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ENERGY
COMMISSION

A GUIDE TO PHOTOVOLTAIC (PV) SYSTEM DESIGN AND INSTALLATION

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Gray Davis, *Governor*

A GUIDE TO PHOTOVOLTAIC (PV) SYSTEM DESIGN AND INSTALLATION

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PREFACE

The California Energy Commission is providing this guide as an information resource to those installing photovoltaic (PV) systems under the Emerging Renewables Buydown Program. This is the first published draft of this guide and represents the current state-of-the-art in PV system installation. Revisions will be made to the document as necessary to address suggestions made by users of the guide. If anyone has suggestions on how to make this guide more useful, please do not hesitate to send those suggestions to the California Energy Commission. We hope that this guide is a worthwhile addition to the resources available for installers and look forward to your constructive comments for continued improvements.

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SECTION 1: INTRODUCTION

Photovoltaic (PV) power systems convert sunlight directly into electricity. A residential PV power system enables a homeowner to generate some or all of their daily electrical energy demand on their own roof, exchanging daytime excess power for future energy needs (i.e. nighttime usage). The house remains connected to the electric utility at all times, so any power needed above what the solar system can produce is simply drawn from the utility. PV systems can also include battery backup or uninterruptible power supply (UPS) capability to operate selected circuits in the residence for hours or days during a utility outage.

The purpose of this document is to provide tools and guidelines for the installer to help ensure that residential photovoltaic power systems are properly specified and installed, resulting in a system that operates to its design potential. This document sets out key criteria that describe a quality system, and key design and installation considerations that should be met to achieve this goal. This document deals with systems located on residences that are connected to utility power, and does not address the special issues of homes that are remote from utility power.

In this early stage of marketing solar electric power systems to the residential market, it is advisable for an installer to work with well established firms that have complete, pre-engineered packaged solutions that accommodate variations in models, rather than custom designing custom systems. Once a system design has been chosen, attention to installation detail is critically important. Recent studies have found that 10-20% of new PV installations have serious installation problems that will result in significantly decreased performance. In many of these cases, the performance shortfalls could have been eliminated with proper attention to the details of the installation.

1.1. Basic Principles to Follow When Designing a Quality PV System

1. Select a packaged system that meets the owner's needs. Customer criteria for a system may include reduction in monthly electricity bill, environmental benefits, desire for backup power, initial budget constraints, etc. Size and orient the PV array to provide the expected electrical power and energy.
2. Ensure the roof area or other installation site is capable of handling the desired system size.
3. Specify sunlight and weather resistant materials for all outdoor equipment.
4. Locate the array to minimize shading from foliage, vent pipes, and adjacent structures.
5. Design the system in compliance with all applicable building and electrical codes.
6. Design the system with a minimum of electrical losses due to wiring, fuses, switches, and inverters.
7. Properly house and manage the battery system, should batteries be required.
8. Ensure the design meets local utility interconnection requirements.

1.2. Basic Steps to Follow When Installing a PV System

1. Ensure the roof area or other installation site is capable of handling the desired system size.
2. If roof mounted, verify that the roof is capable of handling additional weight of PV system. Augment roof structure as necessary.
3. Properly seal any roof penetrations with roofing industry approved sealing methods.
4. Install equipment according to manufacturers specifications, using installation requirements and procedures from the manufacturers' specifications.
5. Properly ground the system parts to reduce the threat of shock hazards and induced surges.
6. Check for proper PV system operation by following the checkout procedures on the PV System Installation Checklist.
7. Ensure the design meets local utility interconnection requirements
8. Have final inspections completed by the Authority Having Jurisdiction (AHJ) and the utility (if required).

SECTION 2: SYSTEM DESIGN CONSIDERATIONS

2.1 Typical System Designs and Options

PV Electrical System Types

There are two general types of electrical designs for PV power systems for homes; systems that interact with the utility power grid and have no battery backup capability; and systems that interact and include battery backup as well.

2.1.1. Grid-Interactive Only (No Battery Backup)

This type of system only operates when the utility is available. Since utility outages are rare, this system will normally provide the greatest amount of bill savings to the customer per dollar of investment. However, in the event of an outage, the system is designed to shut down until utility power is restored.

Typical System Components:

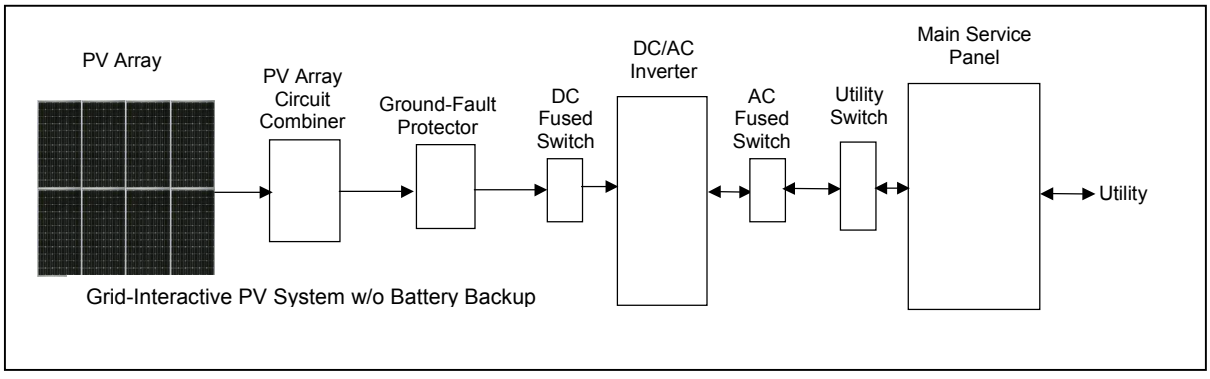
PV Array: A PV Array is made up of PV modules, which are environmentally-sealed collections of PV Cells—the devices that convert sunlight to electricity. The most common PV module that is 5-to-25 square feet in size and weighs about 3-4 lbs./ft^2. Often sets of four or more smaller modules are framed or attached together by struts in what is called a panel. This panel is typically around 20-35 square feet in area for ease of handling on a roof. This allows some assembly and wiring functions to be done on the ground if called for by the installation instructions.

balance of system equipment (BOS): BOS includes mounting systems and wiring systems used to integrate the solar modules into the structural and electrical systems of the home. The wiring systems include disconnects for the dc and ac sides of the inverter, ground-fault protection, and overcurrent protection for the solar modules. Most systems include a combiner board of some kind since most modules require fusing for each module source circuit. Some inverters include this fusing and combining function within the inverter enclosure.

dc-ac inverter: This is the device that takes the dc power from the PV array and converts it into standard ac power used by the house appliances.

metering: This includes meters to provide indication of system performance. Some meters can indicate home energy usage.

other components: utility switch (depending on local utility)



Grid-Interactive PV System w/o Battery Backup

2.1.2. Grid-Interactive With Battery Backup

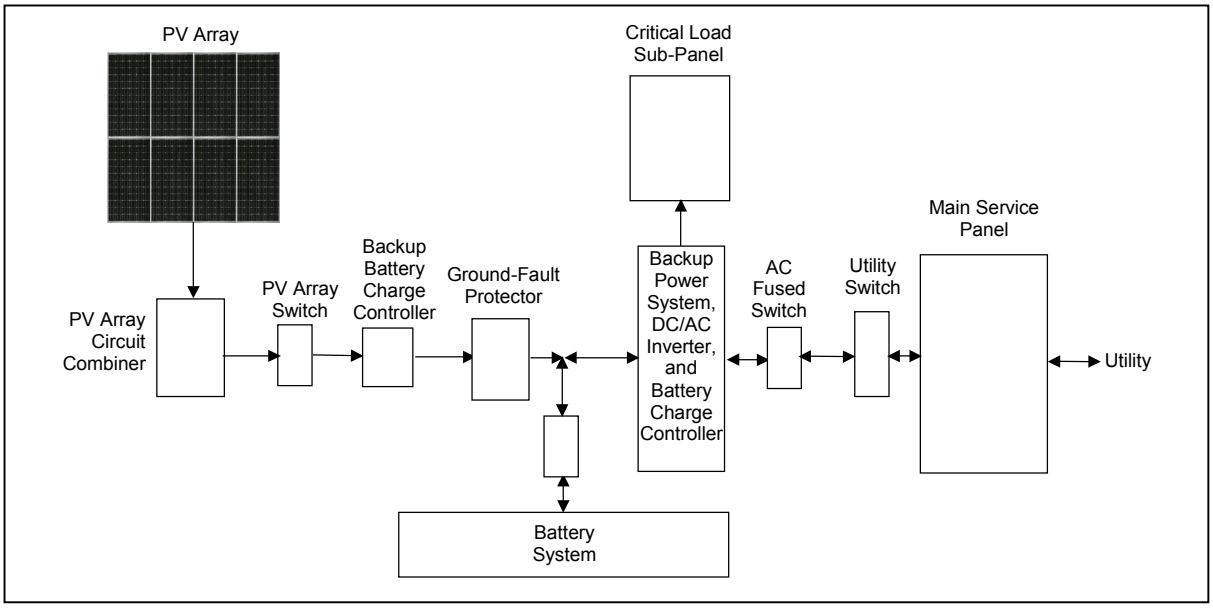
This type of system incorporates energy storage in the form of a battery to keep “critical load” circuits in the house operating during a utility outage. When an outage occurs the unit disconnects from the utility and powers specific circuits in the home. These critical load circuits are wired from a

subpanel that is separate from the rest of the electrical circuits. If the outage occurs during daylight hours, the PV array is able to assist the battery in supplying the house loads. If the outage occurs at night, the battery supplies the load. The amount of time critical loads can operate depends on the amount of power they consume and the energy stored in the battery system. A typical backup battery system may provide about 8kWh of energy storage at an 8-hour discharge rate, which means that the battery will operate a 1-kW load for 8 hours. A 1-kW load is the average usage for a home when not running an air conditioner.

Typical System Components:

In addition to components listed in 2.1.1., a battery backup system may include some or all of the following:

1. batteries and battery enclosures
2. Battery charge controller
3. separate subpanel(s) for critical load circuits



2.2. Mounting Options

There are several ways to install a PV array at a residence. Most PV systems produce 5-to-10 Watts per square foot of array area. This is based on a variety of different technologies and the varying efficiency of different PV products. A typical 2-kW PV system will need 200-400 square feet of unobstructed area to site the system. Consideration should also be given for access to the system. This access space can add up to 20% of needed area to the mounting area required.

Figure 1 Roof Mounted PV System

2.2.1. Roof mount

Often the most convenient and appropriate place to put the PV array is on the roof of the building. The PV array may be mounted above and parallel to the roof surface with a standoff of several inches for cooling purposes. Sometimes, such as with flat roofs,

a separate structure with a more optimal tilt angle is mounted on the roof.

Proper roof mounting can be labor intensive. Particular attention must be paid to the roof structure and the weather sealing of roof penetrations. It is typical to have one support bracket for every 100 Watts of PV modules. For new construction, support brackets are usually mounted after the roof decking is applied and before the roofing materials is installed. The crew in charge of laying out the array mounting system normally installs the brackets. The roofing contractor can then flash around the brackets as they install the roof. A simple installation detail and a sample of the support bracket is often all that is needed for a roofing contractor to estimate the flashing cost.

Masonry roofs are often structurally designed near the limit of their weight-bearing capacity. In this case, the roof structure must either be enhanced to handle the additional weight of the PV system or the masonry roof transitioned to composition shingles in the area where the PV array is to be mounted. By transitioning to a lighter roofing product, there is no need to reinforce the roof structure since the combined weight of composite shingles and PV array is usually less than the displaced masonry product.

2.2.2. Shade Structure

An alternative to roof mounting is to mount the system as a shade structure. A shade structure may be a patio cover or deck shade trellis where the PV array becomes the shade. These shade systems can support small to large PV systems.

Figure 2 Patio Cover or Deck Shade

The construction cost with a PV system is a little different than for a standard patio cover, especially if the PV array is acts as part or the entire shade roof. If the PV array is mounted at a steeper angle than a typical shade structure, additional structural enhancements may be necessary to handle the additional wind loads. The weight of the PV array is 3-to-5 lbs./ft^2, which is well within structural limits of most shade support structures. The avoided cost of installing roof brackets and the associated labor could be counted toward the cost of a fully constructed patio cover. The overall cost of this option will likely be higher than roof mounting, but the value of the shade often offsets the additional costs. Other issues to consider include

- Simplified array access for maintenance
- Module wiring, if visible from underneath, must be carefully concealed to keep the installation aesthetically pleasing
- Cannot grow vines, or must be diligent about keeping it trimmed back from modules and wiring

Figure 3 Building-Integrated Installation

2.2.3. Building-Integrated PV Array (BIPV)

Another type of system displaces some of the conventional roofing product with building-integrated PV modules. Commercially available products currently include roof slates (similar to masonry roofing) and standing seam metal roofing products. Special attention must be paid to ensure that these products are installed properly and carry the necessary fire ratings.

Dimensional tolerances are critical and installation requirements must followed precisely to avoid roof leaks.

2.3 Estimating System Output

PV systems produce power in proportion to the intensity of sunlight striking the solar array surface. The intensity of light on a surface varies throughout a day, as well as day to day, so the actual output of a solar power system can vary substantial. There are other factors that affect the output of a solar power system. These factors need to be understood so that the customer has realistic expectations of overall system output and economic benefits under variable weather conditions over time.

2.3.1. Factors Affecting Output

Standard Test Conditions

Solar modules produce dc electricity. The dc output of solar modules is rated by manufacturers under Standard Test Conditions (STC). These conditions are easily recreated in a factory, and allow for consistent comparisons of products, but need to be modified to estimate output under common outdoor operating conditions. STC conditions are: solar cell temperature = 25 ^{o}C; solar irradiance (intensity) = 1000 W/m^{2} (often referred to as peak sunlight intensity, comparable to clear summer noon time intensity); and solar spectrum as filtered by passing through 1.5 thickness of atmosphere (ASTM Standard Spectrum). A manufacturer may rate a particular solar module output at 100 Watts of power under STC, and call the product a “100-watt solar module.” This module will often have a production tolerance of +/-5% of the rating, which means that the module can produce 95 Watts and still be called a “100-watt module.” To be conservative, it is best to use the low end of the power output spectrum as a starting point (95 Watts for a 100-watt module).

