to prevent the temperature of a conductor from exceeding the temperature rating of its insulation while carrying its rated current or ampacity.

Two rules from Section 8 also apply to the selection of conductor sizes. Rule 8-102 states the requirements for voltage drop in a circuit and Rule 8-104 imposes limitation on the current a conductor may carry based on the calculated load in the circuit. Wire size selection most be checked against both of these rules in addition to the Tables described in Rule 4-004. Read ***Chapter 6*** for more information on Rules 8-102 and 8-104.

Conductor size in a PV system will be chosen on the basis of either the current carrying capacity of the conductor or on the voltage drop – whichever results in the greater size. Often, in PV systems operating at nominal 12 V or 24 V the conductor sizes chosen to limit voltage drop will have ampacities that exceed the current they are required to carry.

The current carrying capacities calculated from the information in Tables 1 through 5C are the maximum values for various conductor types and insulation types under various conditions of operation. These tables are valid for both direct current (DC) and alternating current (AC). By definition, the heating value of a DC Amp is equivalent to the heating value of an AC Amp.

Table 1 through Table 4 are used depending on the material the conductor is made from. Tables 1 and 2 are for copper and Tables 3 and 4 are for aluminum. A further distinction is made between conductors installed in free air or in raceway or cable. A conductor that is enclosed within a raceway or cable is not going to dissipate heat as rapidly as one in free air and thus the ampacities in Tables 1 and 3 for free air, are generally slightly greater for a given wire size than those in Tables 2 and 4, which are for conductors installed in raceway or cable.

Tables 5A, 5B and 5C are used to modify the data in Tables 1 through 4. Table 5A provides correction factors for conductors operating at ambient temperatures above 30°C, Table 5B provides correction factors for Tables 1 and 3 when more than one conductor is present and the conductors are in contact, and Table 5C provides correction factors for cables or raceway that contains more than three conductors.

Table 5A will be used quite extensively in selecting conductors for the photovoltaic source circuits. Photovoltaic modules are often installed on roofs where the ambient temperature may exceed 30°C, and the PV modules often have surface temperatures 20°C to 30°C above the ambient temperature. The conductors for the PV modules are usually installed in junction boxes attached directly to the back of the module and thus the ambient temperature within the junction boxes is essentially the same as the module temperature. Conductors operating at high ambient temperatures can carry less current because the ambient temperature plus the temperature rise created by the current must not exceed the temperature rating of the insulation.

EXAMPLE:

Two conductors of copper RW90 in raceway comprise the photovoltaic source circuit in a photovoltaic array. Each source circuit is protected with a 10 amp fuse. The maximum operating temperature of the photovoltaic module is 70°C. What size conductor is required?

Solution:

Since the source circuit is connected directly to the PV module its temperature will be approximately the same as the PV module. From Table 5A, Row 70°C and Column 4: 85-90°C, the Correction Factor is 0.52 and the ampacity of the conductor must be at least:

$$\frac{10A}{0.52} = 19.23A$$

From Table 2, Column 4: 85-90°C, at least a #12 AWG conductor, with ampacity of 20A, is required for this circuit.

4.3 Insulated Conductors

Rule 4-006 refers to Table 19 which lists the uses for the various types of approved insulated conductors. The table also lists the maximum allowable conductor temperature. Many of the Wire and Cable types may be used in more than a single condition of use. For example you will note that TECK90 may be used in almost all conditions of use. The conductors used for the photovoltaic source circuits will be either exposed, or installed in raceway and must also be suitable for use in wet locations. PV module interconnection are often single conductor RW90 in raceway, Tray Cable (where properly supported), NMWU and TECK90.

EXAMPLE:

RW90 may be used under what conditions?

Solution:
RW90 is listed for the following conditions of use:

- For exposed wiring in wet locations
- For exposed wiring where exposed to the weather
- For use in raceways, except in cable trays, in wet locations
- For use in ventilated and non-ventilated cable trays in vaults and switch rooms
- For concealed wiring used as non-heating leads on heating panels and panel sets

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4.4 Flexible Cord

Rule 4-010 limits the uses of Flexible Cord so that it would not ordinarily be used in a permanent solar photovoltaic system unless that system used a solar tracker. Rule 4-010(2)(g) permits the use of Flexible Cord for, “The connection of electrical components between which relative motion is necessary;”. Since a solar tracker would create motion between the PV modules and the *combiner*, Flexible cord may be permitted. However, Refer to ***Chapter 3: Section 50 – Solar Photovoltaic Systems*** and see Rule 50-014 which amends this interpretation and explicit permits flexible cord to be used for the interconnection of modules.

The size of flexible cord is limited by Rule 4-012. Flexible cord shall be not smaller than a No. 18 AWG copper conductor, except for certain conditions which do not apply to photovoltaic source circuits.

For current carrying capacity, Rule 4-014 refers to Table 12. For 2 or 3 conductors in a flexible cord, the maximum current any copper conductors of a given size may carry is specified in Table 12. Note that Table 12 is based on an Ambient Temperature of 30°C. Although there is no specific rule, it is advisable to determine the Temperature Rating of the flexible cord one is using from Table 11 and apply appropriate temperature derating factors from Table 5A.

4.5 Colour of Conductors

Rule 4-036 states the requirements for the colour of grounding and bonding conductors, which shall be green or green with a yellow stripe. The Rule goes further to state the required colours of the current carrying conductors in a circuit. Rule 4-036(3) is quoted below as it is very specific about the colour of the conductors in dc circuits.

4-036 Colour of Conductors

Where colour coded circuits are required, the following colour coding shall be used, except in the case of service-entrance cable and insofar as Rules 4-030, 4-032, and 6-308 may modify these requirements:

1 phase ac or dc (2-wire) —1 black and 1 red
or
1 black and 1 white† (where identified conductor is required);*
1 phase ac or dc (3-wire) — 1 black, 1 red, and 1 white†;*
3 phase ac — 1 red (phase A),
1 black (phase B),
1 blue (phase C), and
1 white (where neutral is required)*

**Or natural grey;*
†Or white with coloured stripe (see Subrule 4-034).

Rule 4-036(3) specifies that two wire dc circuits should be black and red, or black and white if an identified conductor is required – i.e. if the system is grounded the grounded conductor, which is usually negative, should be white. This white conductor is the system conductor that is bonded to the grounding system and is at the same potential as the earth. Read Section 0 where the term identified is defined. Under definition (a) it states, "… the conductor is either a grounded conductor or a neutral …". Also refer to ***Chapter 7*** and the definition of grounded in Section 0.

This colour coding may result in confusion as the convention in electronics and automotive wiring is that the positive conductor is red and the negative is black. Using red as the positive and white as the negative may be acceptable in certain applications and will help avoid mistakes – check with the electrical inspection authorities to make sure.

5. CEC Section 6 – Services and Service Equipment

5.1 Scope

Section 6 of the Canadian Electrical Code Part 1 applies to services, service equipment and metering for electrical installations. The requirements of Section 36 may apply to installations exceeding 750 V, but for most photovoltaic interconnected or stand-alone systems Section 36 does not need to be referenced.

Although there is no actual supply authority for a photovoltaic stand-alone system, there are still rules in Section 6 that may apply to such an installation. On the other hand, an interconnected system has a supply service, but the scope of a photovoltaic installation would generally not include this service equipment. Nonetheless, because power circuits are entering a building, the installation of the photovoltaic output circuit from the PV array to the main PV array disconnect may be similar to the installation of consumer's service conductors to the service box especially if exposed conductors are used. See *Chapter 6: Section 8* for more on this similarity.

Some PV systems use a separate structure to house the battery and inverter in much the same way that people will construct a separate generator shed (in fact the generator may also be housed in the same structure as the battery and inverter – in separate rooms). When this is done, the conductors from the separate structure become the Consumer's Service Conductors and Section 6 is very relevant to the installation of AC components of the system.

5.2 Overhead Conductors

Rule 6-112 is relevant to photovoltaic installations that include overhead conductors. This rule is intended to protect people and vehicles from contact with overhead conductors. Thus requirements for the clearance of the conductors above finished grade are stipulated and the location and structural characteristics of the point of attachment are also stipulated. The point of attachment should be sufficiently high and strong such that snow and ice accumulation, in addition to the weight of the conductors, will not cause the conductors to sag, the service mast to bend or pull fasteners from the building.

If the PV system is using exposed wiring for the photovoltaic source circuits or photovoltaic output circuit, refer to ***Chapter 8*** which covers Section 12 including Rules 12-300 to 12-318, which are specific to exposed wiring.

