

Australian/New Zealand Standard™

Stand-alone power systems

Part 2: System design



AS/NZS 4509.2:2010

This Joint Australian/New Zealand Standard was prepared by Joint Technical Committee EL-042, Renewable Energy Power Supply Systems and Equipment. It was approved on behalf of the Council of Standards Australia on 26 October 2010 and on behalf of the Council of Standards New Zealand on 22 October 2010. This Standard was published on 22 November 2010.

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Australian/New Zealand Standard™

Stand-alone power systems

Part 2: System design

Originated as AS 4509.2—2002.
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PREFACE

This Standard was prepared by Joint Standards Australia/Standards New Zealand Committee EL-042, Renewable Energy Power Supply Systems and Equipment to supersede AS 4509.2—2002 on publication.

The objective of this Standard is to provide information for the design of stand-alone power systems used for the supply of extra-low and low voltage electric power.

The following changes have been made to AS 4509.2—2002 in producing this edition:

- (a) The Standard is now joint with Standards New Zealand.
- (b) Basic design of a.c. bus systems has been included.
- (c) Referenced documents have been updated and the presentation has been brought into line with current style.

Any comments on the Standard that users wish to submit will be considered by Committee EL-042 when the Standard is next reviewed. Submissions should be forwarded to—

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The term ‘informative’ has been used in this Standard to define the application of the appendix to which it applies. An ‘informative’ appendix is for information and guidance.

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Australian/New Zealand Standard
Stand-alone power systems

Part 2: System design

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard sets out requirements and guidance for the design of stand-alone power systems with energy storage at extra-low voltage used for the supply of extra-low and low voltage electric power in a domestic situation. Equipment up to the system output terminals is covered.

The principles in this Standard are equally applicable to other systems including commercial and industrial applications and should be considered in the design of those systems.

Optimization of system design considering time of energy use is not covered by this Standard.

NOTE: A bibliography containing references to additional material is in Appendix G.

1.2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

AS

- 1170 Structural design actions
- 1170.4 Part 4: Earthquake actions in Australia
- 1359 Rotating electrical machines—General requirements
- 1359.109 Part 109: Noise limits
- 3595 Energy management programs—Guidelines for financial evaluation of a project
- 4086 Secondary batteries for use with stand-alone power systems
- 4777 Grid connection of energy systems via inverters
- 4777.1 Part 1: Installation requirements
- 4777.2 Part 2: Installation and maintenance
- 62310 Static transfer systems (STS)

AS/NZS

- 1044 Limits and methods of measurement of radio disturbance characteristics of electrical motor-operated and thermal appliances for household and similar purposes, electric tools and similar electrical apparatus
- 1170 Structural design actions
- 1170.1 Part 1: Permanent, imposed and other actions
- 1170.2 Part 2: Wind actions
- 1768 Lightning protection
- 3000 Electrical installations (known as the Australian/New Zealand Wiring Rules)
- 3010 Electrical installations—Generating sets

AS/NZS

3823 Performance of electrical appliances—Air conditioners and heat pumps
 3823.2 Part 2: Energy labelling and minimum energy performance standard (MEPS) requirements

4509 Stand-alone power systems

4509.1 Part 1: Safety and installation

4536 Life cycle costing—An application guide

5033 Installation of photovoltaic (PV) arrays

IEC

61836 Solar photovoltaic energy systems—Terms and symbols

NZS

4219 Seismic performance of engineering systems in buildings

6808 Acoustics—The assessment and measurement of sound from wind turbine generators

1.3 DEFINITIONS

For the purpose of this Standard, the definitions below apply.

A glossary of symbols used in this Standard is set out in Appendix F.

1.3.1 Apparent power (alternating current)

Applicable to a.c. circuits and is the product of voltage by current, measured in volt-amperes.

1.3.2 Autonomy

The number of days of operation of the power system without energy input from generators before exceeding the design maximum depth of discharge of the battery.

1.3.3 Battery

A unit consisting of one or more energy storage cells connected in series, parallel or series-parallel arrangement to store electrical energy.

1.3.4 Battery cell

An assembly of electrodes and electrolyte which constitute the basic electrochemical unit used to store electrical energy.

1.3.5 Battery charger

A device which, when connected to a low voltage a.c. supply, provides a d.c. supply suitable for charging batteries.

1.3.6 Complementarity (renewable energy generators)

The degree to which the outputs of different renewable energy sources complement each other by providing output power at different times. (Where there is a high degree of complementarity, the total generated power will show less variation than the power from any individual generator.)

1.3.7 Cooling degree days

A measure of the amount of cooling required to maintain comfortable living conditions.

It is the product of the number of days during a given period (e.g. month) and the difference between the mean temperature for the period and a base comfortable temperature.

Cooling degree days = (number of days) × [(the mean temperature for the period) – (comfortable temperature)]

1.3.8 Coulombic efficiency

The ratio of the charge (ampere hours) removed from a cell or battery during a discharge to the charge required to restore to the initial state of charge (also known as “amphour” efficiency). The coulombic efficiency will depend on the battery charging/discharging cycling regime.

1.3.9 Daily depth of discharge

The nominal depth of discharge of the battery over one day, assuming no energy input to the system.

1.3.10 Demand management

The process of controlling the operation of electrical loads on the power system in order to reduce the energy or power demand on the system.