Temperature

Module output power reduces as module temperature increases. When operating on a roof, a solar module will heat up substantially, reaching inner temperatures of 50-75 ^{o}C. For crystalline modules, a typical temperature reduction factor recommended by the CEC is 89% or 0.89. So the “100-watt” module will typically operate at about 85 Watts (95 Watts x 0.89 = 85 Watts) in the middle of a spring or fall day, under full sunlight conditions.

Dirt and dust

Dirt and dust can accumulate on the solar module surface, blocking some of the sunlight and reducing output. Much of California has a rainy season and a dry season. Although typical dirt and dust is cleaned off during every rainy season, it is more realistic to estimate system output taking into account the reduction due to dust buildup in the dry season. A typical annual dust reduction factor to use is 93% or 0.93. So the “100-watt module,” operating with some accumulated dust may operate on average at about 79 Watts (85 Watts x 0.93 = 79 Watts).

Mismatch and wiring losses

The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules. This difference is a result of slight inconsistencies in performance from one module to the next and is called module mismatch and amounts to at least a 2% loss in system power. Power is also lost to resistance in the system wiring. These losses should be kept to a minimum but it is difficult to keep these losses below 3% for the system. A reasonable reduction factor for these losses is 95% or 0.95.

Dc to ac conversion losses

The dc power generated by the solar module must be converted into common household ac power using an inverter. Some power is lost in the conversion process, and there are additional losses in the wires from the rooftop array down to the inverter and out to the house panel. Modern inverters commonly used in residential PV power systems have peak efficiencies of 92-94% indicated by their manufacturers, but these again are

measured under well-controlled factory conditions. Actual field conditions usually result in overall dc-to-ac conversion efficiencies of about 88-92%, with 90% or 0.90 a reasonable compromise.

So the "100-watt module" output, reduced by production tolerance, heat, dust, wiring, ac conversion, and other losses will translate into about 68 Watts of AC power delivered to the house panel during the middle of a clear day (100 Watts x 0.95 x 0.89 x 0.93 x 0.95 x 0.90 = 67 Watts).

2.3.2. Estimating System Energy Output

Sun angle and house orientation

During the course of a day, the angle of sunlight striking the solar module will change, which will affect the power output. The output from the "100-watt module" will rise from zero gradually during dawn hours, and increase with the sun angle to its peak output at midday, and then gradually decrease into the afternoon and back down to zero at night. While this variation is due in part to the changing intensity of the sun, the changing sun angle (relative to the modules) also has an effect

	Flat	4:12	7:12	12:12	21:12	Vertical
South	0.89	0.97	1.00	0.97	0.89	0.58
SSE,SSW	0.89	0.97	0.99	0.96	0.88	0.59
SE, SW	0.89	0.95	0.96	0.93	0.85	0.60
ESE,WSW	0.89	0.92	0.91	0.87	0.79	0.57
E, W	0.89	0.88	0.84	0.78	0.70	0.52

Table 1: Orientation Factors for Various Roof Pitches and Directions

The pitch of the roof will affect the sun angle on the module surface, as will the East-West orientation of the roof. These effects are summarized in Table 1, which shows that an array on a 7:12-pitch roof facing due South in Southern California gives, for example, the greatest output (correction factor of 1.00), while an East facing roof at that same pitch would yield about 84% of the annual energy of the South facing roof (a correction factor of 0.84 from Table 1).

Table 2 is intended to give a conservative estimate of the annual energy expected from a typical PV system, taking into account the various factors discussed above.

These values are for annual kWh produced from a 1-kilowatt (1kW) STC DC array, as a simple and easy guide. If the system includes battery backup the output may be reduced further by 6-10% due to battery effects.

CITY	kWh/kWstc (range)
Arcata	1092 - 1365
Shasta	1345 - 1681
San Francisco	1379 - 1724
Sacramento	1455 - 1819
Fresno	1505 - 1881
Santa Maria	1422 - 1778
Barstow	1646 - 2058
Los Angeles	1406 - 1758
San Diego	1406 - 1758

Table 2: Annual Energy Production by City per kW_{STC} array rating

Example: A 4 kW_{STC} solar array (as specified under STC conditions) located in the Los Angeles area at a 4:12 pitch and facing southeast should produce at least 5343 kWh of electric energy annually (1406 kWh/kW x 0.95 x 4 kW = 5343 kWh). The typical residential customer in that area uses about 7300 kWh annually[1], meaning such a PV system could produce at least 75% of the total energy needed by such a typical home. And if energy efficiency measures were taken by the owner to reduce the overall electrical consumption of the home, the percentage could approach 100%. Note that the low end of the range was used to calculate the actual savings. It is wise to be conservative when making performance claims.

Net metering has recently been extended to time-of-use customers yielding a potential additional value of 20-30% for the PV electricity generated by the system. With this net time-of-use metering, the homeowner would cover almost their entire electric bill and only have to pay the monthly metering charge.

[1] Actual residential electrical energy usage varies dramatically from one home to the next. It is best to use the previous two years of energy bills to determine actual energy consumption for a particular home. Energy consumption in California can vary from 3,000 kWh/year for a very minimal user to 25,000 kWh/year for a large home with heavy electrical usage.

2.4. Installation Labor Effort

Installation effort is very sensitive to specific house layouts and roofing type. An experienced crew can install a 2 kW non-battery PV system in two-to-four person-days. Systems with large solar arrays are relatively less effort per watt of power and kWh of energy than smaller systems because the installation of the inverter and other hardware required by all PV systems is spread over more solar modules. Systems with battery backup are more labor intensive than non-battery systems because of the additional wiring required for wiring the critical load subpanel. A battery system can add 50-100% to the time required for the installation.

2.5. Incentives to Reduce Costs

Financial incentives are available from the Energy Commission, the CPUC, and several local utilities and municipalities throughout California to reduce these system costs. The CEC buydowns are calculated by multiplying $4.50 times the adjusted peak dc power from the system in Watts (up to a maximum of 50% of the system cost). This buydown is available for all Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E) customers. Some municipal utilities in cities such as Sacramento, Los Angeles, Palo Alto, and Roseville provide the same or even higher incentives.

This level of rebate can reduce the cost of systems by 30 to 50 percent or more and result in much more favorable economics for the owner. An owner can incorporate a basic 1 kW solar power system for as little as $3,000-$5,000. If the system is included in the mortgage of the home, this small increment in house payment may be offset by an equivalent reduction in the monthly utility bill.

2.6. Estimating Electrical Energy Savings

One of the key benefits of residential solar power systems is a lower electric utility bill resulting from the energy that the solar system produces. The energy savings to a homeowner can be estimated by simply multiplying the annual energy in kWh that a PV system might produce times the utility electric energy rate. These rates vary by local utility, and are likely to increase from their current values. Estimated energy savings from small and large PV systems in Southern California are presented below to illustrate the kinds of savings that can be achieves.

Sample Annual Electric Utility Bill Savings

Solar Array (STC)	Estimated Annual Energy	Utility Electric Energy Rate			
		$0.10 /kWh	$0.15 /kWh	$0.20 /kWh	$0.25 /kWh
1.2 kW	1687 kWh	$168.70	$224.93	$337.40	$421.75
4.0 kW	5624 kWh	$562.40	$843.60	$1,124.80	$1406.00

2.7. Supplier and System Qualifications

When choosing a supplier and specifying a PV system, the following are a series of general guidelines to help guide the decision-making process.

2.7.1. Pre-Engineered Systems

When a owner considers an HVAC system for a home, they do not buy a compressor from one manufacturer and a cooling coil from another company, and a fan from a third company and then put these pieces together. The equipment manufacturers have engineered a packaged system that is designed to work together. Each model of a home may need a slightly different unit based on the size and layout, but those variations have been

designed into the product. In the same way, the components of a PV system should be engineered to work together as a unit accounting for variations in system size for different homes.

Since the PV industry is in the early stages of development, there is a wide range of competency levels among PV system integrators. Unless the installer is familiar enough with the technology to recognize whether the system integrator is competent, it is much safer to stay with a firm that provides pre-engineered systems. Pre-engineering may not guarantee a flawless system, but the concerns over product compatibility and specification of individual components have been addressed in the system design.

2.7.2. Warranties

There are several types of warranties that come with a system or can be purchased in addition to a standard warranty. These include (1) product warranties covering defects in manufacture; (2) system warranties covering proper operation of equipment for a specific time period (5 or 10 years); and, (3) annual energy performance warranties covering the guaranteed output of the PV system. The installer, to guarantee proper system installation, often covers the system and annual energy performance warranties.

Product warranties:
It is common these days to see warranties on PV modules of 20 or more years. Although this is impressive and indicates the level of confidence manufacturers place in the longevity of their products, there are many other components in these systems that may not have the same life expectancy. Inverters may have 10-year, five-year, or even one-year warranties. This must be considered when reviewing the cost of inverters and other system components.

System warranties:
It is equally important to look for entire system-level warranties of five years or more. This indicates that the manufacturer has taken many other operational issues into account. Since these systems generate electrical power, it is helpful to have system performance included as part of the warranty. For instance, a typical system-level warranty might state that the system is guaranteed to produce two kilowatts (2 kW) of AC power at PVUSA Test Conditions (PTC) (PTC is 1kW/m^2 irradiance, 1 m/s wind speed, 20^{o}C ambient temperature) in the fifth year of operation. The equipment to perform this test is expensive, but the fact that a company would know enough to specify this type of warranty is an indication that they are confident in their system design. Currently, the California Energy Commission Buydown program requires installing contractor to provide these warranties. The intent of this requirement is to improve customer acceptance of PV systems.

Annual energy performance warranties:
Although there are very few companies selling systems with this type of warranty, an energy performance warranty guaranties that the system will perform consistently over a period of time. This is particularly helpful in ensuring that the customer receives the bill savings that they expect. This type of warranty is more common with energy efficiency retrofit projects for commercial and industrial clients. Adequate metering to verify the system power output and energy generation is necessary to help the system owner understand whether the system is operating properly, or has warranty-related performance issues. With an adequate meter, the customer can readily identify when the system is malfunctioning.

2.7.3. Company Reputation (years in business, previous projects)

The reputation of the PV manufacturer is a critical piece of the decision-making process. The size of the company, number of years in business, number of previous projects completed, are all important issues that need to be reviewed before choosing a company's products. Although price is often the strongest single consideration in reviewing proposals, the other less tangible considerations often add up to a similar level of importance with cost. Fortunately, there are several companies with very strong financial and historical records in this field. It is recommended that you research the background and history of the prospective vendor thoroughly.

2.8. Overall Project Coordination

Once the decision is made to install a PV system, several issues must then be addressed.

2.8.1. Utility Considerations

The electric utility company providing service to the residence plays a very important role in this process. Interconnecting a PV system to the utility grid is not a trivial undertaking. Fortunately, PV has a well-developed set of utility interconnection standards making the process fairly straightforward. However, utilities are generally cautious since most have little experience interconnecting PV systems. The key point is to involve the utility as early as possible in the installation. Most knowledgeable utilities have adopted IEEE 929-2000 *Recommended Practice for Utility Interface of Photovoltaic (PV) Systems*. If the utility is unfamiliar with this document, make sure that they obtain a copy and thoroughly review it.. An inverter listed to UL 1741 (with the words "Utility-Interactive" printed on the listing mark) indicates that the unit is fully compliant with IEEE 929-2000.

The other major utility-related consideration is metering requirements. In California, as in many other states, there is legislation mandating utility companies to “net-meter” a certain amount of PV systems. Net metering refers to a standard house utility meter that measures the flow of electricity in and out of the home[2]. California law allows customers to carry-over excess energy from month-to-month with an annual true-up and payment of the electrical bill for any net consumption over the whole year. The net metering law does not require the utility to compensate the customer for excess electricity at the end of that 12-month period. For more information about this and other consumer-related PV issues, download the document, *Buying a Photovoltaic Solar Electric System: A Consumers Guide,* from the California Energy Commission’s website at http://www.energy.ca.gov/reports/500-99-008.PDF or call 1-800-555-7794 (Renewable Energy Call Center) to receive a copy by mail.

2.8.2. Acceptance of Systems (performance evaluation)

Typically, the installer verifies that the system has been installed according to the manufacturer’s procedures. A checkout procedure should be developed, such as the one provided in section 4 of this guide, to ensure an efficient and complete installation. Obtaining extremely accurate performance is difficult and requires expensive test equipment. Fortunately, it is not necessary to define the performance with extreme accuracy. A system can be checked with some common test equipment to verify proper installation and performance. A key to keeping the system testing simple is to do the tests on cloudless days. Clouds can cause fluctuations that confound evaluation of the results. The PV System Installation Checklist that accompanies this guide has a detailed System Acceptance Test.

2.8.3. System Documentation

Up to this point, selection, installation, and performance of PV systems have been discussed. Of similar importance are operation and ongoing maintenance of the equipment. As with other major systems in a home, it is essential that the owner have complete documentation on the system. System documentation should include an owner’s manual and copies of relevant drawings for whatever system maintenance might be required in the future.

2.8.4. System Monitoring

The key component of the system providing feedback to the customer is the power and energy metering. Without proper metering the customer will never know whether the system is operating properly or not. A simple meter, registering the power output of the PV system and recording the energy delivered to the house, can provide the owner with the satisfaction that they can monitor the performance of the system.

[2] Yes, out! Even a 500-Watt PV system on a sunny day may generate more electricity than the home consumes at any given time.

Maximum power output of most properly installed PV systems occurs near midday on sunny days in the spring and fall. If the owner fully understands this characteristic they will not be disappointed with unavoidable low output in the middle of the winter. The meter is also a way of proving to the owner that the equipment is properly installed. Often, the owner's primary indication of whether they feel the system is operating properly on not is their monthly electric bill. If the owner suddenly begins using more electricity, they may not see much decrease in their bill and assume the PV system is under-performing. A meter can help avoid disputes between the installer and the owner by showing that the system performs as advertised.