5.3 Terminating Conductors

Rule 6-114 is intended to protect cables and conduit from water infiltration. This can be accomplished by using a rain-tight service head, cable terminations suitable for exposure to the weather, or tape or heat shrink tubing. Drip loops and suitable clamps, fittings or terminations to hold cables securely in place are also required as shown in Figure 5

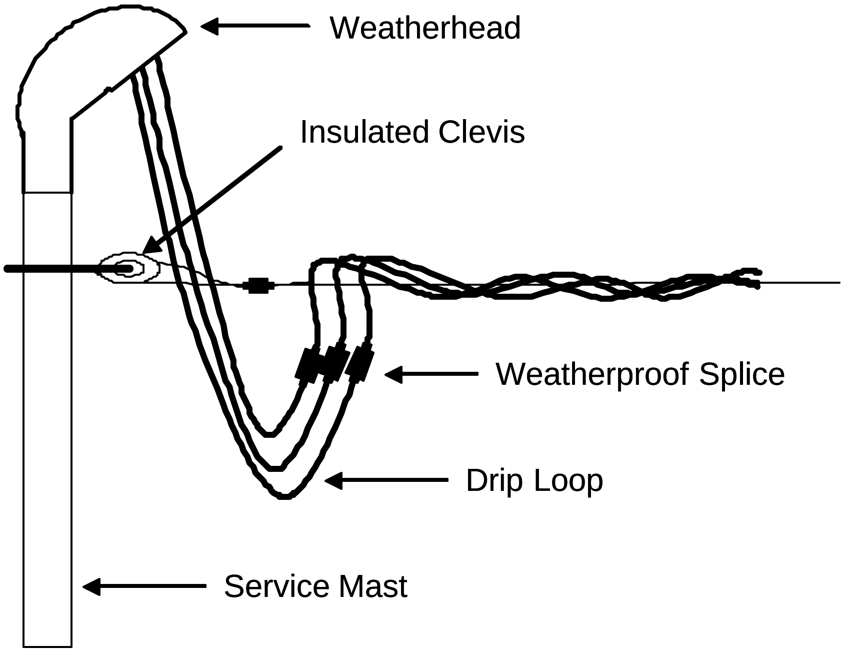

Figure 5: Rain-tight service head, indicating drip loops and attachment

5.4 Consumer’s Service Equipment Location

Rule 6-206 sets out the requirements for the location of **service boxes** or other service equipment. The equipment must be readily accessible or have the means of operation readily accessible. In addition the equipment should be located within the structure being served and located as close as practicable to the point where the consumer’s service conductors enter the building. (see Consumer’s Service Conductors Location below) In a stand-alone photovoltaic system, the service equipment may include the DC disconnect for the PV array and the inverter. However if a separate structure houses the battery and inverter the Service Equipment only includes the AC wiring and the Service Equipment is more conventional.

There is an exception to this rule if the environmental conditions within the structure are unsuitable. Some of the unsuitable conditions are described in 6-206(1)(c) and include dangerous or **hazardous locations**.

If the service equipment is located outside, it must be protected from both the weather and mechanical injury. This will entail using proper weatherproof enclosures and raceway or conduit for protecting conductors.

5.5 Consumer's Service Conductors Location

Rule 6-208 requires service conductors to be located outside of buildings except in special circumstances described in Rules 6-208(1)(a), (b), and (c). The **raceway** or **cables** containing the **consumer's service** conductors may only enter the building to connect to the **service box**.

There are established methods in the electrical industry for installing overhead conductors, terminating conductors in wet environments and installing consumer's service conductors. These methods are readily adapted to the installation of photovoltaic source circuits and photovoltaic output circuits. Figure 5 shows some of the details for bringing overhead wiring into a building, but such techniques are beyond the scope of this manual.

6. CEC Section 8 – CIRCUIT LOAD AND DEMAND FACTORS

6.1 Scope

Rule 8-000 defines the scope of Section 8.

It covers the conductor ampacity and equipment ratings for consumers services, feeders, and branch circuits and the number of branch circuit positions for residential buildings.

8-108 discusses the number of branch circuits required in a residential dwelling however these rules assume that the branch circuits are supplied with 120V AC. Since the scope of this manual is the DC only portion of a PV system rule 8-108 will not be discussed.

There are 2 factors that are used to determine the size of a conductor: either the current capacity of the conductor or the ohmic voltage drop of that conductor. Whichever method results in the larger conductor size is the one that must be used. Section 4 discusses the selection of conductors on the basis of current carrying capacity and the use of Tables 1 through 5C, but Section 8 also contains rules that apply to conductor selection.

6.2 Conductor Selection on the basis of Current Carrying Capacity

Since CEC Part 1 is primarily written for AC systems and based on electrical energy distributed by a Supply Authority, Section 8 has been written with that in mind. In these systems a consumers service consists of the conductors between the connection to the Supply Authority and the main disconnect in a residence. Thus the Rules governing Services and Feeders, Branch Circuits and Automobile Heater Receptacles would be difficult to apply to a PV system since many of the assumed loads are not practical in a PV system. Nonetheless, the AC wiring of a residence or structure should be wired in compliance with Section 8 to allow for future changes such as extension of the utility grid.

6.3 Voltages to be used when determining conductor current ratings

Voltages to be used for calculating currents are specified by 8-100 and are the normal AC voltages of 120, 208, 240, 277, etc. The voltages used for PV systems typically span the extra low voltage and low voltage of CEC Part 1 definitions (see definition of Voltage in Section 0). Because the service voltages of most PV systems are 12V, 24V or 48V, and the conductor voltage drop may have a major impact on the operation of a PV system, the actual voltage rather than nominal values should be used. When the system includes batteries the battery voltage must be used – and the battery voltage will vary with the SOC. For convenience Figure 6 has been reproduced from PVT210.

State of Charge	Specific Gravity	Cell Voltage	Battery Open Circuit Voltage		
			12 V	24 V	48 V
Fully Charged	1.2650	2.12	12.72	25.44	50.88
75%	1.2250	2.10	12.60	25.20	50.40
50%	1.1900	2.08	12.48	24.96	49.92
25%	1.1550	2.03	12.18	24.36	48.72
Discharged	1.1200	1.95	11.70	23.40	46.80

Figure 6 Battery State of Charge

EXAMPLE 6-1

A 24V PV system supplies a summer cottage. On the basis of Figure 6, determine the voltage to be used to determine the current in the conductors:

a. Between the PV array and the fused disconnect ahead of the battery.

b. Between the batteries and the loads.

Solution

a. When determining the current rating of a conductor the maximum possible current must be determined. Typically a calculation is required to determine that current. The maximum current between the PV array and the battery will be determined by the short circuit PV module rating and Rule 50-008. Hence, the basis of the current rating will be the nameplate of the module and not the voltage of the battery.

b. If the battery supplies an inverter the maximum current will occur when the battery voltage is lowest, therefore use 23.4V.[1] If there is no inverter and the battery is supplying resistive loads, the maximum current will occur at maximum voltage, hence use the highest voltage of 25.4V.

When close to the maximum rating for that conductor always choose the next larger conductor. (See Section 0, CEC page 1 paragraph 3).

6.4 Conductor Selection on the basis of Voltage Drop

The maximum voltage drop for AC systems is governed by 8-102 and is specified as 3% for any portion of a circuit and 5% overall. For the purposes of PV systems the photovoltaic

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[1] Note that discharged does not mean that there is no current available. Terminal voltage is an indication only of SOC. A battery with a terminal voltage of say 23.5 V will still yield considerable current to a load.

source circuits and photovoltaic output circuits may be interpreted as feeders and/or branch circuits In PV Systems the maximum voltage drop allowed between the PV array and the battery is 5%, with no more than 3% allowed on any portion of the circuit. Feeder and Branch circuits on the DC side should be treated as though they were AC circuits. Figure 7 illustrates this concept.

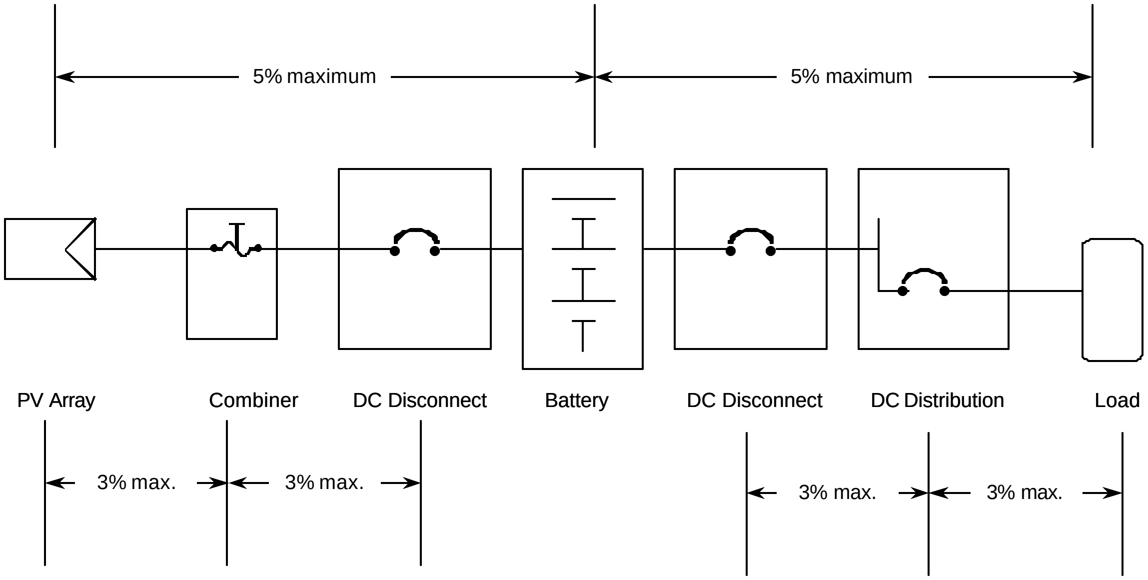

Figure 7 Maximum Allowable Voltage Drop in Circuits

There is always the question of what to take as the current when determining the voltage drop. Subrule 2 states that if the actual current is not known then one is to use 80% of the rating of the overload device protecting that conductor. This is reasonable since a fuse or circuit breaker exposed to its listed rating will take a considerable time to trip. Instantaneous trip currents will be considerably higher than the name plate value.