One of the attractive attributes of PV system is low maintenance. However, even electrical systems need to be maintained from time to time. With proper metering, an informed owner can easily determine if their system is operating properly or not. It is important that the owner have contact information for contractors that can perform system maintenance in their area. Although many areas do not have full-time PV contractors, it is always helpful to provide a list of two or three local contractors that offer PV maintenance services. Along with the information on local contractors, the system warranty information should be provided so that the customer clearly understands what is and is not covered by their warranty.

2.9. References

1999 National Electrical Code (NEC) Article 690 and Article 702.

Emerging Renewables Buy-Down Program Information: http://www.energy.ca.gov/greengrid

Buying a Photovoltaic Solar Electric System: A Consumers Guide: http://www.energy.ca.gov/reports/500-99-008.PDF

Clean Power Estimator: http://www.energy.ca.gov/cleanpower/index.html

List of Certified PV Modules: http://www.energy.ca.gov/greengrid/certified_pv_modules.html

List of Certified Inverters: http://www.energy.ca.gov/greengrid/certified_inverters.html

California Energy Commission, 1516 9th Street, Sacramento, CA 95814-5512, 800-555-7794 (Renewable Energy Call Center)

UL Standard 1703, Standard for Flat-plate Photovoltaic Modules and Panels

UL Standard 1741, Inverters, Converters, and Controllers for Independent Power Systems

IEEE Standard 929-2000, Recommended Practice for Utility Interface of Photovoltaic (PV) Systems

IEEE Standard 1262-1995, Recommended Practice for Qualification of Photovoltaic (PV) Modules

Environmental benefits of PV systems can be found at the following USEPA website: http://199.223.18.230/epa/rew/rew.nsf/solar/index.html

SECTION 3: SYSTEM INSTALLATION

3.1. General Recommendations

The following is a list of general recommendations to help the installer choose the right materials, equipment, and installation methods that will help ensure that the system will provide many years of reliable service. These recommendations can be used to evaluate pre-engineered system designs and compare system features from one supplier to another.

3.1.1. Materials recommendations

- Materials used outdoors should be sunlight/UV resistant
- Urethane sealants should be used for all non-flashed roof penetrations.
- Materials should be designed to withstand the temperatures to which they are exposed.
- Dissimilar metals (such as steel and aluminum) should be isolated from one another using non-conductive shims, washers, or other methods.
- Aluminum should not be placed in direct contact with concrete materials.
- Only high quality fasteners should be used (stainless steel is preferred).
- Structural members should be either:
    - corrosion resistant aluminum, 6061 or 6063
    - hot dip galvanized steel per ASTM A 123
    - coated or painted steel (only in low corrosive environments such as deserts)
    - stainless steel (particularly for corrosive marine environments)

3.1.2. Equipment recommendations and installation methods

- All electrical equipment should be listed for the voltage and current ratings necessary for the application.
- PV modules should be listed to UL 1703 and warranted for a minimum of 5 years (20-25 year warranties are available).
- Inverters should be listed to UL 1741 and warranted for a minimum of 5 years (outside CA these may not be available).
- All exposed cables or conduits should be sunlight resistant.
- All required overcurrent protection should be included in the system and should be accessible for maintenance
- All electrical terminations should be fully tightened, secured, and strain relieved as appropriate.
- All mounting equipment should be installed according to manufacturers' specifications
- All roof penetrations should be sealed with an acceptable sealing method that does not adversely impact the roof warranty
- Integral roofing products should be properly rated (e.g., class A roofing materials)
- All cables, conduit, exposed conductors and electrical boxes should be secured and supported according to code requirements.
- PV Array should be free of shade between 9:00 a.m. and 4:00 p.m. This requirement includes even small obstructions such as vent pipes and chimneys. A small amount of shade can have a disproportionately high impact on system performance

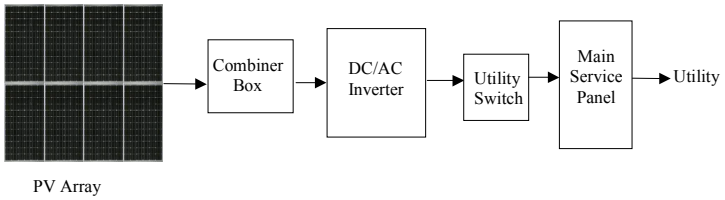


Figure 4 Simple PV System Diagram

3.2. PV System Design And Installation

3.2.1. Preparation Phase

1. Contact the California Energy Commission 1-800-555-7794 (Renewable Energy Call Center) to receive a copy of the guide for the Buydown program or download the guide from the Buydown Website at www.energy.ca.gov/greengrid.

2. Obtain past electric bills for the home if available and audit home to determine what can be done to reduce electricity usage.

3. Determine the size of the PV system based on budget, energy cost reduction, and available mounting area for the system. The PV system supplier typically provides the customer with sizing and performance information. The method in section 2 of this document is intended to provide a basis to identify those suppliers who are thorough in their sizing estimates.

4. Determine the physical size and dimensions of the PV array and its primary components. This is critically important in determining where the PV array and ancillary equipment is to be mounted.

3.2.2. Design Phase

1. Examine location options for mounting the PV array (i.e. roof, patio cover, other structure).

2. Review available pre-engineered system packages that contain the desired options. Compare the various product and system warranties available from each supplier.

3. Confirm that the PV equipment has the necessary listings required by building officials (e.g. UL 1703, UL 1741, and any applicable evaluation reports from National Evaluation Services (NES) or International Conference of Building Officials (ICBO) Evaluation Services)

4. Select system options making sure the equipment meets the guidelines of local incentive programs. For the California Buydown Program check that the PV modules and inverter are listed on the Buydown Website at www.energy.ca.gov/greengrid

5. Contact local utility company (PG&E, SCE, or SDG&E) to obtain the required documents for interconnection and net metering.

6. Review documents to ensure system meets local interconnection requirements

7. Purchase the equipment.

8. Send completed Buydown Reservation package to the California Energy Commission.

9. Lay out PV array on roof plan or other structure. If roof mounted, determine required location of PV modules on roof and any potential roof penetrations due to plumbing or combustion appliance vents that could affect array placement or shade the array. Some obstructions can be relocated to another portion of the roof should the penetration dramatically impact the location of the array. Attempt to provide for an aesthetically pleasing layout by attempting to follow the dimensional shape of the roof section (example: if the roof is rectangular, try to maintain the same shape rectangle in the array layout). If modules are to be grouped in panels of several modules for ease of wiring and mounting, try to arrange the panels in symmetrical arrangements.

10. Calculate the impact of shading on the PV array layout with the assistance of a Solar Pathfinder (http://www.solarpathfinder.com/). Consider other locations to mount the PV array if the proposed location receives too much shade. Review the mounting options discussed in section two of this guide for alternatives.

11. Measure the distance between the estimated locations of all system components and develop site drawing and one-line diagram of PV system installation for the permit package. (See example drawing).

12. Assemble the permit package for the local authority having jurisdiction (AHJ). This package should include the following:

    a. Site drawing showing the location of the main system components--PV Array, conduit runs, electrical boxes, inverter enclosure, critical load subpanel, utility disconnect, main service panel, and utility service entrance. (see drawing EX-1 in Appendix)
    b. One-line diagram showing all significant electrical system components. (see drawings EX-2 and EX-3 in Appendix)
    c. Cut sheets for all significant electrical system components (PV modules, inverter, combiner, dc-rated switches and fuses, etc…).
    d. Copy of filled out utility contract.
    e. Structural drawing if the system is incorporated into a separate structure.
    f. Structural calculations as necessary

3.2.3. Installation Phase

1. Submit required permit materials to the AHJ and pay for permit to begin construction.

2. Receive equipment and prepare for installation. Examine all equipment to be sure that all equipment was shipped and that none was damaged in shipping.

3. Review installation instructions for each component to become familiar with the installation process.

4. Estimate length of wire runs from PV modules to combiner and inverter.

5. Check ampacity of PV array circuits to determine the minimum wire size for current flow. Size wire for the run based on maximum short circuit current for each circuit and the length of the wire run. Example using drawing EX-1 in the appendix:
   Check ampacity of PV array circuits:
   a. Minimum wire ampacity for the wire run from modules to combiner is based on module maximum series fuse rating printed on the listing label (i.e. 15-amps on 100-Watt module). From Table A-1 in the appendix, use the column for 90C in an open rack, use at least #14 AWG USE-2 wire. This is the minimum wire size and may need to be enlarged to reduce voltage drop.
   b. Minimum wire ampacity for the wire run from combiner to inverter is based on the number of module series strings times the maximum series fuse rating (5 series strings = 5 x 15 amps = 75 amps). From Table A-1 in the appendix, use the column titled “Ampacity of 75C wet rated conductors (45C)”, for a minimum of #3 AWG THWN wire in conduit. This is the minimum wire size and may need to be enlarged due to voltage drop.

6. Size PV array wiring such that the maximum voltage drop at full power from the PV modules to the inverter is 3% or less (6-amps for a 100-Watt module). If array combiner box is located remote from the inverter, spread the voltage drop accordingly between the PV array-to-combiner wiring and the combiner-to-inverter wiring (example from EX-1 in the appendix: with a 100-foot wire run from PV modules to inverter (3% total) comprised of a 25-foot wire run from PV modules to combiner box and a 75-foot wire run from combiner box to inverter—use a maximum of 1% for the 25-foot run and 2% loss for the 75-foot section for a total of 3%)
   a. wire run from modules to combiner is 25 feet. From the 48-Volt Table A-3 in the appendix, 1% voltage drop for 25 feet and 6 amps (to use table for 1% voltage drop, find D-Factor for 3% voltage drop for 6-amps at 25 feet (1.1), then multiply this value by 3 (3.3) to obtain proper size of wire on Table A-1in the appendix), use #10 AWG wire.
   b. wire run from combiner to inverter is 75 feet. From the 48-Volt Table A-3 in the appendix, 2% voltage drop for 75 feet and 30 amps (to use table for 2% voltage drop, find D-Factor for 3% voltage drop for 30 amps at 120 feet (16) then multiply this value by 1.5 (24) to obtain proper size of wire on Table A-1in the appendix), use #2 AWG wire.

7. Estimate length of wire run from inverter to main service panel (Example drawing EX-1 in the appendix: wire run from inverter to panel is 25 feet).
   Example using sample drawing EX-1 in the appendix:
   Goal is 1% voltage drop for ac-side of system (3% absolute maximum)
   From 120-Volt table A-4, 1% voltage drop for 30 feet and 35 amps (to use table for 1% voltage drop, find D-Factor for 3% voltage drop for 30-amps at 30 feet (2.5), then multiply this value by 3 (7.5) to obtain proper size of wire on Table A-1), use #6 AWG wire.

8. Examine main service panel to determine if the panel is adequately sized to receive the PV breaker or whether the panel must be upgraded.

   Many homes in California are fed by a 100-amp service panel. For residential applications, the NEC 690-64 allows the total supply (utility plus PV) to the busbar of the service panel to equal 120% of the busbar rating (100-amps x 1.2 = 120-amps). This means that a 100-amp service panel can have a 100-amp main breaker and a 20-amp PV breaker. If our example system can supply 45-amps of continuous power, we need room for a 60-amp circuit breaker (45-amps x 1.25 = 56.25 amps). A system that size will require either replacing the 100-amp main breaker with a 75-amp unit (not usually recommended) or replacing the existing 100-amp service panel with a 200-amp service panel. The 200-amp service panel is allowed 240-amps of supply (200-amps x 1.2= 240-amps) so if the PV breaker is rated at 60-amps, the main breaker can be up to 180 amps (240 amps – 60 amps = 180 amps)

9. If system includes a critical load subpanel (battery standby system), determine which circuits are critical. These circuits must be adequately designed to handle the anticipated electrical loads. The standby portion of the system is considered by the NEC to be an Optional Standby System covered by Article 702.
   a. Warning: Multi-wire branch circuits in a home must be closely evaluated to allow them to be wired to a 120VAC optional standby system. There are four main ways to deal with these types of circuits:
      i. Install an autotransformer on the output of the inverter to step up the supplied voltage from 120Vac to 240Vac if necessary. The critical load subpanel can then be powered without concern of neutral overload.
      ii. Rerun one new branch circuit with each multiwire circuit so that one of the supply conductors of the multiwire circuit can be eliminated and the two circuits no longer share the neutral.
      iii. Avoid multiwire branch circuits in the home. This is often unacceptable since refrigerators and other key loads are normally found on multiwire branch circuits.
      iv. Derate the supply breaker to match the ampacity of the neutral wire. This is done by first determining that the maximum load on the two circuits is less than 80% of the rating of one pole of the double-pole supply breaker. For instance, if the supply breaker is a 20-amp double-pole breaker, the maximum allowable load on both circuits is a total of 16-amps at 120-Vac. To confirm this load, turn on all the loads intended to be operated at the same time and measure the load current with a clamp-on ammeter. If the total from the two circuits is less than 16-amps, the circuit may be supplied by a single-pole 20-amp circuit breaker, which protects the neutral from overload.
   b. All loads to be connected to the optional standby system must be carefully evaluated to determine if the actual power consumption and daily usage for each load can be met by the system in standby mode.
   c. All standby loads must be wired into a separate sub-panel for connection to the standby output of the inverter.
   d. Average power consumption for the standby power system loads must be calculated to determine how long the storage battery will provide uninterrupted power for typical electric usage.

e. Article 702--Optional Standby Systems allows sizing based on supply of all equipment intended to be operated at one time (NEC 702-5). This means that all the 120-Volt loads could be run off of a single-pole 60-amp breaker from an optional standby system as long as the actual continuous load is below the 80% limit for continuous operation of a breaker (48 amps).
f. It is recommended that the storage battery system consist of maintenance-free valve-regulated lead-acid (VRLA) batteries with absorbed glass mat (AGM) construction since these require no maintenance by the homeowner. Other types of batteries may become available in the future that are equally suited to this application, but do not attempt to use any battery that has not been thoroughly tested in Uninterruptible Power System (UPS) applications.
g. Battery storage cabinet must be kept out of the sun and in as cool a place as practical.
h. Every battery storage system, whether it includes flooded lead-acid, or valve-regulated lead-acid batteries, requires ventilation. Battery storage cabinet must be ventilated to the outdoors; vents need to be at the high and low points in the cabinet. For battery systems in utility rooms in a living space, follow the same ventilation requirements as needed for gas-fired service water heaters.

10. Determine location of critical load subpanel, install subpanel and prepare to move circuits

11. Install PV array. Packaged systems should include detailed instructions on each phase of the installation process. Some basic guidelines that may help in reviewing installation procedures are:
    a. Prepare structure for mounting of PV array. If roof-mounted, hire roofing contractor to install roof mounts according to manufacturer's directions.
    b. Check modules visually and check the open circuit voltage and short circuit current of each module before hauling onto the structure to verify proper operation—see checklist.
    c. Use plug connectors to connect panels together where listed products are available. This reduces installation time.
    d. Use only as many attachment points and roof penetrations as necessary for structural loading concerns. The number of attachment points and structural requirements of the roof must be specifically identified in the drawings.
    e. Mount PV array to support structure.

12. Install PV combiner, inverter, and associated equipment to prepare for system wiring.

13. Connect properly sized wire (determined in step 6 of installation phase) to each circuit of modules and run wire for each circuit to the circuit combiner(s). (WARNING: It is advisable to terminate the circuits in the circuit combiner prior to completing the final connection for each string at the PV array end of the circuit.)

14. Run properly sized wire (determined in step 6 of installation phase) from circuit combiner to inverter overcurrent/disconnect switch (if available--follow installation procedure supplied by manufacturer).

15. Run properly sized wire (determined in step 7 of installation phase) from inverter to utility disconnect switch (WARNING: Make sure the neutral wire does not get routed through one of the switch poles in the disconnect box.)

16. Run properly sized wire (determined in step 7 of installation phase) from utility disconnect switch to main service panel and connect circuit to the main utility service.

17. Use the checklist in section 4 to ensure proper installation throughout the system.

18. Verify that all PV circuits are operating properly and the system is performing as expected. The PV System Installation Checklist in section 4 of this guide has a detailed performance testing procedure entitled System Acceptance Test.

19. Shut system down and call for final inspections (AHJ first then utility--if necessary).

20. Once approval to parallel is received from the utility, begin system operation.

21. Mail completed Buydown Request Form, with all necessary attachments, to the California Energy Commission to receive Buydown payment.

22. Enjoy watching your meter spin backward. (note: Time-Of-Use net meters do not have a meter disk to watch run backward—it has a digital readout instead).

3.2.4. Maintenance and Operation Phase

1. Wash PV array, during the cool of the day, when there is a noticeable buildup of soiling deposits.

2. Periodically inspect the system to make sure all wiring and supports stay intact.

3. On a sunny day near noon on March 21 and September 21 of each year, review the output of the system (assuming the array is clean) to see if the performance of the system is close to the previous year's reading. Maintain a log of these readings so you can identify if the system is performance is staying consistent, or declining too rapidly, signifying a system problem.

SECTION 4: SOLAR ELECTRIC (PV) SYSTEM INSTALLATION CHECKLIST

Following the completion of each item on the checklist below, check the box to the left of the item and insert the date and initials of the person completing the item whether that is the installing contractor or owner-installer. Remember to follow the proper safety procedures while performing the system installation. The appropriate safety equipment for each section of the checklist is listed above each section of the checklist.

Before starting any PV system testing: (hard hat and eye protection recommended)

❑ 1._____Check that non-current carrying metal parts are grounded properly. (array frames, racks, metal boxes, etc. are connected to the grounding system)

❑ 2._____Ensure that all labels and safety signs specified in the plans are in place.

❑ 3. _____Verify that all disconnect switches (from the main AC disconnect all the way through to the combiner fuse switches) are in the open position and tag each box with a warning sign to signify that work on the PV system is in progress.

PV ARRAY--General (hard hat, gloves, and eye protection recommended)

❑ 1. _____Verify that all combiner fuses are removed and that no voltage is present at the output of the combiner box.

❑ 2. _____Visually inspect any plug and receptacle connectors between the modules and panels to ensure they are fully engaged.

❑ 3. _____Check that strain reliefs/cable clamps are properly installed on all cables and cords by pulling on cables to verify.

❑ 4. _____Check to make sure all panels are attached properly to their mounting brackets and nothing catches the eye as being abnormal or misaligned.

❑ 5. _____Visually inspect the array for cracked modules.

❑ 6. _____Check to see that all wiring is neat and well supported.

PV ARRAY CIRCUIT WIRING (hard hat and eye protection recommended)

❑ 1._____Check home run wires (from PV modules to combiner box) at DC string combiner box to ensure there is no voltage on them.

❑ 2. _____Recheck that fuses are removed and all switches are open.

❑ 3. _____Connect the home run wires to the DC string combiner box terminals in the proper order and make sure labeling is clearly visible.

REPETITIVE SOURCE CIRCUIT STRING WIRING (hard hat, gloves, and eye protection recommended)
The following procedure must be followed for each source circuit string in a systematic approach—i.e. east to west or north to south. Ideal testing conditions are midday on cloudless days March through October.

❑ 4. _____Check open-circuit voltage of each of the panels in the string being wired to verify that it provides the manufacturer's specified voltage in full sun. (Panels under the same sunlight conditions should have similar voltages--beware of a 20 Volt or more shift under the same sunlight conditions.)

❑ 5._____Verify that the both the positive and negative string connectors are identified properly with permanent wire marking.

❑ 6._____Repeat this sequence for all source circuit strings.

CONTINUATION OF PV ARRAY CIRCUIT WIRING (hard hat, gloves, and eye protection recommended)

❑ 7._____Recheck that DC Disconnect switch is open and tag is still intact.

❑ 8._____**VERIFY POLARITY** OF EACH SOURCE CIRCUIT STRING in the DC String Combiner Box (place common lead on the negative grounding block and the positive on each string connection--pay particular attention to make sure there is NEVER a negative measurement). Verify open-circuit voltage is within proper range according to manufacturer's installation manual and number each string and note string position on as-built drawing. (Voltages should match closely if sunlight is consistent.)

WARNING: IF POLARITY OF ONE SOURCE CIRCUIT STRING IS REVERSED, THIS CAN START A FIRE IN THE FUSE BLOCK RESULTING IN THE DESTRUCTION OF THE COMBINER BOX AND POSSIBLY ADJACENT EQUIPMENT. REVERSE POLARITY ON AN INVERTER CAN ALSO CAUSE DAMAGE THAT IS NOT COVERED UNDER THE EQUIPMENT WARRANTY.

❑ 9._____Retighten all terminals in the DC String Combiner Box.

WIRING TESTS--Remainder of System: (hard hat, gloves, and eye protection recommended)

- ❑ 10. _____Verify that the only place where the AC neutral is grounded is at the main service panel.
- ❑ 11._____Check the AC line voltage at main AC disconnect is within proper limits (115-125 Volts AC for 120 Volts and 230-250 for 240 Volts).
- ❑ 12._____If installation contains additional AC disconnect switches repeat the step 11 voltage check on each switch working from the main service entrance to the inverter AC disconnect switch closing each switch after the test is made except for the final switch before the inverter (it is possible that the system only has a single AC switch).

INVERTER STARTUP TESTS (hard hat, gloves, and eye protection recommended)

- ❑ 1._____Be sure that the inverter is off before proceeding with this section.
- ❑ 2._____Test the continuity of all DC fuses to be installed in the DC string combiner box, install all string fuses, and close fused switches in combiner box.
- ❑ 3._____Check open circuit voltage at DC disconnect switch to ensure it is within proper limits according to the manufacturer's installation manual.
- ❑ 4._____If installation contains additional DC disconnect switches repeat the step 4 voltage check on each switch working from the PV array to the inverter DC disconnect switch closing each switch after the test is made except for the final switch before the inverter (it is possible that the system only has a single DC switch).
- ❑ 5._____At this point consult the inverter manual and follow proper startup procedure (all power to the inverter should be off at this time).
- ❑ 6._____Confirm that the inverter is operating and record the DC operating voltage in the following space._____
- ❑ 7._____Confirm that the operating voltage is within proper limits according to the manufacturer's installation manual.
- ❑ 8._____After recording the operating voltage at the inverter close any open boxes related to the inverter system.

❑ 9._____Confirm that the inverter is producing the expected power output on the supplied meter.

❑ 10._____Provide the homeowner with the initial startup test report.

SYSTEM ACCEPTANCE TEST (hard hat and eye protection recommended)

Ideal testing conditions are midday on cloudless days March through October. However, this test procedure accounts for less than ideal conditions and allows acceptance tests to be conducted on sunny winter days.

❑ 1._____Check to make sure that the PV array is in full sun with no shading whatsoever. If it is impossible to find a time during the day when the whole array is in full sun, only that portion that is in full sun will be able to be accepted.

❑ 2._____If the system is not operating, turn the system on and allow it to run for 15 minutes before taking any performance measurements.

❑ 3._____Obtain solar irradiance measurement by one of two methods and record irradiance on this line:_____W/m^2. To obtain percentage of peak sun, divide irradiance by 1000 W/m^2 and record the value on this line _____. (example: 692 W/m^2 ÷ 1000 W/m^2 = 0.692 or 69.2%.)
Method 1: Take measurement from calibrated solar meter or pyranometer.
Method 2: Place a single, properly operating PV module, of the same model found in the array, in full sun in the exact same orientation as the array being tested. After 15 minutes of full exposure, test the short circuit current with a digital multimeter and place that reading on this line:_____Amps. Divide this number into the short circuit current (Isc) value printed on the back of the PV module and multiply this number by 1000 W/m^2 and record the value on the line above. (example: Isc-measured = 3.6 Amps; Isc-printed on module = 5.2 Amps; Irradiance = 3.6 Amps/5.2 Amps * 1000 W/m^2 = 692 W/m^2)

❑ 4._____Sum the total of the module ratings and place that total on this line _____$Watts_{STC}$. Multiply this number by 0.7 to obtain expected peak AC output and record on this line _____$Watts_{AC\text{-}estimated}$.

❑ 5._____Record AC Watt output from the inverter or system meter and record on this line _____$Watts_{AC\text{-}measured}$.

❑ 6._____Divide $Watts_{AC\text{-}measured}$ by percent peak irradiance and record on this line _____$Watts_{AC\text{-}corrected}$. This “AC-corrected” value is the rated output of PV system. This number must be within 90% or higher of $Watts_{AC\text{-}estimated}$ recorded in step 4. If it is less than 90%, the PV system is either shaded, dirty, miswired, fuses are blown, or the modules or inverter are not operating properly.

Example:

A PV system is made up of 20, 100 $Watt_{STC}$ PV modules operating at an estimated irradiance of 692 W/m^2 using method 2 shown above. The power output is measured to be 1000 $Watts_{AC\text{-}measured}$ at the time of the test. Is this system operating properly or not?

Solution:

Sum of module ratings = 100 $Watts_{STC}$ per module x 20 modules = 2,000 $Watts_{STC}$.

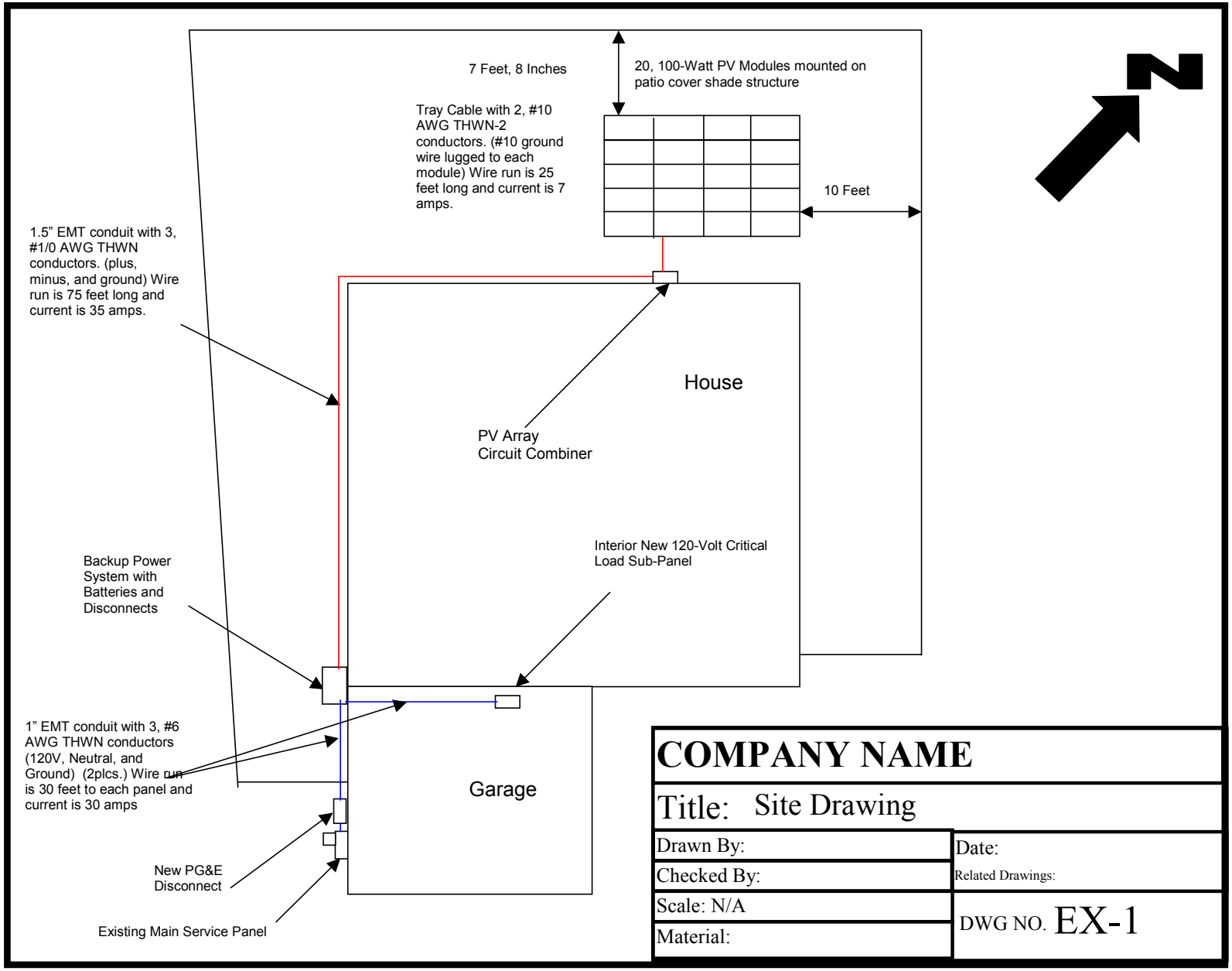
Estimated AC power output = 2,000 $Watts_{STC}$ x 0.7 = 1,400 $Watts_{AC\text{-}estimated}$.