Conductors to be used for PV systems shall follow this rule. The size of a conductor is to be based on the maximum current that can exist in that conductor and then choose from the conductors listed in Tables 1 to Table 4 of the CEC as long as the voltage drop meets the 3% or 5% rule. For 120V AC circuits and systems Tables 1 to 4 will be correct in most applications. For the DC portion of PV systems, because of the voltages used, a conductor selected based Tables 1 to Table 4 may have a voltage drop greater than that allowed by Rule 8-102.

EXAMPLE 6-2

Specify the size of copper conductors to be used in the photovoltaic output circuit, connecting the *combiner* box of a 24V PV 15[2]A array to the battery disconnect, if the one way distance is 5 metres.

Solution:

Table 2 specifies that 14 AWG is rated at 15A. But what is the voltage drop for this conductor? By 8-102 it shall not be greater than 3% or in this case 0.72 volts. Ohms law, can be used to determine the voltage drop. Table 10 of PVT100 states that the resistance of #14 AWG is 8.46 Ω/km. The voltage drop will be:

Vd = current times resistance

= 15A x 8.46$\Omega/1000$ x (2 x 5m) = 1.27V

Since the voltage drop is higher than that allowed, the next larger wire (a #12 AWG) must be chosen – as long as it will meet the requirement of less than a 3% drop. It is left to the reader to determine this.

Alternate Solution:

Using Table D4, #12 wire can conduct 15 A with 5% voltage drop a one-way distance of 1.9 meters at 6 Volts. Using the formula provided the maximum run length for 3% voltage drop is:

$$1.9m \times \frac{3\%}{5\%} \times \frac{24V}{6V} \times \frac{15A}{15A} = 4.56m$$

4.56 meters is less than 5 meters. Therefore #12 is not suitable, according to Table D4, and #10 would have to be used.

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[2] In this case to keep things simple we are assuming that the 15A array current is already enhanced by 125% (see 50-008)

6.5 Maximum Circuit Loading

Rule 8-104 appears at first reading to be confusing and contradictory. Unfortunately code rules have developed over time and generally they do not get rewritten – they only have additions.

In plain words Rule 8-104 states that conductors and equipment must not carry more than the current that they are rated for. 8-104(1) states that the lesser rating of either the conductor or the overcurrent device[3] determines the maximum allowable current in a circuit. Some electrical equipment is rated as continuous at 100%, as described in Rule 8-104(4) and some is rated continuous at 80% of rated current, as described in Rule 8-104(5).

Some loads are continuous and some are intermittent and Rule 8-104(3) explains how to determine this. An examination of Tables 1 to 4 and Tables 5A to 5C will indicate that the rated current of a wire depends upon size, the type of conductor, the ambient temperature, the number of conductors in contact and whether it is a cable or in free air. With all of these variables it becomes very difficult to produce rules that ensure the compliance to the first sentence – conductors and equipment must not carry more current than they are rated for.

It is best to proceed using a step by step process, which might be:

1. Determine the calculated load using 8-104(3) and 50-008 if working on the photovoltaic source circuits.
2. Select the conductor to be used from Tables 1 to 4 (Insulation types, hence temperature –Columns 2, to 7) and whether a cable (Tables 2 or 4) or free air (Tables 1 or 3) or whether copper (Tables 2 or 4) or aluminum (Tables 1 or 3).
3. Select the overcurrent device or other equipment that it will be connected to (is it rated at 100% or only 80%)[4]
4. Ensure that the conductor is still cable of carrying the rated current of the selected overcurrent device.
5. Ensure that the voltage drop of the conductor is not more than 3%[5].

EXAMPLE 6-3

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[3] An overcurrent device is interpreted as a fuse or circuit breaker. Most frequently it is a circuit breaker.

[4] Examine the name plate ratings. If it does not indicate continuous at 100% then it must be taken as 80% of the nameplate rating. See 8-104, Appendix B.

[5] Remember – individual voltage drop cannot exceed 3%. 5% is the overall total voltage drop. Add all of the individuals up – the sum shall not be greater than 5%.

A stand-alone solar system consists of 6 – 64 Watt 12 V modules each having a short circuit current of 4A connected to charge a 24V battery that supplies an inverter. Specify the conductors and disconnect switch for the photovoltaic output circuit that connects the *combiner* box to the charge controller for this system. Assume that the conductors are copper and in a RW90 cable installed totally within the building. The one-way length of the cable is 5 metres and the disconnect switch does not have a 100% continuous rating. Assume the circuit configuration is that shown by 50-002 in Appendix B.

Solution

As indicated above it is best to use a step by step approach to select the components

Step 1: Determine the load (current)

This is a 24 V system used to charge a battery. The voltage to use will be as given by Figure 6 and the module current in this case must be taken as 125% of the short circuit current (50-008) and modified depending upon whether it is deemed to be continuous (8-104(3)(a)). The sun certainly can persist at 100% for more than 1 hour in any 2 hour period.

The rated current is:

12 x 1.25 =15A (3 strings of 2 modules in series).

Step 2: Select the service conductors

The conductors are copper, in a cable and inside the building; hence the temperature will be not greater than 30°C[6] hence select #12 AWG.

Step 3: Select the Switch Rating

The current is rated as continuous (8-104(3)(a)) and the switch to be used is not rated 100% continuous therefore it must be de-rated by 80% (8-104, Appendix B), hence the rating of switch must be 15A/0.8 = 18.75 A.

Switches do not have fractional ratings hence the next larger must be selected.

The switch to be used must have name plate rating of 20A or greater.

Step 4: Check the voltage drop

In this case the section that we are concerned with is classified as a feeder circuit hence it must comply with the 3% rule.

Table D4 can be used for this calculation. Using the equation shown we have:

L= 24/6 X 3/5 X 15/18.75 X 1.9 = 3.65 m

Even # 12 AWG too small! Using the same equation for #10 yields 5.95 metres.
The wire to be used to connect the *combiner* box to the overcurrent device must be #10 AWG.

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[6] The most common type of wire used is RW90 (column 4 of table 2) and it has a temperature rating of 90°C.

7. CEC Section 10 – GROUNDING AND BONDING

Grounding and Bonding are difficult concepts for many people to grasp. Generally, the question is “Why are systems grounded and bonded”? Rule 10-002 provides the answer to this question and it is:

- To protect life from the danger of electric shock, and property from damage by bonding to ground non-current-carrying metal systems; and
- To limit the voltage upon a circuit when exposed to higher voltages than that for which the circuit is designed; and
- In general, to limit ac circuit voltages-to-ground to 150V or less on circuits supplying interior wiring systems; and
- To facilitate the operation of electrical apparatus and systems; and
- To limit the voltage on a circuit which might otherwise occur through exposure to lighting

There is considerable confusion regarding grounding and bonding and the differences between the two. Section 0 defines the two terms.

Bonding means a low impedance path obtained by permanently joining all non-current-carrying metal parts to assure electrical continuity and having the capacity to conduct safely any current likely to be imposed on it.

Grounding means a permanent and continuous conductive path to the earth with sufficient ampacity to carry any fault current liable to be imposed on it, and of a sufficiently low impedance to limit the voltage rise above ground and to facilitate the operations of the protective devices in the circuit.

Enclosures of electrical equipment are connected together with a conductor (they are bonded) and the bonding conductor is connected to earth. And because an electrical system is grounded (connected to earth) this also means that the enclosures of electrical equipment will be at earth potential regardless of the type of fault or the magnitude of current that happens to be in the bonding or earthing conductor.