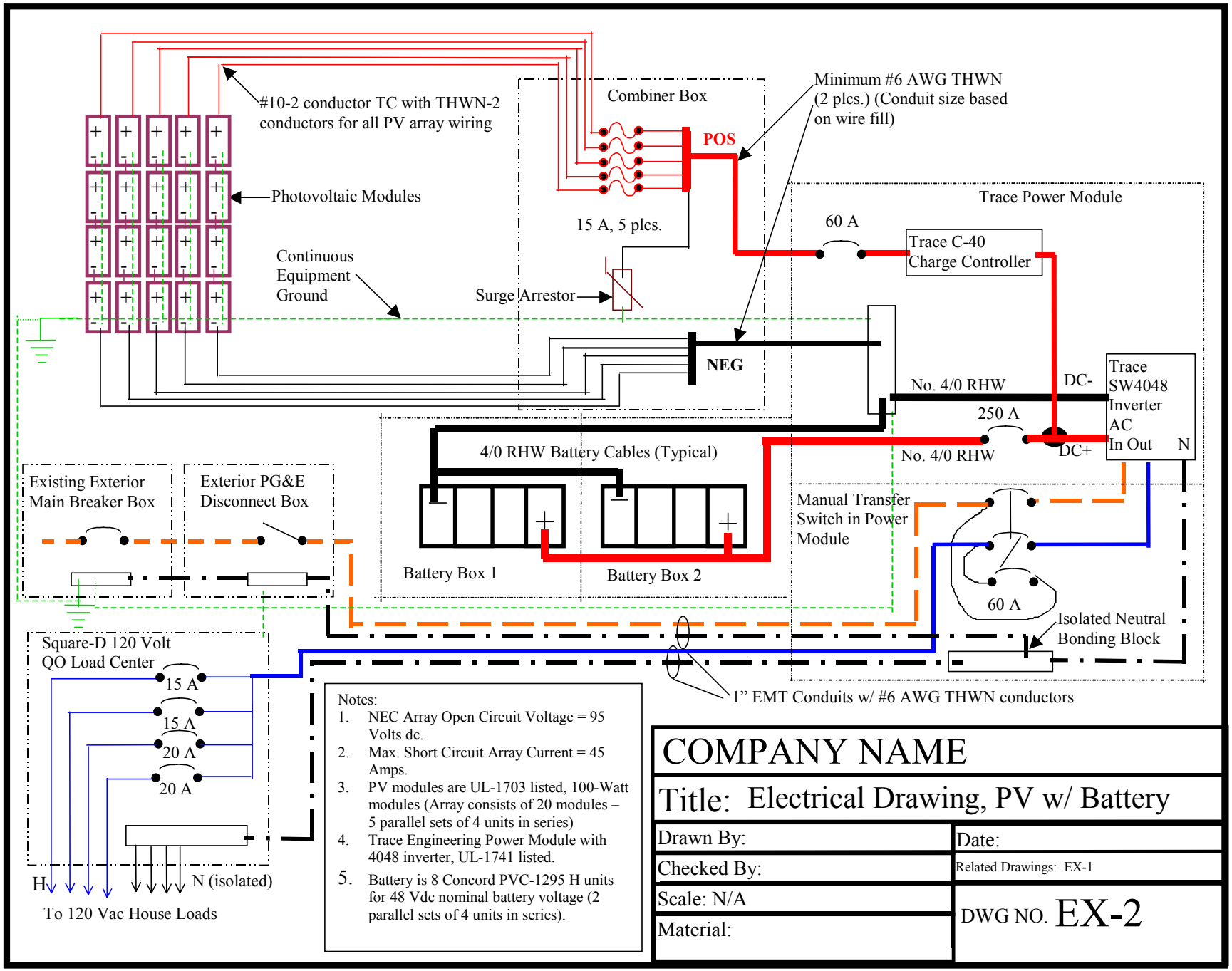
Measured AC output = 1,000 $Watts_{AC\text{-}measured}$.

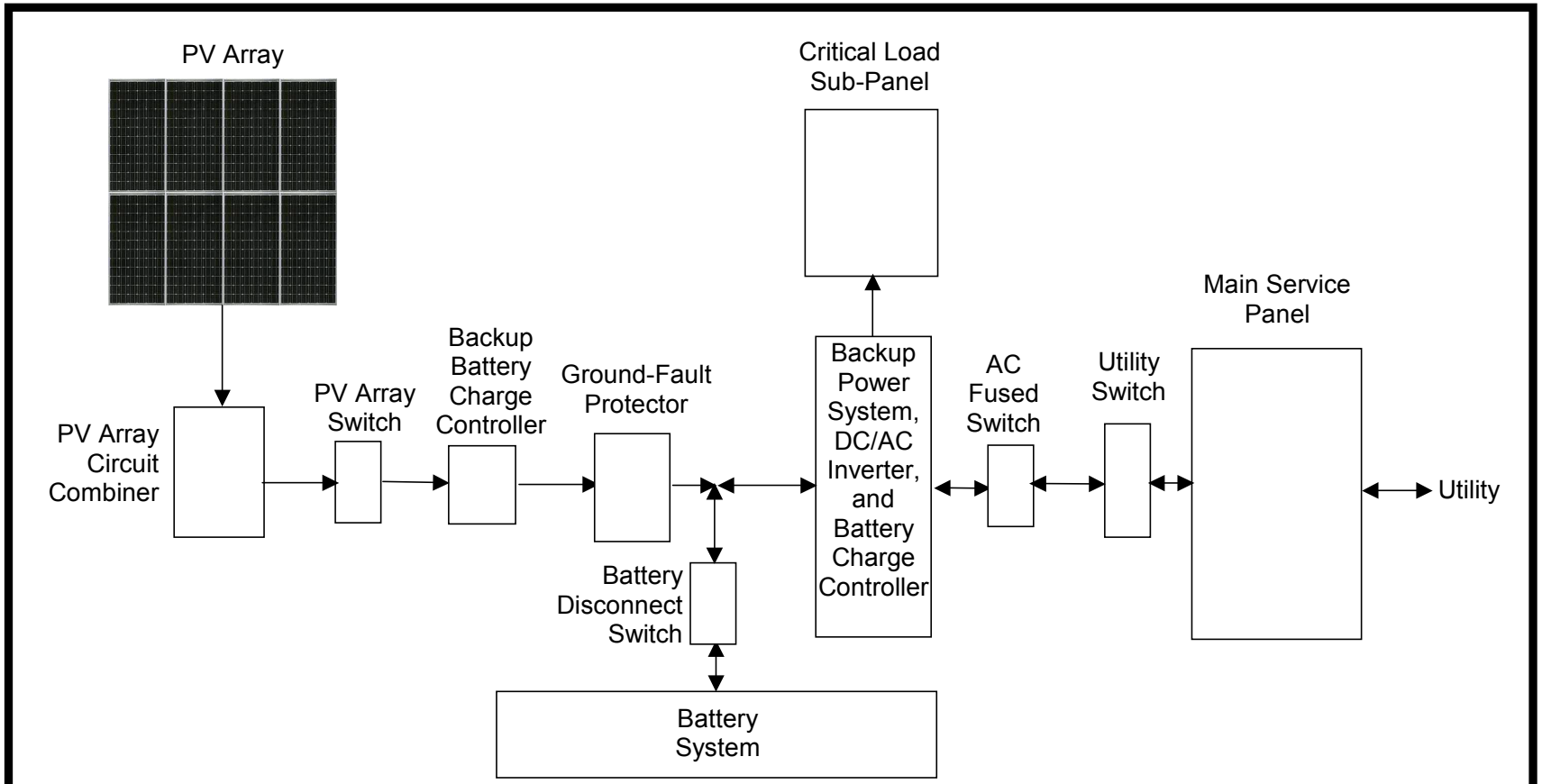
Corrected AC output = 1,020 $Watts_{AC\text{-}corrected}$ ÷ 0.692 = 1,474 $Watts_{AC\text{-}corrected}$.

Comparison of corrected and estimated outputs: 1,474 $Watts_{AC\text{-}corrected}$ ÷ 1,400 $Watts_{AC\text{-}estimated}$ = 1.05 ≥ 0.9 (acceptable performance)

APPENDIX


7 Feet, 8 Inches
20, 100-Watt PV Modules mounted on patio cover shade structure
Tray Cable with 2, #10 AWG THWN-2 conductors. (#10 ground wire lugged to each module) Wire run is 25 feet long and current is 7 amps.
10 Feet
1.5" EMT conduit with 3, #1/0 AWG THWN conductors. (plus, minus, and ground) Wire run is 75 feet long and current is 35 amps.
House
PV Array Circuit Combiner
Interior New 120-Volt Critical Load Sub-Panel
Backup Power System with Batteries and Disconnects
1" EMT conduit with 3, #6 AWG THWN conductors (120V, Neutral, and Ground) (2plcs.) Wire run is 30 feet to each panel and current is 30 amps
Garage
New PG&E Disconnect
Existing Main Service Panel
COMPANY NAME
Title: Site Drawing
Drawn By:
Date:
Checked By:
Related Drawings:
Scale: N/A
DWG NO. EX-1
Material:

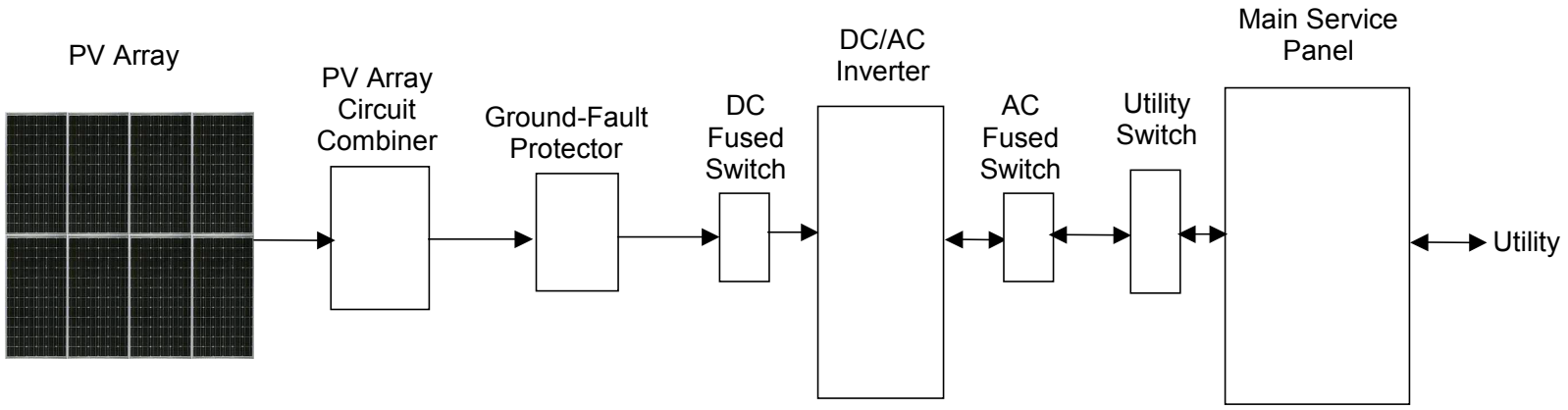

#10-2 conductor TC with THWN-2 conductors for all PV array wiring
Photovoltaic Modules
Continuous Equipment Ground
Combiner Box
POS
15 A, 5 plcs.
Surge Arrestor
NEG
Minimum #6 AWG THWN (2 plcs.) (Conduit size based on wire fill)
Trace Power Module
60 A
Trace C-40 Charge Controller
No. 4/0 RHW
DC-
250 A
DC+
No. 4/0 RHW
Trace SW4048 Inverter AC In Out N
4/0 RHW Battery Cables (Typical)
Existing Exterior Main Breaker Box
Exterior PG&E Disconnect Box
Battery Box 1
Battery Box 2
Manual Transfer Switch in Power Module
60 A
Isolated Neutral Bonding Block
1" EMT Conduits w/ #6 AWG THWN conductors
Square-D 120 Volt QO Load Center
15 A
15 A
20 A
20 A
H
N (isolated)
To 120 Vac House Loads
Notes:
1. NEC Array Open Circuit Voltage = 95 Volts dc.
2. Max. Short Circuit Array Current = 45 Amps.
3. PV modules are UL-1703 listed, 100-Watt modules (Array consists of 20 modules – 5 parallel sets of 4 units in series)
4. Trace Engineering Power Module with 4048 inverter, UL-1741 listed.
5. Battery is 8 Concord PVC-1295 H units for 48 Vdc nominal battery voltage (2 parallel sets of 4 units in series).
COMPANY NAME
Title: Electrical Drawing, PV w/ Battery
Drawn By:
Date:
Checked By:
Related Drawings: EX-1
Scale: N/A
Material:
DWG NO. EX-2



Notes:

1. PV Array contains five 48-Volt DC series strings of 100-Watt Modules (20-modules)
2. PV Array Circuit Combiner contains 15-Amp fuses rated at 125Vdc.
3. PV Array Switch fused at 60-amps, 125Vdc (may be circuit breaker)
4. Ground-Fault Protection required only on roof-mounted PV arrays.
5. Battery Disconnect Switch fused at 250-amps, 125-Vdc (may be circuit breaker)
6. Battery System contains eight 12Vdc 100 Ahr AGM VRLA Batteries configured in two strings of four batteries in series for a 48Vdc output. (9 kWh of battery storage)
7. DC/AC Inverter rated at 4 kW AC at 120-Volts and is Listed to UL-1741 "Utility-Interactive"
8. AC Fused Switch rated at 60-amps, 240Vac (may be circuit breaker)
9. Utility Switch is visible open, lockable in open position, 240-Vac, 60-amp switch.
10. 200-Amp Busbar in Main Service Panel with 125-Amp main breaker and a 60-Amp single-Pole Circuit Breaker for Interactive Point of Connection
11. Equipment ground equivalent to PV array conductor size on DC-side of system.
12. Equipment ground according to NEC Table 250-122 on AC-side.
13. Negative pole of PV array referenced to ground at the Inverter.
14. All grounds connected to main service ground in Main Service Panel.

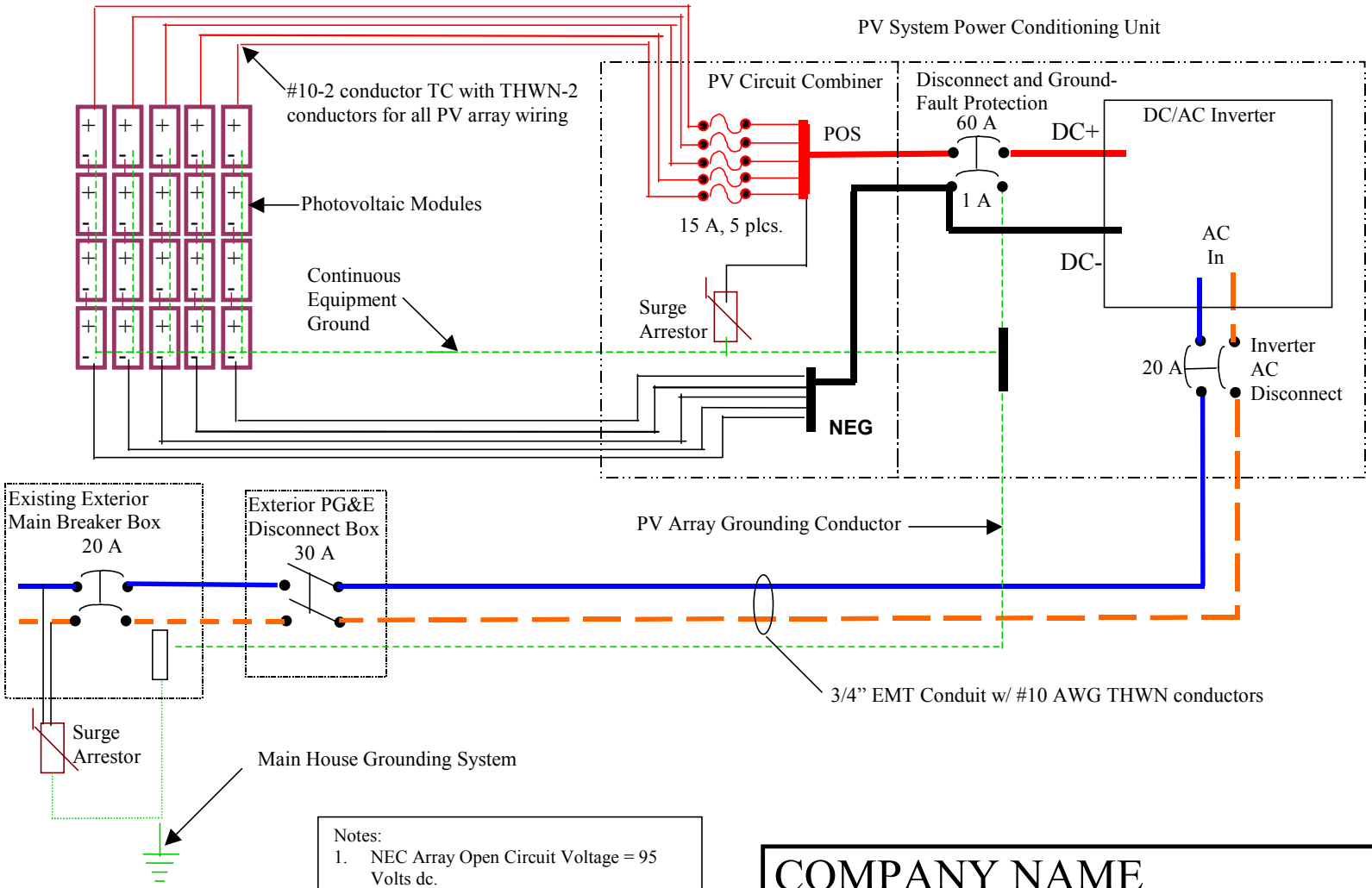
COMPANY NAME	
Title: Grid-Tied PV System w/ Battery	
Drawn By:	Date:
Checked By:	Related Dwgs:
Scale: N/A	DWG NO. EX-3
Material:	



Notes:

1. PV Array contains five 48-Volt DC series strings of 100-Watt Modules (20-modules)
2. PV Array Circuit Combiner contains 15-Amp fuses rated at 125Vdc.
3. Ground-Fault Protection required only on roof-mounted PV arrays.
4. DC Fused Switch rated at 60-amps, 125-Vdc (may be circuit breaker)
5. DC/AC Inverter rated at 2 kW AC output at 240-Volts and is Listed to UL-1741 "Utility-Interactive"
6. AC Fused Switch rated at 30-amps, 240Vac (may be circuit breaker)
7. Utility Switch is visible open, lockable in open position, 240-Vac, 60-amp switch.
8. 100-Amp Main Service Panel with 20-Amp Two-Pole Circuit Breaker for Interactive Point of Connection (up to 3.5 kW, 240-Volt inverter)
9. Equipment ground equivalent to PV array conductor size on DC-side of system.
10. Equipment ground according to NEC Table 250-122 on AC-side.
11. Negative pole of PV array referenced to ground at the Inverter.

COMPANY NAME	
Title: Example Grid-Tied PV System	
Drawn By:	Date:
Checked By:	Related Dwgs:
Scale: N/A	DWG NO. **EX-4**
Material:	



Notes:
1. NEC Array Open Circuit Voltage = 95 Volts dc.
2. Max. Short Circuit Array Current = 45 Amps.
3. PV modules are Astropower model # AP-100, UL-1703 Listed. Array consists of 20 modules – 5 parallel sets of 4 units in series.
4. 48-Volt DC, 240-Volt AC inverter, UL-1741 listed.

COMPANY NAME	
Title: Electrical Drawing, Grid-Tied PV System	
Drawn By:	Date:
Checked By:	Related Drawings: EX-4
Scale: N/A	DWG NO. EX-5
Material:	

TABLE A-1

WIRE SIZING TABLE FOR AMPACITY AND VOLTAGE DROP

Wire Size (AWG)	D Factor	Ampacity of 90 C Wet Wire Roof Mounted Modules (80 C)	Ampacity of 90 C Wet Wire Rack Mounted Modules (70 C)	Ampacity of 75 C Wet Wire Rack Mounted Modules (70 C)	Ampacity of 90 C Wet Wire BOS Wiring (45 C)	Ampacity of 75 C Wet Wire BOS Wiring (45 C)	Ampacity of 60 C Wet Wire BOS Wiring (45 C)
14	1.5	10	15	7	22	16	14
12	2.5	12	17	8	26	21	18
10	3.9	16	23	12	35	29	21
8	6.0	23	32	17	48	41	28
6	9.7	31	44	21	65	53	39
4	15.6	39	55	28	83	70	50
3	19	N/A	N/A	N/A	96	82	60
2	25	N/A	N/A	N/A	113	94	67
1	31	N/A	N/A	N/A	131	107	78
1/0	39	N/A	N/A	N/A	148	123	89
2/0	50	N/A	N/A	N/A	170	144	103
3/0	62	N/A	N/A	N/A	196	164	117
4/0	80	N/A	N/A	N/A	226	189	138
300MCM	112	N/A	N/A	N/A	278	234	170
500MCM	189	N/A	N/A	N/A	374	312	227

To determine D-Factor for 1% voltage drop simply multiply D-Factor from 3% tables by 3.

Example: 48V, 6Amps, 70ft--D Factor = 2.9 for 3%. Multiplying by 3 yields D Factor = 8.7

Solution: Need #10 AWG to stay under 3% voltage drop and #6 to stay under 1% voltage drop

To determine D-Factor for 2% voltage drop simply multiply D-Factor from 3% tables by 1.5.

Example: 48V, 6Amps, 70ft--D Factor = 2.9 for 3%. Multiplying by 1.5 yields D Factor = 4.4

Solution: Need #10 AWG to stay under 3% voltage drop and #8 to stay under 2% voltage drop

TABLE A-2 **D FACTOR**

3% VOLTAGE DROP--24-VOLT CIRCUITS-COPPER

ONE-WAY WIRE DISTANCE (FT)

AMPS	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	120.0	140.0	160.0	180.0	200.0	220.0	240.0	260.0	280.0	300.0	320.0	340.0	360.0	380.0	400.0
2	0.3	0.6	0.8	1.1	1.4	1.7	1.9	2.2	2.5	2.8	3.3	3.9	4.4	5.0	5.6	6.1	6.7	7.2	7.8	8.3	8.9	9.4	10.0	10.6	11.1
4	0.6	1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.6	6.7	7.8	8.9	10.0	11.1	12.2	13.3	14.4	15.6	16.7	17.8	18.9	20.0	21.1	22.2
6	0.8	1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3	10.0	11.7	13.3	15.0	16.7	18.3	20.0	21.7	23.3	25.0	26.7	28.3	30.0	31.7	33.3
8	1.1	2.2	3.3	4.4	5.6	6.7	7.8	8.9	10.0	11.1	13.3	15.6	17.8	20.0	22.2	24.4	26.7	28.9	31.1	33.3	35.6	37.8	40.0	42.2	44.4
10	1.4	2.8	4.2	5.6	6.9	8.3	9.7	11.1	12.5	13.9	16.7	19.4	22.2	25.0	27.8	30.6	33	36	39	42	44	47	50	53	56
12	1.7	3.3	5.0	6.7	8.3	10.0	11.7	13.3	15.0	16.7	20.0	23.3	26.7	30.0	33.3	36.7	40	43	47	50	53	57	60	63	67
14	1.9	3.9	5.8	7.8	9.7	11.7	13.6	15.6	17.5	19.4	23.3	27.2	31.1	35.0	38.9	42.8	47	51	54	58	62	66	70	74	78
16	2.2	4.4	6.7	8.9	11.1	13.3	15.6	17.8	20.0	22.2	26.7	31.1	35.6	40.0	44.4	48.9	53	58	62	67	71	76	80	84	89
18	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	30.0	35.0	40	45	50	55	60	65	70	75	80	85	90	95	100
20	2.8	5.6	8.3	11.1	13.9	16.7	19.4	22.2	25.0	27.8	33.3	38.9	44	50	56	61	67	72	78	83	89	94	100	106	111
25	3.5	6.9	10.4	13.9	17.4	20.8	24.3	27.8	31.3	34.7	41.7	48.6	56	63	69	76	83	90	97	104	111	118	125	132	139
30	4.2	8.3	12.5	16.7	20.8	25.0	29.2	33	38	42	50	58	67	75	83	92	100	108	117	125	133	142	150	158	167
35	4.9	9.7	14.6	19.4	24.3	29.2	34.0	39	44	49	58	68	78	88	97	107	117	126	136	146	156	165	175	185	194
40	5.6	11.1	16.7	22.2	27.8	33.3	38.9	44	50	56	67	78	89	100	111	122	133	144	156	167	178	189	200	211	222
45	6.3	12.5	18.8	25.0	31.3	38	44	50	56	63	75	88	100	113	125	138	150	163	175	188	200	213	225	238	250
50	6.9	13.9	20.8	27.8	34.7	42	49	56	63	69	83	97	111	125	139	153	167	181	194	208	222	236	250	264	278
60	8.3	16.7	25.0	33	42	50	58	67	75	83	100	117	133	150	167	183	200	217	233	250	267	283	300	317	333
70	9.7	19.4	29.2	39	49	58	68	78	88	97	117	136	156	175	194	214	233	253	272	292	311	331	350	369	389
80	11.1	22.2	33.3	44	56	67	78	89	100	111	133	156	178	200	222	244	267	289	311	333	356	378	400	422	444
90	12.5	25.0	37.5	50	63	75	88	100	113	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
100	13.9	27.8	41.7	56	69	83	97	111	125	139	167	194	222	250	278	306	333	361	389	417	444	472	500	528	556
110	15.3	30.6	45.8	61	76	92	107	122	138	153	183	214	244	275	306	336	367	397	428	458	489	519	550	581	611
120	16.7	33	50	67	83	100	117	133	150	167	200	233	267	300	333	367	400	433	467	500	533	567	600	633	667
130	18.1	36	54	72	90	108	126	144	163	181	217	253	289	325	361	397	433	469	506	542	578	614	650	686	722
140	19.4	39	58	78	97	117	136	156	175	194	233	272	311	350	389	428	467	506	544	583	622	661	700	739	778
150	20.8	42	63	83	104	125	146	167	188	208	250	292	333	375	417	458	500	542	583	625	667	708	750	792	833
160	22.2	44	67	89	111	133	156	178	200	222	267	311	356	400	444	489	533	578	622	667	711	756	800	844	889
170	23.6	47	71	94	118	142	165	189	213	236	283	331	378	425	472	519	567	614	661	708	756	803	850	897	944
180	25.0	50	75	100	125	150	175	200	225	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
190	26.4	53	79	106	132	158	185	211	238	264	317	369	422	475	528	581	633	686	739	792	844	897	950	1003	1056
200	27.8	56	83	111	139	167	194	222	250	278	333	389	444	500	556	611	667	722	778	833	889	944	1000	1056	1111

TABLE A-3 D FACTOR

3% VOLTAGE DROP--48-VOLT CIRCUITS-COPPER

ONE-WAY WIRE DISTANCE (FT)