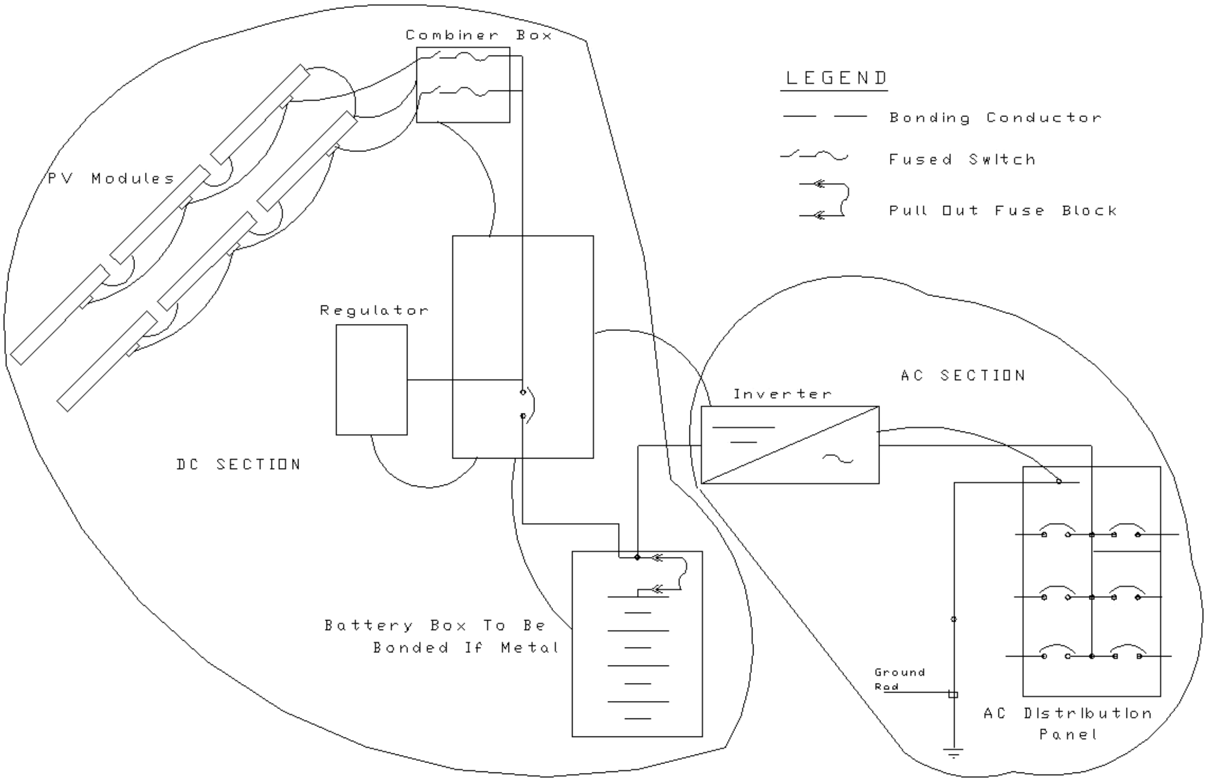

Figure 8: Drawing of typical PV System with Bonding Conductors

7.1 Grounding

A perusal of Figure 8 will indicate that for a typical PV system there are 2 distinct circuit sections – the DC section and the AC section. We must observe the rules for each section.

7.1.1 The DC Section

For voltages between 50 V and 300 V inclusive, DC systems must be grounded as indicated by 10-102(1).

10-102 Two-Wire Direct-Current Systems

(1) Two-wire direct-current systems supplying interior wiring and operating at not more than 300 V or not less than 50 V between conductors shall be grounded, unless such system is used for supplying industrial equipment in limited areas and the circuit is equipped with a ground detector.

For voltages less than 50 V Rule 10-114, provides guidance.

10-114 Circuits of Less than 50 V.

Circuits of less than 50 V shall be grounded:

(a) Where run overhead outside of buildings

(b) Where supplied by transformers energized from: …

For the PV case (a) is applicable and the rationale as stated by the Handbook is that out of door wires may be exposed to higher AC voltages (i.e. a supply grid). While a standalone system such as Fig 7 is unlikely to be exposed to supply grid wires it definitely is exposed to lightning. Grounding (and bonding) will insure that the all components of a PV system will be at ground potential by providing a low electrical resistance path to earth for lightning strikes.

There is one other interesting aspect to solar systems (both PV and thermal). It is that a solar module mounted and exposed to the sun is essentially a large flat plate capacitor (a conductive plate with insulation on each side) and as such under certain atmospheric conditions will become charged with respect to earth (as does a cloud). Grounding and bonding will insure that any static charge will be neutralized.

10-114(b) does not have any relevance as there will be no transformers on a DC system.

10-104: Three-Wire Direct Current System

The neutral conductor of all 3-wire direct-current systems supplying interior wiring shall be grounded.

This rule is in keeping with the object of grounding (see 10-002) which is to limit voltages for interior wiring to 150 V or less. PV systems designed for grid tied applications typically operate at much higher voltages than those designed for stand alone applications. Typical grid tied inverter output voltages are 120 V or 208 V. By connecting modules in series the input voltage to the inverter will be approximately the same as the output voltage thus eliminating the need for a transformer. The intent of 10-002 can be met by using a 3 wire system i.e. a conductor is connected to the electrical center of the array and then grounded. Thus the maximum voltage to earth is 50% of the maximum system voltage. By definition this conductor becomes a neutral (see section 0).

As indicated by 10-002 the purpose of grounding and bonding is to protect life from the danger of electric shock. Grounding and bonding achieves this by ensuring that when an electric fault occurs the potential of the metal parts of enclosures will be maintained at a safe value with respect to earth and/or the fault will cause the system to be disconnected by a protective device. A logical extension to this thinking is that conductors that carry current in the event of a fault must have a current carrying capacity equal to that of other system conductors thereby causing the over current device to operate and disconnect the circuit. It is for this reason that it is the size of system conductors and or overcurrent devices that governs the size of the grounding and bonding conductors.

Tables 16 and 17 are used to select bonding and grounding conductors.

10-202: Grounding Connections for Direct-Current Systems

Direct-current systems which are to be grounded shall have the grounding connections made at one or more supply stations but not at individual services nor elsewhere on interior wiring.

The purpose of 10-202 is to ensure that there is only one grounding point for each source. If a system is grounded in two locations an alternate circuit (the earth circuit will be in parallel with the neutral conductor) through the earth results. This could result in electrolytic action.

7.1.2 The AC Section

10-106 Alternating-Current Systems (see Appendix B)

(1) Except as otherwise provided for in this Code, alternating-current systems shall be grounded if:

(a) By so doing, their maximum voltage-to-ground does not exceed 150V; or

(b) The system incorporates a neutral conductor.

(2) Wiring systems supplied by an ungrounded supply shall be equipped with a suitable ground detection device to indicate the presence of a ground fault

10-106(1)(a) is really a restatement of 10-102 (1), that systems whose voltages are less than 150 V shall be grounded and that if a system is not grounded then notification of the existence of a fault must exist. Notification is not required on a grounded system because a fault will cause a protective device to operate and disconnect the circuit.

In the case of a PV Stand-Alone system having an inverter (the circuit of figure 7-1) as long as the output of the inverter is less than 150 V then grounding is not necessary, but if it is not grounded then a ground fault detector must be installed. If the inverter output is greater than 150 V (i.e. 120/240V system for example) then by (a) it must be grounded.

In either case it is best to ground the system as ground fault detectors are expensive and are intended to only de-energize the system. De-energizing the system will not protect the system from lightning or a static charge, whereas grounding will.

7.2 Bonding

10-400 and 10-402 attempts to provide guidance as to what and how electrical equipment is to be grounded and bonded. It is difficult to relate these 2 rules specifically to PV systems but the intent is very clear. ALL electrical equipment shall be bonded. In fact, even non-electrical equipment that is in the vicinity of electrical equipment shall be bonded (See 10-406).

7.2.1 Bonding Methods

10-600: Clean Surfaces
This rule specifically states that a considerable effort shall be made to insure that good electrical connections exist. Specifically it states that paint and any other coatings shall be removed so as to provide a low resistance path.

10-602 recognizes that galvanic action may take place and shall be avoided by using one type of metal. For situations where this cannot be avoided there is a paste that can be applied to the dissimilar metals that will minimize the galvanic action. This is very important for bonding of PV module frames as these are made of aluminum and the bonding conductors are usually copper.

10-810 Grounding Conductor Size for DC Circuits

(1) The ampacity of the grounding conductor for a direct-current supply system or generator shall be not less than that of the largest conductor supplied by the system, except that where the grounded circuit conductor is a neutral derived from a balancer winding or a balancer set, the size of the grounding conductor shall be not less that that of the neutral conductor.

Rule 10-810 is very specific and easy to follow. Unfortunately conforming to this can be a problem as the following example illustrates.

EXAMPLE 7-1

A PV system is used to supply a cottage with 120 VAC using a 2500 Watt 12 Volt inverter. Determine the size of the grounding conductor.

Solution

The grounding wire shall be the same size as the largest conductor. The conductors between the batteries and the inverter in this case as suggested by the Manufacturer are 4/0 for distances greater than 1.5 meters. The grounding conductor therefore is to be 4/0. A 4/0 conductor has a diameter of 11.6 mm! This is very difficult to work with and also very expensive. Increasing the voltage to 48 volts will reduce the required size of the conductors to 1/0 (8.28 mm) – which will mitigate the problem somewhat.

7.3 Grounding Electrodes

As indicated by 10-702, a grounding electrode shall be a concrete encased electrode, a rod electrode, a plate electrode, or some other acceptable device. It is to be noted that section 10-702 states that these devices are “Artificial Grounding Electrodes” because the preferred grounding method is a water piping system. PV Systems may be installed where underground water systems either do not exist or are of PVC materials. A ground rod would therefore be required in most PV systems. An acceptable grounding system would be as indicated by 10-702 (3) to 10-702 (9).

7.4 Lightning Arrestors

A PV system typically is mounted such that it is vulnerable to lightning. A flash of lightning is an electrical arc from the earth to a cloud that is the result of an electrical potential between the earth and the cloud. The resistance between earth and the cloud is the ohmic resistance of air hence the ohmic resistance will be less for a device that is physically above the earths surface (less distance to the cloud). By connecting a PV array to earth via a grounding conductor a path is provided for the discharge current.

10-1000: Lightning Arrestors on Secondary Services – 750V or Less

(1) Where a lightning arrestor is installed on a secondary service[7], the connections to the service conductors and to the grounding conductor shall be as short as practicable.

(2) The grounding conductor shall be permitted to be:
  (a) The grounded service conductor, or
  (b) The common grounding conductor
  (c) The service equipment grounding conductor; or
  (d) A separate grounding conductor.