AMPS	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	120.0	140.0	160.0	180.0	200.0	220.0	240.0	260.0	280.0	300.0	320.0	340.0	360.0	380.0	400.0
2	0.1	0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.3	1.4	1.7	1.9	2.2	2.5	2.8	3.1	3.3	3.6	3.9	4.2	4.4	4.7	5.0	5.3	5.6
4	0.3	0.6	0.8	1.1	1.4	1.7	1.9	2.2	2.5	2.8	3.3	3.9	4.4	5.0	5.6	6.1	6.7	7.2	7.8	8.3	8.9	9.4	10.0	10.6	11.1
6	0.4	0.8	1.3	1.7	2.1	2.5	2.9	3.3	3.8	4.2	5.0	5.8	6.7	7.5	8.3	9.2	10.0	10.8	11.7	12.5	13.3	14.2	15.0	15.8	16.7
8	0.6	1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.6	6.7	7.8	8.9	10.0	11.1	12.2	13.3	14.4	15.6	16.7	17.8	18.9	20.0	21.1	22.2
10	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	6.9	8.3	9.7	11.1	12.5	13.9	15.3	17	18	19	21	22	24	25	26	28
12	0.8	1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3	10.0	11.7	13.3	15.0	16.7	18.3	20	22	23	25	27	28	30	32	33
14	1.0	1.9	2.9	3.9	4.9	5.8	6.8	7.8	8.8	9.7	11.7	13.6	15.6	17.5	19.4	21.4	23	25	27	29	31	33	35	37	39
16	1.1	2.2	3.3	4.4	5.6	6.7	7.8	8.9	10.0	11.1	13.3	15.6	17.8	20.0	22.2	24.4	27	29	31	33	36	38	40	42	44
18	1.3	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.3	12.5	15.0	17.5	20	23	25	28	30	33	35	38	40	43	45	48	50
20	1.4	2.8	4.2	5.6	6.9	8.3	9.7	11.1	12.5	13.9	16.7	19.4	22	25	28	31	33	36	39	42	44	47	50	53	56
25	1.7	3.5	5.2	6.9	8.7	10.4	12.2	13.9	15.6	17.4	20.8	24.3	28	31	35	38	42	45	49	52	56	59	63	66	69
30	2.1	4.2	6.3	8.3	10.4	12.5	14.6	17	19	21	25	29	33	38	42	46	50	54	58	63	67	71	75	79	83
35	2.4	4.9	7.3	9.7	12.2	14.6	17.0	19	22	24	29	34	39	44	49	53	58	63	68	73	78	83	88	92	97
40	2.8	5.6	8.3	11.1	13.9	16.7	19.4	22	25	28	33	39	44	50	56	61	67	72	78	83	89	94	100	106	111
45	3.1	6.3	9.4	12.5	15.6	19	22	25	28	31	38	44	50	56	63	69	75	81	88	94	100	106	113	119	125
50	3.5	6.9	10.4	13.9	17.4	21	24	28	31	35	42	49	56	63	69	76	83	90	97	104	111	118	125	132	139
60	4.2	8.3	12.5	17	21	25	29	33	38	42	50	58	67	75	83	92	100	108	117	125	133	142	150	158	167
70	4.9	9.7	14.6	19	24	29	34	39	44	49	58	68	78	88	97	107	117	126	136	146	156	165	175	185	194
80	5.6	11.1	16.7	22	28	33	39	44	50	56	67	78	89	100	111	122	133	144	156	167	178	189	200	211	222
90	6.3	12.5	18.8	25	31	38	44	50	56	63	75	88	100	113	125	138	150	163	175	188	200	213	225	238	250
100	6.9	13.9	20.8	28	35	42	49	56	63	69	83	97	111	125	139	153	167	181	194	208	222	236	250	264	278
110	7.6	15.3	22.9	31	38	46	53	61	69	76	92	107	122	138	153	168	183	199	214	229	244	260	275	290	306
120	8.3	17	25	33	42	50	58	67	75	83	100	117	133	150	167	183	200	217	233	250	267	283	300	317	333
130	9.0	18	27	36	45	54	63	72	81	90	108	126	144	163	181	199	217	235	253	271	289	307	325	343	361
140	9.7	19	29	39	49	58	68	78	88	97	117	136	156	175	194	214	233	253	272	292	311	331	350	369	389
150	10.4	21	31	42	52	63	73	83	94	104	125	146	167	188	208	229	250	271	292	313	333	354	375	396	417
160	11.1	22	33	44	56	67	78	89	100	111	133	156	178	200	222	244	267	289	311	333	356	378	400	422	444
170	11.8	24	35	47	59	71	83	94	106	118	142	165	189	213	236	260	283	307	331	354	378	401	425	449	472
180	12.5	25	38	50	63	75	88	100	113	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
190	13.2	26	40	53	66	79	92	106	119	132	158	185	211	238	264	290	317	343	369	396	422	449	475	501	528
200	13.9	28	42	56	69	83	97	111	125	139	167	194	222	250	278	306	333	361	389	417	444	472	500	528	556

TABLE A-4 **D FACTOR**

3% VOLTAGE DROP--120-VOLT CIRCUITS-COPPER

ONE-WAY WIRE DISTANCE (FT)

AMPS	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	120.0	140.0	160.0	180.0	200.0	220.0	240.0	260.0	280.0	300.0	320.0	340.0	360.0	380.0	400.0
2	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.0	2.1	2.2
4	0.1	0.2	0.3	0.4	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.6	1.8	2.0	2.2	2.4	2.7	2.9	3.1	3.3	3.6	3.8	4.0	4.2	4.4
6	0.2	0.3	0.5	0.7	0.8	1.0	1.2	1.3	1.5	1.7	2.0	2.3	2.7	3.0	3.3	3.7	4.0	4.3	4.7	5.0	5.3	5.7	6.0	6.3	6.7
8	0.2	0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.2	2.7	3.1	3.6	4.0	4.4	4.9	5.3	5.8	6.2	6.7	7.1	7.6	8.0	8.4	8.9
10	0.3	0.6	0.8	1.1	1.4	1.7	1.9	2.2	2.5	2.8	3.3	3.9	4.4	5.0	5.6	6.1	6.7	7.2	7.8	8.3	8.9	9.4	10.0	10.6	11.1
12	0.3	0.7	1.0	1.3	1.7	2.0	2.3	2.7	3.0	3.3	4.0	4.7	5.3	6.0	6.7	7.3	8.0	8.7	9.3	10.0	10.7	11.3	12.0	12.7	13.3
14	0.4	0.8	1.2	1.6	1.9	2.3	2.7	3.1	3.5	3.9	4.7	5.4	6.2	7.0	7.8	8.6	9.3	10.1	10.9	11.7	12.4	13.2	14.0	14.8	15.6
16	0.4	0.9	1.3	1.8	2.2	2.7	3.1	3.6	4.0	4.4	5.3	6.2	7.1	8.0	8.9	9.8	10.7	11.6	12.4	13.3	14.2	15.1	16.0	16.9	17.8
18	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0
20	0.6	1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.6	6.7	7.8	8.9	10.0	11.1	12.2	13.3	14.4	15.6	16.7	17.8	18.9	20.0	21.1	22.2
25	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	6.9	8.3	9.7	11.1	12.5	14	15	17	18	19	21	22	24	25	26	28
30	0.8	1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3	10.0	11.7	13.3	15.0	17	18	20	22	23	25	27	28	30	32	33
35	1.0	1.9	2.9	3.9	4.9	5.8	6.8	7.8	8.8	9.7	11.7	13.6	15.6	17.5	19	21	23	25	27	29	31	33	35	37	39
40	1.1	2.2	3.3	4.4	5.6	6.7	7.8	8.9	10.0	11.1	13.3	15.6	17.8	20.0	22	24	27	29	31	33	36	38	40	42	44
45	1.3	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.3	12.5	15.0	17.5	20.0	22.5	25	28	30	33	35	38	40	43	45	48	50
50	1.4	2.8	4.2	5.6	6.9	8.3	9.7	11.1	12.5	13.9	16.7	19.4	22.2	25.0	28	31	33	36	39	42	44	47	50	53	56
60	1.7	3.3	5.0	6.7	8.3	10.0	11.7	13	15	17	20	23	27	30	33	37	40	43	47	50	53	57	60	63	67
70	1.9	3.9	5.8	7.8	9.7	11.7	13.6	16	18	19	23	27	31	35	39	43	47	51	54	58	62	66	70	74	78
80	2.2	4.4	6.7	8.9	11.1	13.3	15.6	18	20	22	27	31	36	40	44	49	53	58	62	67	71	76	80	84	89
90	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20	23	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100	2.8	5.6	8.3	11.1	13.9	16.7	19.4	22	25	28	33	39	44	50	56	61	67	72	78	83	89	94	100	106	111
110	3.1	6.1	9.2	12.2	15.3	18.3	21.4	24	28	31	37	43	49	55	61	67	73	79	86	92	98	104	110	116	122
120	3.3	6.7	10.0	13.3	16.7	20.0	23.3	27	30	33	40	47	53	60	67	73	80	87	93	100	107	113	120	127	133
130	3.6	7.2	10.8	14.4	18.1	21.7	25.3	29	33	36	43	51	58	65	72	79	87	94	101	108	116	123	130	137	144
140	3.9	7.8	11.7	16	19	23	27	31	35	39	47	54	62	70	78	86	93	101	109	117	124	132	140	148	156
150	4.2	8.3	12.5	17	21	25	29	33	38	42	50	58	67	75	83	92	100	108	117	125	133	142	150	158	167
160	4.4	8.9	13.3	18	22	27	31	36	40	44	53	62	71	80	89	98	107	116	124	133	142	151	160	169	178
170	4.7	9.4	14.2	19	24	28	33	38	43	47	57	66	76	85	94	104	113	123	132	142	151	161	170	179	189
180	5.0	10.0	15.0	20	25	30	35	40	45	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
190	5.3	10.6	15.8	21	26	32	37	42	48	53	63	74	84	95	106	116	127	137	148	158	169	179	190	201	211
200	5.6	11.1	16.7	22	28	33	39	44	50	56	67	78	89	100	111	122	133	144	156	167	178	189	200	211	222

TABLE A-5 D FACTOR

3% VOLTAGE DROP--240-VOLT CIRCUITS-COPPER

ONE-WAY WIRE DISTANCE (FT)

AMPS	10	20	30	40	50	60	70	80	90	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
2	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.1	1.1
4	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.0	2.1	2.2
6	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.8	1.0	1.2	1.3	1.5	1.7	1.8	2.0	2.2	2.3	2.5	2.7	2.8	3.0	3.2	3.3
8	0.1	0.2	0.3	0.4	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.6	1.8	2.0	2.2	2.4	2.7	2.9	3.1	3.3	3.6	3.8	4.0	4.2	4.4
10	0.1	0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.3	1.4	1.7	1.9	2.2	2.5	2.8	3.1	3.3	3.6	3.9	4.2	4.4	4.7	5.0	5.3	5.6
12	0.2	0.3	0.5	0.7	0.8	1.0	1.2	1.3	1.5	1.7	2.0	2.3	2.7	3.0	3.3	3.7	4.0	4.3	4.7	5.0	5.3	5.7	6.0	6.3	6.7
14	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	1.9	2.3	2.7	3.1	3.5	3.9	4.3	4.7	5.1	5.4	5.8	6.2	6.6	7.0	7.4	7.8
16	0.2	0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.2	2.7	3.1	3.6	4.0	4.4	4.9	5.3	5.8	6.2	6.7	7.1	7.6	8.0	8.4	8.9
18	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
20	0.3	0.6	0.8	1.1	1.4	1.7	1.9	2.2	2.5	2.8	3.3	3.9	4.4	5.0	5.6	6.1	6.7	7.2	7.8	8.3	8.9	9.4	10.0	10.6	11.1
25	0.3	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.1	3.5	4.2	4.9	5.6	6.3	6.9	7.6	8.3	9.0	9.7	10.4	11.1	11.8	12.5	13.2	13.9
30	0.4	0.8	1.3	1.7	2.1	2.5	2.9	3.3	3.8	4.2	5.0	5.8	6.7	7.5	8.3	9.2	10.0	10.8	11.7	12.5	13.3	14.2	15.0	16	17
35	0.5	1.0	1.5	1.9	2.4	2.9	3.4	3.9	4.4	4.9	5.8	6.8	7.8	8.8	9.7	10.7	11.7	12.6	13.6	14.6	15.6	16.5	17.5	18	19
40	0.6	1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.6	6.7	7.8	8.9	10.0	11.1	12.2	13.3	14.4	15.6	16.7	17.8	18.9	20.0	21	22
45	0.6	1.3	1.9	2.5	3.1	3.8	4.4	5.0	5.6	6.3	7.5	8.8	10.0	11.3	12.5	13.8	15.0	16	18	19	20	21	23	24	25
50	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	6.9	8.3	9.7	11.1	12.5	13.9	15.3	16.7	18	19	21	22	24	25	26	28
60	0.8	1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3	10.0	11.7	13.3	15.0	17	18	20	22	23	25	27	28	30	32	33
70	1.0	1.9	2.9	3.9	4.9	5.8	6.8	7.8	8.8	9.7	11.7	13.6	15.6	17.5	19	21	23	25	27	29	31	33	35	37	39
80	1.1	2.2	3.3	4.4	5.6	6.7	7.8	8.9	10.0	11.1	13.3	15.6	17.8	20.0	22	24	27	29	31	33	36	38	40	42	44
90	1.3	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.3	12.5	15.0	17.5	20.0	22.5	25	28	30	33	35	38	40	43	45	48	50
100	1.4	2.8	4.2	5.6	6.9	8.3	9.7	11.1	12.5	13.9	16.7	19.4	22.2	25.0	28	31	33	36	39	42	44	47	50	53	56
110	1.5	3.1	4.6	6.1	7.6	9.2	10.7	12.2	13.8	15.3	18.3	21.4	24.4	27.5	31	34	37	40	43	46	49	52	55	58	61
120	1.7	3.3	5.0	6.7	8.3	10.0	11.7	13.3	15.0	17	20	23	27	30	33	37	40	43	47	50	53	57	60	63	67
130	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.3	18	22	25	29	33	36	40	43	47	51	54	58	61	65	69	72
140	1.9	3.9	5.8	7.8	9.7	11.7	13.6	15.6	17.5	19	23	27	31	35	39	43	47	51	54	58	62	66	70	74	78
150	2.1	4.2	6.3	8.3	10.4	12.5	14.6	17	19	21	25	29	33	38	42	46	50	54	58	63	67	71	75	79	83
160	2.2	4.4	6.7	8.9	11.1	13.3	15.6	18	20	22	27	31	36	40	44	49	53	58	62	67	71	76	80	84	89
170	2.4	4.7	7.1	9.4	11.8	14.2	16.5	19	21	24	28	33	38	43	47	52	57	61	66	71	76	80	85	90	94
180	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20	23	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
190	2.6	5.3	7.9	10.6	13.2	16	18	21	24	26	32	37	42	48	53	58	63	69	74	79	84	90	95	100	106
200	2.8	5.6	8.3	11.1	13.9	17	19	22	25	28	33	39	44	50	56	61	67	72	78	83	89	94	100	106	111
210	2.9	5.8	8.8	11.7	14.6	18	20	23	26	29	35	41	47	53	58	64	70	76	82	88	93	99	105	111	117
220	3.1	6.1	9.2	12.2	15.3	18	21	24	28	31	37	43	49	55	61	67	73	79	86	92	98	104	110	116	122
230	3.2	6.4	9.6	12.8	16.0	19	22	26	29	32	38	45	51	58	64	70	77	83	89	96	102	109	115	121	128
240	3.3	6.7	10.0	13.3	16.7	20	23	27	30	33	40	47	53	60	67	73	80	87	93	100	107	113	120	127	133
250	3.5	6.9	10.4	13.9	17.4	21	24	28	31	35	42	49	56	63	69	76	83	90	97	104	111	118	125	132	139
260	3.6	7.2	10.8	14.4	18	22	25	29	33	36	43	51	58	65	72	79	87	94	101	108	116	123	130	137	144
270	3.8	7.5	11.3	15.0	19	23	26	30	34	38	45	53	60	68	75	83	90	98	105	113	120	128	135	143	150
280	3.9	7.8	11.7	15.6	19	23	27	31	35	39	47	54	62	70	78	86	93	101	109	117	124	132	140	148	156
290	4.0	8.1	12.1	16.1	20	24	28	32	36	40	48	56	64	73	81	89	97	105	113	121	129	137	145	153	161
300	4.2	8.3	12.5	16.7	21	25	29	33	38	42	50	58	67	75	83	92	100	108	117	125	133	142	150	158	167

TABLE A-6 MAXIMUM ONE-WAY WIRE DISTANCE (FT)

3% VOLTAGE DROP--24-VOLT CIRCUITS-COPPER

AMERICAN WIRE GAUGE (AWG) WIRE SIZE

AMPS	WATTS	14	12	10	8	6	4	3	2	1	1/0	2/0	3/0	4/0	300MCM	500MCM
2	48	55	88	140	222	353	561	709	896	1125	1417	1782	2258	2875	4036	6792
4	96	28	44	70	111	176	280	354	448	563	709	891	1129	1438	2018	3396
6	144	18	29	47	74	118	187	236	299	375	472	594	753	958	1345	2264
8	192	14	22	35	56	88	140	177	224	281	354	446	565	719	1009	1698
10	240		18	28	44	71	112	142	179	225	283	356	452	575	807	1358
12	288		15	23	37	59	93	118	149	188	236	297	376	479	673	1132
14	336			20	32	50	80	101	128	161	202	255	323	411	577	970
16	384			17	28	44	70	89	112	141	177	223	282	359	504	849
18	432			16	25	39	62	79	100	125	157	198	251	319	448	755
20	480			14	22	35	56	71	90	113	142	178	226	288	404	679
25	600				18	28	45	57	72	90	113	143	181	230	323	543
30	720				15	24	37	47	60	75	94	119	151	192	269	453
35	840					20	32	40	51	64	81	102	129	164	231	388
40	960					18	28	35	45	56	71	89	113	144	202	340
45	1080					16	25	31	40	50	63	79	100	128	179	302
50	1200					14	22	28	36	45	57	71	90	115	161	272
60	1440						19	24	30	38	47	59	75	96	135	226
70	1680						16	20	26	32	40	51	65	82	115	194
80	1920						14	18	22	28	35	45	56	72	101	170
90	2160							16	20	25	31	40	50	64	90	151
100	2400							14	18	23	28	36	45	58	81	136
110	2640								16	20	26	32	41	52	73	123
120	2880								15	19	24	30	38	48	67	113
130	3120								14	17	22	27	35	44	62	104
140	3360									16	20	25	32	41	58	97
150	3600									15	19	24	30	38	54	91
160	3840									14	18	22	28	36	50	85
170	4080										17	21	27	34	47	80
180	4320										16	20	25	32	45	75
190	4560										15	19	24	30	42	71
200	4800										14	18	23	29	40	68

TABLE A-7 MAXIMUM ONE-WAY WIRE DISTANCE (FT)

3% VOLTAGE DROP--48-VOLT CIRCUITS-COPPER

AMERICAN WIRE GAUGE (AWG) WIRE SIZE

AMPS	WATTS	14	12	10	8	6	4	3	2	1	1/0	2/0	3/0	4/0	300MCM	500MCM
2	96	110	176	279	445	706	1121	1417	1791	2250	2835	3564	4517	5751	8072	13585
4	192	55	88	140	222	353	561	709	896	1125	1417	1782	2258	2875	4036	6792
6	288	37	59	93	148	235	374	472	597	750	945	1188	1506	1917	2691	4528
8	384	28	44	70	111	176	280	354	448	563	709	891	1129	1438	2018	3396
10	480	22	35	56	89	141	224	283	358	450	567	713	903	1150	1614	2717
12	576	18	29	47	74	118	187	236	299	375	472	594	753	958	1345	2264
14	672	16	25	40	64	101	160	202	256	321	405	509	645	822	1153	1941
16	768		22	35	56	88	140	177	224	281	354	446	565	719	1009	1698
18	864		20	31	49	78	125	157	199	250	315	396	502	639	897	1509
20	960		18	28	44	71	112	142	179	225	283	356	452	575	807	1358
25	1200			22	36	56	90	113	143	180	227	285	361	460	646	1087
30	1440			19	30	47	75	94	119	150	189	238	301	383	538	906
35	1680			16	25	40	64	81	102	129	162	204	258	329	461	776
40	1920				22	35	56	71	90	113	142	178	226	288	404	679
45	2160				20	31	50	63	80	100	126	158	201	256	359	604
50	2400				18	28	45	57	72	90	113	143	181	230	323	543
60	2880				15	24	37	47	60	75	94	119	151	192	269	453
70	3360					20	32	40	51	64	81	102	129	164	231	388
80	3840					18	28	35	45	56	71	89	113	144	202	340
90	4320					16	25	31	40	50	63	79	100	128	179	302
100	4800						22	28	36	45	57	71	90	115	161	272
110	5280						20	26	33	41	52	65	82	105	147	247
120	5760						19	24	30	38	47	59	75	96	135	226
130	6240						17	22	28	35	44	55	69	88	124	209
140	6720						16	20	26	32	40	51	65	82	115	194
150	7200						15	19	24	30	38	48	60	77	108	181
160	7680							18	22	28	35	45	56	72	101	170
170	8160							17	21	26	33	42	53	68	95	160
180	8640							16	20	25	31	40	50	64	90	151
190	9120							15	19	24	30	38	48	61	85	143
200	9600								18	23	28	36	45	58	81	136

TABLE A-8					**MAXIMUM ONE-WAY WIRE DISTANCE (FT)**											
					3% VOLTAGE DROP--120-VOLT CIRCUITS-COPPER											
					AMERICAN WIRE GAUGE (AWG) WIRE SIZE											
		14	**12**	**10**	**8**	**6**	**4**	**3**	**2**	**1**	**1/0**	**2/0**	**3/0**	**4/0**	**300MCM**	**500MCM**
AMPS	**WATTS**															
2	240	276	439	698	1112	1765	2804	3543	4478	5625	7087	8911	11292	14377	20179	33962
4	480	138	220	349	556	882	1402	1772	2239	2813	3543	4455	5646	7188	10090	16981
6	720	92	146	233	371	588	935	1181	1493	1875	2362	2970	3764	4792	6726	11321
8	960	69	110	174	278	441	701	886	1119	1406	1772	2228	2823	3594	5045	8491
10	1200	55	88	140	222	353	561	709	896	1125	1417	1782	2258	2875	4036	6792
12	1440	46	73	116	185	294	467	591	746	938	1181	1485	1882	2396	3363	5660
14	1680	39	63	100	159	252	401	506	640	804	1012	1273	1613	2054	2883	4852
16	1920	35	55	87	139	221	350	443	560	703	886	1114	1412	1797	2522	4245
18	2160	31	49	78	124	196	312	394	498	625	787	990	1255	1597	2242	3774
20	2400	28	44	70	111	176	280	354	448	563	709	891	1129	1438	2018	3396
25	3000	22	35	56	89	141	224	283	358	450	567	713	903	1150	1614	2717
30	3600	18	29	47	74	118	187	236	299	375	472	594	753	958	1345	2264
35	4200	16	25	40	64	101	160	202	256	321	405	509	645	822	1153	1941
40	4800		22	35	56	88	140	177	224	281	354	446	565	719	1009	1698
45	5400		20	31	49	78	125	157	199	250	315	396	502	639	897	1509
50	6000		18	28	44	71	112	142	179	225	283	356	452	575	807	1358
60	7200		15	23	37	59	93	118	149	188	236	297	376	479	673	1132
70	8400			20	32	50	80	101	128	161	202	255	323	411	577	970
80	9600			17	28	44	70	89	112	141	177	223	282	359	504	849
90	10800			16	25	39	62	79	100	125	157	198	251	319	448	755
100	12000				22	35	56	71	90	113	142	178	226	288	404	679
110	13200				20	32	51	64	81	102	129	162	205	261	367	617
120	14400				19	29	47	59	75	94	118	149	188	240	336	566
130	15600				17	27	43	55	69	87	109	137	174	221	310	522
140	16800				16	25	40	51	64	80	101	127	161	205	288	485
150	18000				15	24	37	47	60	75	94	119	151	192	269	453
160	19200					22	35	44	56	70	89	111	141	180	252	425
170	20400					21	33	42	53	66	83	105	133	169	237	400
180	21600					20	31	39	50	63	79	99	125	160	224	377
190	22800					19	30	37	47	59	75	94	119	151	212	357
200	24000					18	28	35	45	56	71	89	113	144	202	340

TABLE A-9					**MAXIMUM ONE-WAY WIRE DISTANCE (FT)**											
					3% VOLTAGE DROP--240-VOLT CIRCUITS-COPPER											
					AMERICAN WIRE GAUGE (AWG) WIRE SIZE											
		14	**12**	**10**	**8**	**6**	**4**	**3**	**2**	**1**	**1/0**	**2/0**	**3/0**	**4/0**	**300MCM**	**500MCM**
AMPS	**WATTS**															
2	480	552	878	1395	2225	3529	5607	7087	8955	11250	14173	17822	22585	28754	40359	67925
4	960	276	439	698	1112	1765	2804	3543	4478	5625	7087	8911	11292	14377	20179	33962
6	1440	184	293	465	742	1176	1869	2362	2985	3750	4724	5941	7528	9585	13453	22642
8	1920	138	220	349	556	882	1402	1772	2239	2813	3543	4455	5646	7188	10090	16981
10	2400	110	176	279	445	706	1121	1417	1791	2250	2835	3564	4517	5751	8072	13585
12	2880	92	146	233	371	588	935	1181	1493	1875	2362	2970	3764	4792	6726	11321
14	3360	79	125	199	318	504	801	1012	1279	1607	2025	2546	3226	4108	5766	9704
16	3840	69	110	174	278	441	701	886	1119	1406	1772	2228	2823	3594	5045	8491
18	4320	61	98	155	247	392	623	787	995	1250	1575	1980	2509	3195	4484	7547
20	4800	55	88	140	222	353	561	709	896	1125	1417	1782	2258	2875	4036	6792
25	6000	44	70	112	178	282	449	567	716	900	1134	1426	1807	2300	3229	5434
30	7200	37	59	93	148	235	374	472	597	750	945	1188	1506	1917	2691	4528
35	8400	32	50	80	127	202	320	405	512	643	810	1018	1291	1643	2306	3881
40	9600	28	44	70	111	176	280	354	448	563	709	891	1129	1438	2018	3396
45	10800	25	39	62	99	157	249	315	398	500	630	792	1004	1278	1794	3019
50	12000	22	35	56	89	141	224	283	358	450	567	713	903	1150	1614	2717
60	14400	18	29	47	74	118	187	236	299	375	472	594	753	958	1345	2264
70	16800	16	25	40	64	101	160	202	256	321	405	509	645	822	1153	1941
80	19200		22	35	56	88	140	177	224	281	354	446	565	719	1009	1698
90	21600		20	31	49	78	125	157	199	250	315	396	502	639	897	1509
100	24000		18	28	44	71	112	142	179	225	283	356	452	575	807	1358
110	26400		16	25	40	64	102	129	163	205	258	324	411	523	734	1235
120	28800		15	23	37	59	93	118	149	188	236	297	376	479	673	1132
130	31200			21	34	54	86	109	138	173	218	274	347	442	621	1045
140	33600			20	32	50	80	101	128	161	202	255	323	411	577	970
150	36000			19	30	47	75	94	119	150	189	238	301	383	538	906
160	38400			17	28	44	70	89	112	141	177	223	282	359	504	849
170	40800			16	26	42	66	83	105	132	167	210	266	338	475	799
180	43200			16	25	39	62	79	100	125	157	198	251	319	448	755
190	45600			15	23	37	59	75	94	118	149	188	238	303	425	715
200	48000				22	35	56	71	90	113	142	178	226	288	404	679