---

[7] A secondary service is an electrical distribution system that is supplied from a transformer secondary winding. For example 2 or 3 houses will be supplied from one transfomer secondary. The primary winding/circuit will have lightning strike protection but because the primary and secondary of the transformer are not connected electrically, lighting protection on the primary does not extend to the secondary circuit. Lightning protection may be required on the secondary because of this and that it why rule 10-1000 exits

(3)The bonding or grounding conductor shall be of copper not smaller than No. 6 AWG.

While Rule 10-1000 specifically applies to Secondary Services the intent is clear. It is to provide a low resistance path for the discharge current. By 10-1000 (1) the grounding conductor shall be as short as possible (low resistance) and by (3) shall be no smaller than No. 6 AWG and shall be copper.

Section 10 outlines the rules for grounding and bonding. Over time the rules have been revised and refined to cover a myriad of situations. A first time review of these rules leaves one with a fogged mind. Conforming to Section 10 for a PV system is much simplier if one is able to keep several key factors in mind. The key factors are:

1. Earth is taken as a reference because our feet are normally at earth potential.
2. The object of Grounding and Bonding is to insure that the potential of an electrical neutral (if it exists) and all electrical equipment enclosures are at earth potential.
3. We do not want galvanic action
4. If a fault occurs, then a protective device shall disconnect the circuit or in the case of insulation breakdown the resulting current, if insufficient to trip the overcurrent device, will not cause any equipment to rise above earth potential.
5. An arbitrary value of 150 V is used as the maximum voltage to which a person can be exposed to when touching a “live “ conductor.

Number 1 above is achieved by standing on a metal grid that is electrically connected to a ground rod (this is done if there is a question regarding the potential of the material with respect to earth that a person is standing on)

Number 2 is achieved by electrically connecting both the neutral and all equipment cases together and to earth.

Number 3 is achieved by insuring that earth is not used as a conductor (i.e. the connection to earth occurs at one point only)

Number 4 is achieved by selecting the size of the grounding and bonding conductors to be approximately the same size as the system conductors. (See Tables 16 and 17) and that all connections in the grounding and bonding systems have a very low resistance

8. Section 12 – Wiring Methods

8.1 Scope

Section 12 of the Canadian Electrical Code Part 1 applies to all wiring installations operating at 750 V or less. This includes solar photovoltaic installations except for specific types of installations listed in Rules 12-000(1)(a) to (e), such as Class 2 circuits as described in Section 16. The requirements of Section 36 may apply to installations exceeding 750 V, but for most photovoltaic **interconnected** or **stand-alone systems** Section 36 does not need to be referenced.

8.2 Underground Installations

Rule 12-012 deserves a lot of attention. It covers the installation of direct buried conductors, cables or raceway. Ground mounted PV arrays often have underground wiring for the photovoltaic output circuit and installation of this wiring must comply with these rules. Refer to Table 53, *Minimum Cover Requirements for Direct Buried conductors, Cables, or Raceway* to determine how deep your circuits must be buried. NMWU cable and USEB cable belong in the first category, conductors or cable not having a metal sheath or armour, and require 600 mm or 900 mm of cover on top of the cable depending on whether the installaion is in a vehicular area or not. This distance is not measured from the bottom of the trench, but from the top of the cable. TECK, ACWU and all Raceway (except EMT) require much less cover – 450 mm and 750 mm respectively.

Note also that direct buried conductors and cables require screened sand or earth both above and below the conductors. The screen size is to be 6 mm. One must also mark the installation adequately to prevent accidental damage when someone is digging in the area. This usually takes the form of approved marking tape that is laid in the trench above the conductors, cables or raceway. The tape should be not less than 200 mm below finished grade, but preferably at least 300 mm above the conductors.

8.3 Conductors in Parallel

Rule 12-108 limits the size of conductors in parallel to 1/0 AWG or larger. The only exception is for supplying control power to indicating instruments and devices, contactors, relays, solenoid, and similar control devices as described in Rule 12-108(3)

The motivation for paralleling conductors is that large wire sizes are heavy, stiff, difficult to work with and may not be readily available.

In photovoltaic systems large wire sizes are often selected in order to limit voltage drop rather than to meet ampacity requirements and the ampacity of the selected conductor often exceeds the current rating of the circuit. This is due to the use of 12 Volt, 24 Volt and 48 volt DC in many photovoltaic systems. If parallel conductors are used to minimize voltage drop, conductor sizes can be selected such that any one of the parallel conductors could carry the full rated current of the circuit without posing a hazard.

EXAMPLE:

Two conductors of 4/0 AWG copper RW90 in raceway carries 100 A at nominal 12V and an ambient temperature not exceeding 30°C. The maximum distance without exceeding 2% voltage drop is:

From Table D3 a 4/0 conductor is suitable for 1% voltage drop over 31.6 meters at 120V and 60°C.

Table 2 allowable ampacity of 4/0 AWG copper is 235 A. Therefore the current is, 100/235 = 42.5% of the allowable ampacity. The Distance Correction Factor (Note 3) from 90°C row and 40% column is 1.08.

The maximum run length is:

$$31.6m \times \frac{2\%}{1\%} \times 1.08 \times \frac{12V}{120V} = 6.8m$$

If smaller conductors are used:

From Table 2 a #3 AWG conductor has an allowable ampacity of 105A. And from Table D3 a #3 AWG conductor is suitable for a 1% voltage drop over 7.9 meters at 120V and 60°C.

The Distance Correction Factor (Note 3) from 90°C row and 100% column is 1.00.

The maximum run length is:

$$7.9m \times \frac{2\%}{1\%} \times 1.00 \times \frac{12V}{120V} = 1.58m$$

Four parallel conductors would have a maximum run length of:

$$7.9m \times 4 = 6.32m$$

Therefore to maintain a 2% or less voltage drop, four parallel #3 AWG conductors could be substituted for a single 4/0 AWG conductor as long as the run length did not exceed 6.32

meters. Additionally, the ampacity of any one #3 AWG conductor would be adequate for the full 100A.

8.4 Types of Conductors

Rule 12-100 requires that conductors installed in any location be suitable for the condition of use as indicated in Table 19. Thus all the conductors used in a photovoltaic system should be selected from Table 19. There is an explicit exception to this in Section 50. Rule 50-014 permits flexible cords of a type specified in Table 11 for extra-hard usage to be used for the interconnection of **modules** within an **array**.

Rule 25-552(c) also permits the use of jacketed flexible cord for the wiring between cells and batteries and other electrical equipment. Equipment wire may also be suitable for such wiring. Both flexible cord and equipment wire are listed in Table 11.

The use of welding cable for wiring between cells and batteries and other electrical equipment is not permitted by Rule 12-100 or any of the exceptions mentioned. There are alternatives to welding cable that have the extra flexibility desired for battery wiring as well as having the appropriate CSA Type designation from either Table 11 or Table 19. Diesel Locomotive Cable and Drilling Rig Cable often have an R90 or RW90 designation making it a suitable choice. Some equipment wire may also be suitable – although remember to use Table 12 to determine the allowable ampacity of equipment wire rather than Tables 1 through 5B.

8.5 Exposed Wiring

Roof mounted photovoltaic arrays may have exposed wiring on the exterior of the building. According to Rule 12-300, “Rules 12-302 to Rule 12-318 apply only to exposed wiring run on the exterior surfaces of buildings or between buildings on the same premises.” These Rules describe the proper supports, sizes, clearances and other installation requirements for exposed wiring. A PV installer should be familiar with these rules.

8.6 Non-metallic sheathed cable

Non-metallic sheathed cable is the most common cable used in residential wiring. The most common types are NMD90 or “Loomex”, NMW and NMWU. Rules 12-500 to 12-526 apply to its installatin.

8.7 Armoured Cable

There are a variety of armoured cables and Rules 12 600 to 12618 apply to their installation. Common types of armoured cable are:

- AC90, which is also known as “BX”. It has no PVC jacket.
- TECK90, which has copper conductors and both an inner and outer PVC jacket.
- ACWU is similar to TECK but has aluminum conductors and an outer PVC jacket.

A common mistake is to omit the “bushing of insulating material or equivalent devices” mentioned in Rule 12-610 for terminating armoured cable. The common name for this bushing is “anti-short”. It is used on all armoured cable and flexible metallic conduit. The anti-short is to be visible, through the connector, for inspection after the installation. You will notice a small hole in connectors designed for use with BX or flexible metallic conduit. Armoured cable must be supported in accordance with in the same manner as non-metallic sheathed cable.

8.8 Raceways

There are several different types of raceway employed in PV systems. The most common are Rigid and Flexible Metal Conduit, Rigid PVC Conduit, Liquid Tight Flexible Conduit and Electrical Metallic Tubing (EMT). Do not confuse EMT with Rigid conduit as their application is very different.

The Rules governing Raceways are extensive, but some important points to note are:

- The conductors used in raceway must be suitable for use in a Raceway as shown in Table 19. Loomex cannot be installed in a raceway.
- Bushing must be used to protect conductors where they emerge from raceway.
- Lubricants that will not damage the insulation on conductors can be used to insert conductors into raceway. “Yellow 77” is a common lubricant.
- Thermal expansion and contraction of raceway must be accounted for. This is especially critical when installing raceway outdoors.
- There are two types of Liquid Tight Flexible Conduit – metallic and PVC. These are only to be used in short lengths.
- Refer to Table 6 to determine the maximum number of conductors one can install in conduit or tubing. Note that these are maximum numbers and increasing conduit size may make installation easier in practice.

9. CEC Section 14 – PROTECTION AND CONTROL

9.1 Scope

The purpose of section 14 is to ensure that an electrical system cannot cause a hazardous situation to operating personnel or to property. A hazardous situation would be a fire, an arc, or an unsafe voltage. This assurance is provided by the use of adequately sized conductors, and the installation of fuses, circuit breakers, and switches. Rule 14-010 outlines the requirements for those devices.

Rule 14-010: Protective and Control Devices Required

> Electrical apparatus and ungrounded conductors shall, except as otherwise provided for in this section or in other sections dealing with specific equipment, be provided with:
>
> (a) Devices for the purpose of automatically opening the electrical circuit thereto:
>
> (i) If the current therein reaches a value which will produce a dangerous temperature in the apparatus or conductor; and
> (ii) In the event of a ground fault, in accordance with rule 14-102; and
>
> (c) Devices which, when necessary, will open the electrical circuit thereto in the event of failure of voltage in such circuit.

The rationale provided by the Handbook for rule 14-010 is that despite the use of high quality components and installation techniques electrical component degradation and accidental faults do occur. Typical faults are short-circuits, ground faults and overloads. Electrical faults result in component overheating and if left to continue may result in fire. In addition to overheating, short circuits and ground faults may cause equipment to be live with respect to earth, and hence the exposure of personnel to electrical shock. The response to any of these faults shall be to disconnect the circuit automatically. Additionally, electrical equipment must be disconnected periodically for routine maintenance. A suitably rated disconnecting device (a switch, or circuit breaker) is therefore required and shall be strategically placed so as to disconnect the faulty component(s) or the circuit to be maintained.

Rule 14-100 indicates the overcurrent devices that are required.

Rule 14-100: Overcurrent Devices Required.

> Each ungrounded conductor shall be protected by an overcurrent device at the point where it receives its supply of current and at each point where the size of conductor is decreased, ………...

The above paragraph is the essence of the rule. The subrules are all exceptions. The rule states that in the event of an overcurrent an electric circuit shall be disconnected at its source. It then goes on to say that where the capacity of the circuit decreases (i.e. connection to a smaller wire), protection shall also be provided.

From the point of view of a PV array this rule would appear to be redundant. The rated current is approximately the maximum current and therefore a short circuited PV array could not be a fire hazard as long as the conductors are capable of carrying the rated current.

When thinking about the placement and selection of electrical protection for a circuit one is always asking the question “What if ….”. This is certainly the case regarding PV systems. For example it is always assumed that because a PV array is self limiting (i.e. – the short circuit current is the maximum possible), it does not pose a hazard under short circuit conditions. In the case of an array being used to charge batteries though, an internal short ***may*** cause the battery to drive current backwards into the module. The current will only be limited by the ohmic resistance of the wire. This is a short. Switches and overload protection are required for PV array supply conductors, both for protection and, as indicated by the Handbook, when electrical equipment must be disconnected for routine maintenance.

Section 50 recognizes that a PV system is unique by rule 50-012.

Rule 50-0012: Overcurrent Protection for Apparatus and Conductors.

Overcurrent protection shall be provided from all photovoltiac conductors and apparatus in compliance with the requirements of section 14 except that individual overcurrent protection devices shall not be required where the available short-circuit current is not greater than the rated capacity of the apparatus or conductor.

Conductors between the PV panels and the service box are not required to have fuses or circuit breakers, providing the interconnecting conductors are capable of carrying the fault current. ***Chapter 3*** describes how to apply this rule appropriately. They are however, required to have a method of disconnection as is indicated by 50-014.

Rule 14-104 contains important information for selecting overcurrent devices. The rule states that the rating or setting of overcurrent devices shall not exceed the ampacity of the conductors they protect, except where a fuse or circuit breaker of that value is not available. The reader must refer to Table 13, which provides guidelines on selecting overcurrent devices with ratings greater than the ampacity of the conductor it is protecting. An application of this rule would be when 4/0 AWG RW90 in raceway is the conductor between the battery and inverter. From Table 2 we see that the ampacity of this conductor is 235A. From Table 13, we see that we can use a 250A circuit breaker as overcurrent protection.

Rule 50-014: Disconnecting Means

1. Means shall be provided to disconnect all equipment, including the power conditioning unit, filter assembly and the like from all ungrounded conductors of all sources.
2. Where the equipment in subsection (1) is energized from more than one source, the disconnecting means shall comply with Rule 14-414.
3. Where any portion of a photovoltiac output circuit or source circuit operates at more than 30 V, means shall be provided to disable that portion of the array or panel and to isolate it from other energized conductors and equipment.
4. Subrule 2 occurs because of the possibility of an unsafe condition arising when a system is energized from more than one source. Many PV systems are interconnected with a generator and a battery bank therefore during maintenance it is possible for the other sources of emf to energize any of the other circuits. This is recognized and provision is made to prevent this from happening.

When a PV system is interconnected with another source of supply then “Each supply circuit shall be provided with a disconnecting means integral with or adjacent to the equipment, and the disconnecting means shall be grouped together” (rule 14-414 1 (b)). If this is observed then the operator will be able to disconnect all sources of emf during maintenance and can be assured that it cannot be energized inadvertently.

9.2 AC and DC Ratings

In a PV system there can a combination of both DC and AC circuitry. The designer/installer must keep this in mind when selecting components.

9.2.1 Wires

The wire tables in CEC Part 1 are based on temperature rise and the effect of temperature on the insulation surrounding the wire. By definition the heating value of a DC ampere is identical to an AC ampere. Therefore Tables 1 to Table 4 can be used for wire selection for either DC or AC operation.

9.2.2 Fuses and Circuit Breakers

While the heating effect of 1 amp DC and 1 amp AC current is identical, the interruption of a DC arc versus an AC arc is very different. DC is much more difficult to interrupt because the current is continuous whereas an AC arc goes to zero and then is re-established several times each second. Unless explicitly stated, fuse and circuit breaker ratings are AC values and not DC. It is temperature that causes a fuse to rupture but the powder surrounding the fuse element determines the interrupting capacity.

A circuit breaker is both magnetically and thermally operated. From a thermal point of view a circuit breaker will operate at the rated current – AC or DC but the magnetic and arc quenching characteristics can be quite different.

9.2.3 Switches

The rating of a switch is based on the current carrying capacity of the internal components and the arc interrupting abilities of the contacts. As with fuses and circuit breakers unless specified the rating of a switch is AC rating unless specified.

When choosing protective devices for the DC section of a PV system one must ensure that the component is DC rated and that it is adequately sized for the application. DC rated components must also be connected properly. Many DC rated switches and circuit breakers are only DC rated if both poles of a double pole switch are used. This usually means both the negative and positive conductors are switched. In a grounded DC system the grounded conductor cannot be switched and it may be allowable to run the positive circuit through two legs of a double pole switch as shown in Figure 9.

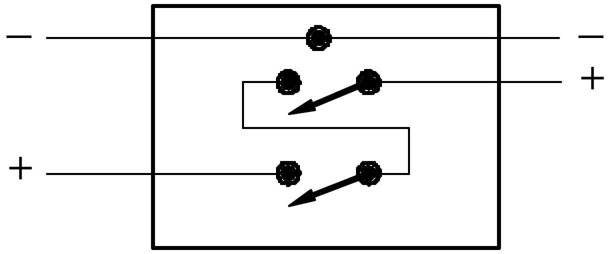

Figure 9 Double Pole Switch used for a DC Disconnect in a Grounded System

EXAMPLE 9-1

The principles of Section 14 will be illustrated by examining the DC portion of the Typical PV System shown in Chapter 7. The rationale for the placement of the protective devices and their size is outlined in the discussion below along with Figure 10.

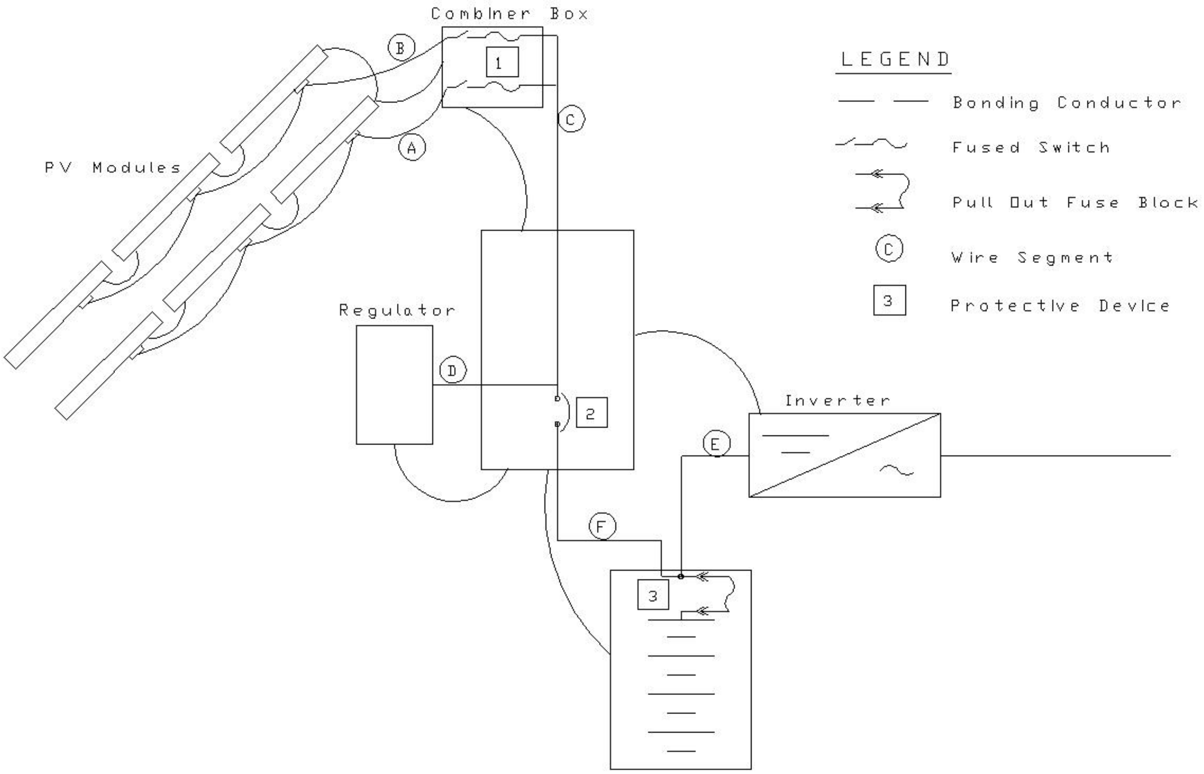

Figure 10 The DC Portion of a Typical PV System

The Combiner Box Switched Fuses (#1)

The size of these fuses will be based on the maximum current of the PV modules. Similarly the conductors A and B must be of adequate size to safely carry the maximum PV array current. The purpose of the switch is to allow maintenance on cable C. Note also that the placement of the fuse and switch is important. The switch must be placed ahead of the fuse so that when the fuse is replaced the fuse will not be live. If the locations were reversed then the fuse would be live during replacement. PV modules are a particular problem for maintenance as it is impossible to shut them off. It is recommended that a black cover be placed over the PV array during maintenance.

Circuit Breaker (#2)

Conductor C must carry the rated current of the PV array hence the size of the wire is based on that value. Circuit Breaker #2 will have a similar rating. Note the placement of Circuit Breaker #2. It is between the battery and the Regulator. The reason for this is that in the event of current flowing from the battery to the PV array (a fault condition) then Circuit Breaker #2 will interrupt the circuit. An unsafe situation would exist if Circuit Breaker #2 were placed ***before*** the Regulator and there was a short to earth within the regulator – conductor D would not be protected. Conductor F can be the same size as conductor C because the normal current is the rated PV array current, and it will be protected by Circuit Breaker #2.

Fused Disconnect #3

This device is both a switch and a fuse holder. To replace the fuse one simply "pulls out" the fuse holder and replaces the fuse. Conductor E must be selected on the basis of the inverter rating and fuse #3 also must be capable of carrying the maximum current that the inverter is expected to draw – and be capable of interrupting the short circuit current that may occur in the event of a short to the negative battery terminal. Note, however, that if the fuse blows or the disconnect is opened the inverter will be exposed to the voltage from the PV array, which may be the open circuit voltage. This may not be a satisfactory situation and a different circuit arrangement may be required.

Device Maintenance

In addition to appropriate capacity selection for all disconnect devices they must be strategically placed such that any piece of equipment can be rendered dead for maintenance. For example, if one needs to remove or perform service on the charge regulator, both circuit breaker #2 and fused switch #1 in the *combiner* must be opened to render the circuit safe. If the *combiner* is located far away from the charge regulator, an additional circuit breaker should be added on the PV side of the regulator to facilitate maintenance.

As an exercise it is left to the student to determine which disconnects must be operated if maintenance is require on the various components of this circuit.

10. CEC Section 18 – Hazardous Location

Hazardous locations refer to areas where electrical equipment may cause an explosion because of a spark due to a set of contacts interrupting a circuit current, or because of an electrical fault. There are many areas where combustible materials are either present or are produced and electrical equipment is required to operate in these areas. The rules of Section 18 provide installations guidelines which, if followed, will result in an installation that will operate safely in combustible areas. Essentially the method is to either exclude the combustible materials or gases from the electrical equipment or design the electrical circuit to be intrinsically safe.

10.1 Location Classes

Hazardous locations are broken down into 3 categories: Class I, Class II, and Class III as indicated by rule 18-004 depending upon the nature of the hazard. These Classes are further broken into Zones 0 to 3 for Class I areas, and Divisions 1 and 2 for each of Classes II and III.

Class I Locations

These areas are those that have flammable gases, vapours or ignitable mixtures present in sufficient quantities to possibly cause an explosion. An example of this type of environment would be a gas plant or oil refinery or the interior of a battery enclosure of a PV system.

Class II Locations

These areas may contain combustible or electrically conductive dusts. Areas having this designation would include all facilities that process grain products. Dust resulting from grain or grain products (flour, cereals etc.) is very combustible.

Class III Locations

These areas may contain ignitable fibres or flyings but not of sufficient quantities to cause ignition. Textile mills and woodworking facilities are examples of this type of environment.

10.2 Installations in Hazardous Locations

There are three methods of dealing with electrical installations in Classified areas. They are:

1. The use of equipment approved for the area
2. Install equipment outside of the Classified Area
3. The use of intrinsically safe equipment.

10.3 Equipment Approved for use in Hazardous Locations

If electrical equipment is to be installed in a Hazardous location the equipment must be installed in an enclosure system that will prevent the inward migration of explosive gasses. Fittings approved for these locations are very robust as they must be capable of withstanding an internal explosion. An explosion proof box is shown as Figure 11. Note that it is a casted box with a bolted cover. The cover will be fitted with a gasket to insure that no gases are able to migrate into the box. Threaded rigid conduit and fittings must be used in classified areas and all threads must have a sealer/lubricant applied prior to installation thereby insuring that no gases can migrate into the electrical fittings.

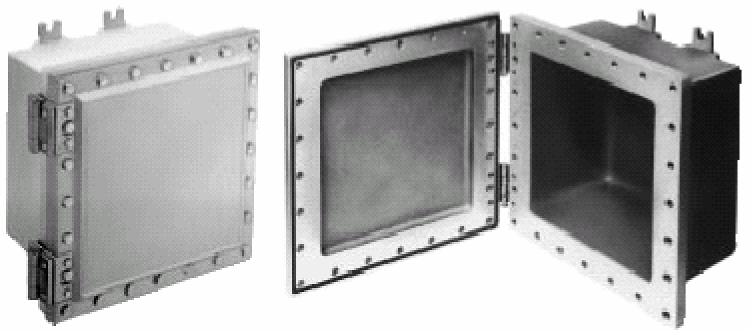

Figure 11 A Crouse Hinds Explosion proof Enclosure

Additionally, by 18-108 a ***Seal*** must be provided within 450 mm of an enclosure or where a conduit leaves a Class 1 Zone 1 area. A seal is a fitting that is inserted into the conduit run and has an epoxy (called chico) poured into the fitting that becomes hard and provides a gas tight seal around the conductors. The purpose of the seal is to insure that explosive gases cannot migrate from the Hazardous area into the conduit system.

Crouse Hinds manufacture enclosures that are approved for installation in Hazardous areas and their website shows the various fittings and enclosures available. The following animated website demonstrates the installation of a seal.

http://www.interactcompany.com/eclips/coopercrousehinds/ch0001_01.html

10.3.1 Installing Equipment Outside The Classified Area

Obviously, this is the easiest and typically the least expensive solution to the problem. The code provides guidance as to where a hazardous areas ceases to exist. See Appendix J of the CEC for these diagrams.

10.3.2 Intrinsically Safe Equipment

The third method of installing electrical equipment in a hazardous area is to use equipment deemed to be Intrinsically Safe. The concept of a piece of electrical equipment being "Intrinsically Safe" is based on the fact that even though explosive gases or dusts may be present, a minimum level of energy is required to cause an explosion. When a fault occurs in Intrinsically Safe equipment the heat energy produced is below that minimum level. Equipment is made Intrinsically safe by using Barriers and choosing very low power devices. The following article by Crouse Hinds reviews the fundamentals of Intrinsically Safe equipment.

http://www.isbarriers.com/haz/ha0004/ch02.html

10.4 Photovoltaic Arrays

Photovoltaic Modules and Arrays are very popular in the Oil and Gas Industry. Oil and gas wells are located in remote areas where the electrical grid is not available. All of these well sites require telemetry equipment used to transmit status reports to a central location. The data loggers and communication equipment at the well site will be within the Hazardous area and mounted in explosion proof enclosures. The installation of a PV array must follow rules of Section 18, and the most logical solution is to mount the array outside the Hazardous area as shown in Figure 12. A conduit will be required to route the conductors to the equipment that it powers and ***seals*** must be installed as per 18-104 and 18-106 to prevent the migration of explosive gasses. The diagrams on page 514 and 515 and Table JT-63 of the CEC provide guidance for acceptable clearances from gas sources.

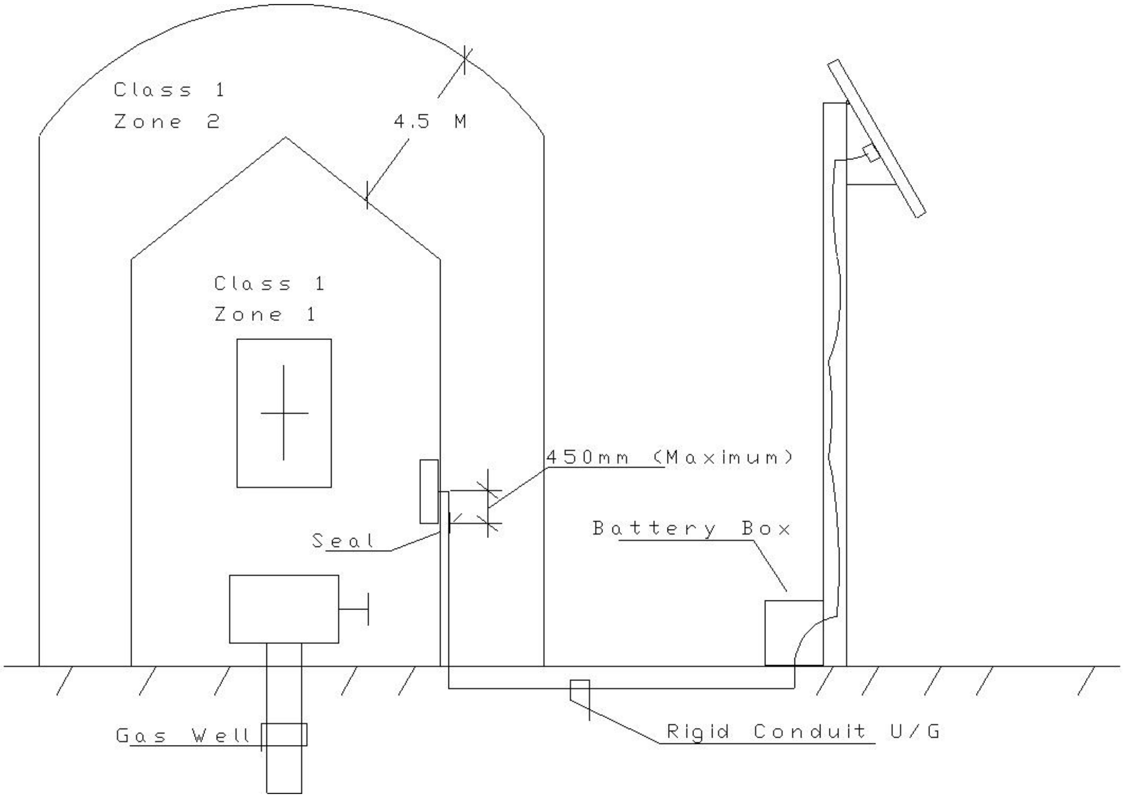

Figure 12 A Typical PV Powered Data Gathering Gas Well Installation

11. CEC Section 26 – Installation of Electrical Equipment

Section 26 covers the installation of all electrical equipment. From a Photovoltaic perspective the most important sections are Storage Batteries (Rules 26-540 to 26-554) and the section on Receptacles (26-700).

11.1 Storage Batteries

Batteries are fundamental to PV systems. In the context of a system used to supply electricity for a residence the question of battery location is of major importance. It is the authors' opinion that the section on batteries in Section 26 is of limited use to an installer of PV systems. The development of Rules 26-540 to 26-554 have been in response to Industrial and Commercial applications. The installation of a battery bank for a residential PV system is quite different. Some of the rules are appropriate and they are the rules dealing with ventilation (26-546), that batteries shall be mounted on an insulating material (26-550)(1) (c) and that batteries shall be spaced apart by 10 mm (26-550)(2). Another rule that is useful is that the wiring shall be either bare or can be a jacketed flexible cable (26-552)(1)(a) and (c). It is not advisable to use bare conductors in a residential system because of the possibility of dropping tools on the bare conductors while working on the battery. Flexible cables are recommended, as they are much easier to install. Spacing the batteries apart by a minimum of 10 mm allows air circulation and battery wall flexing.

If wiring between batteries and other equipment is installed in rigid conduit or EMT, Rule 26-552 requires the end of the raceway to be sealed and the raceway exit to be located at least 300mm above the highest cell terminal. Thus if batteries are installed in a box and conduit is used for the battery to inverter cables, the box must be at least 300mm higher than the battery terminals. Similarly, while not a requirement, providing adequate working spacing above the batteries (300 mm) is recommended.

Batteries should be installed in a room in a building or a battery box built specifically that purpose. For outside installation a battery box must be provided. In all cases, care must be taken to insure adequate ventilation to disperse the hydrogen that is generated during charging.

A very useful publication for the installation of batteries for PV systems is "Guidelines for the use of Batteries in Photovoltaic Systems" published by the Canadian Energy Diversification Research Laboratory of CANMET and Neste Advanced Power Systems (NAPS), Finland.

11.1.1 Battery Ventilation

The following ventilation information is a combination of that contained in the CEC and Guidelines for the use of Batteries in Photovoltaic Systems.

When a battery is being charged it will produce both hydrogen and Oxygen gases. Hydrogen is lighter (least dense) and will tend to become concentrated at the top of the battery enclosure. A concentration of greater than 4% constitutes an explosion hazard. Adequate ventilation therefore must be provided to insure that this build up does not occur. The maximum recommended concentration is between 1 and 2%. One method of insuring proper ventilation is to use a fan, however energy is always at a premium in PV systems, and the use of a fan would not be a fail-safe system. A much better solution is to use natural ventilation. The following illustrates how to properly ventilate a battery enclosure.

For a PV system the maximum amount of hydrogen that will be produced in one hour is given by:

Vh (cu m of hydrogen per hour) = .00045 x (no of cells) x (the maximum charging current)

The concentration in % of hydrogen for each hour in the enclosure will be determined by;

Vh x (100)/Free air space in the enclosure in cu m.

If this calculated concentration were 1% then the air would have to be replaced once each hour to maintain the 1%. If the calculated concentration were 2% then the air would have to be replaced twice each hour and so on. This leads to the following equation for the required number of air changes per hour to maintain a concentration of less than 1%.

Ac (per hour) = Calculated % Concentration in 1 hour/Required concentration in %

Rooms used for battery storage have natural ventilation due to window and door leakage. Typically a room would have approximately 1 air change each 4 hours. Boxes built for battery storage may not have as much air leakage so it is best to assume that no natural ventilation takes place and provide an inlet at the bottom and an outlet at the top. Since hydrogen is lighter than air, natural circulation will take place providing the required ventilation. The following equations are used to calculate the vent sizes.

$$V = 836A(h)^{.5}$$

Where V = the required volume of air in m^3 per hour

And h = the vertical height difference between inlet and outlet in M

And A = the combined area of the vents in m^2

EXAMPLE 11-1

An enclosure is used to house a 24 kWh battery bank. There are 24-2 volt cells and the maximum charging current is 35 Amps. If the total volume of the batteries are 0.36 m^3 and the total volume of the enclosure is 1.36 m^3 (a free air volume of 1 m^3) determine the size of the top and bottom vents if the battery box has a height of 1m.

The amount of Hydrogen produced per hour by these cells is given by:

$Vh = 0.00045 \times 24 \times 35 = 0.378\ m^3$ per hour

This results in a concentration build up of :

$0.378 \times 100/1 = 38\%$

The required number of air changes per hour to keep the concentration to 1% will be

$38\%/1\% = 38$ air changes per hour which will be $38 \times 1.0\ m^3 = 38\ m^3/hr$.

The total area of the 2 vents can be determined by:

$38 = 836(A)(1)^{.5}$ and solving for A yields 0.0455 m^2 total

= 455 cm^2 or 227 cm^2 for each vent area

The required vent size is 15 cm by 15 cm on the top and bottom of the box.

Some sort of protection will be required to keep out bugs and lint. A screen could reduce the effective area by 25%, hence the hole size must be increased to compensate for the screen. Increasing the area by 25% to compensate for the screen would yield a hole size of:

$227 \times 1.25 = 284\ cm^2$ which will yield a required vent size of 17 cm by 17 cm.

Note that the vents should be placed on opposite ends and sides of the battery box to provide a uniform venting action.

Some adjustment of vent size can be achieved by using a chimney on the vent. That is - connect a vertical pipe to the top vent. This effectively increases the vertical height difference between inlet and outlet. A greater inlet/outlet height differential provides a greater venting force. If in the above example a vent pipe was used such that the vertical height difference was

2 m rather that the 1 m, the resulting vent dimensions would be 14.1 cm by 14.1 cm. But what size of pipe? It should be at least have the same area as the vent hole area.

11.2 Receptacle Configurations

In some cases a cottage owner may decide to power household appliances with DC rather than install an inverter. This is acceptable but the question is “What is an acceptable receptacle configuration?” Rules 2 and 3 of 26-700 provides the answer.

Rule 26-700

> 2. Unless otherwise acceptable, receptacles having configurations in accordance with Diagrams 1 and 2 shall only be connected to circuits having a nominal system voltage corresponding to the rating of the configurations.
>
> 3. Receptacles connected to circuits having different voltages, frequencies, or types of current (ac or dc) on the same premises shall be of such design that attachment plugs used on such circuits are not interchangeable.

Thus it is an accepted practice to use a 6-15R or 6-20R receptacle and corresponding plus on the DC circuits in a residence. This is because such receptacle configurations will prevent the accidental connection of an 120VAC appliance, yet such receptacles can be readily obtained from electrical supply houses.