1.3.11 Depth of discharge (DOD)

The amount of charge removed from a fully charged battery at a specified discharge rate. Depth of discharge is expressed as a percentage of the battery’s rated capacity. (For example, the removal of 25 Ah from a battery with a rating of 100 Ah results in a 25% depth of discharge).

NOTE: Battery capacity rating depends on the rate of discharge.

1.3.12 Design load energy

The calculated total daily electrical energy to be provided by the power system in order to supply the expected loads, referenced to the d.c. bus.

1.3.13 Design maximum depth of discharge

The maximum depth of discharge that the batteries should experience under design conditions (i.e. exceeding this DOD may result in damage to, or reduced life of, the batteries).

1.3.14 Diffuse irradiance

The component of solar radiation reaching a surface that has been scattered by the atmosphere, and thus comes from all directions in the sky.

1.3.15 Direct irradiance

The component of solar radiation reaching a surface directly from the sun, often called ‘beam irradiance’.

1.3.16 Draught tube (hydro turbines)

The pipe that carries water from the turbine to a discharge point in reaction type hydro turbines.

1.3.17 Energy services

Services that are provided by the direct use of energy in any form.

1.3.18 Energy star rating

A rating, consisting of a number of stars, is given to electrical appliances of a given type and size, on the basis of their energy efficiency. More stars are awarded to appliances with higher energy efficiency. (See AS/NZS 3823.2 for additional information.)

1.3.19 Generating set (generating sets)

A unit consisting of alternator, d.c. generator or combination thereof, and an engine.

1.3.20 Heating degree days

A measure of the amount of heating required to maintain comfortable living conditions.

It is the product of the number of days during a given period (e.g. month) and the difference between a base comfortable temperature, and the mean temperature for the period.

Heating degree days = (number of days) $\times$ [(comfortable temperature) – (the mean temperature for the period)]

1.3.21 Hybrid system

A stand-alone power system which incorporates more than one type of energy source.

1.3.22 I-V curves

The characteristic curves for a photovoltaic module or array that describe the relationship between current and voltage for the device under given conditions of irradiance and temperature.

1.3.23 Insolation

A term which in common usage may mean either irradiance or irradiation. The use of the terms irradiance or irradiation is preferred.

1.3.24 Interactive battery inverters

Sine wave inverters which allow power flow in both directions and are capable of synchronising their output to that of another a.c. source in order to manage the loading on the a.c. source as well as the battery.

1.3.25 Inverter

A device that uses semiconductor devices to convert d.c. power into a.c. power at standard mains voltage and frequency.

1.3.26 Inverter-charger

An inverter that operates as a battery charger in the presence of another a.c. source.

1.3.27 Irradiance

Radiant solar power incident upon unit area of surface, measured in watts per square metre.

NOTE: This definition is from IEC 61836.

1.3.28 Irradiation

The total quantity of radiant solar energy per unit area received over a given period, i.e. the energy of the solar radiation per unit area over that period. Units in common usage include MJ/m^2 , kWh/m^2 and peak sun hours (PSH).

NOTE: $1 \text{ kWh/m}^2 \equiv 1 \text{ PSH} \equiv 3.6 \text{ MJ/m}^2$.

1.3.29 Isovent map

A map showing contours of average wind speed at a given height and over a given period, e.g. monthly or annually. Isovent maps generally cover a large area and do not account for local variations in terrain.

1.3.30 Life cycle cost

The cost, including capital, ongoing and disposal costs, of a project evaluated over its projected life. Future costs are discounted to a present value.

1.3.31 Load diversity

The consideration that all loads might not be switched on at the same time and therefore the maximum or surge demand is not necessarily the sum of the power ratings of all loads.

1.3.32 Maximum demand

The maximum 30 minute average of apparent power or d.c. power consumption (measured in volt-amperes for a.c. and watts for d.c.).

1.3.33 Maximum power point

The operating point at which the maximum output power of a device is produced. The term is most commonly used in relation to photovoltaic solar cells and modules.

1.3.34 Micro-hydro generator

A generating set that typically consists of a hydraulic turbine mechanically coupled to an electric generator or alternator.

1.3.35 Net head (for micro-hydro generators)

The static head minus hydraulic losses, not including losses in the turbine.

1.3.36 Nominal d.c. voltage

The nominal voltage of the d.c. bus, defined by the nominal battery voltage.

1.3.37 Orientation (of photovoltaic modules)

The horizontal angle between true north and the direction the surface is facing, measured clockwise from true north.

1.3.38 Parallel configuration

A hybrid system configuration in which the generating set, when running, operates in parallel with an interactive battery inverter.

1.3.39 Peak sun hours (PSH)

Refer to Clause 1.3.28—Irradiation

1.3.40 Penstock (for micro-hydro generators)

The pipe which takes water from the watercourse to the turbine.

1.3.41 Photovoltaic (PV) module/array

A module is an electrical device in which the energy of solar radiation is converted to electrical energy. An array is a collection of modules wired to supply electrical energy.

1.3.42 Power factor

The ratio of real power to apparent power in an a.c. circuit.

1.3.43 Power temperature co-efficient (γ) (photovoltaic modules)

The proportion of rated power output which is lost for every degree Celsius increase in cell temperature above standard operating conditions.

1.3.44 Real power (alternating current)

The product of voltage, current and power factor, also equal to the rate of flow of electrical energy. The unit of measurement of real power is the watts (W).

1.3.45 Regulator

A device whose function is to control the flow of current from a generating source to the battery.

1.3.46 Renewable energy fraction

The fraction of the total design load energy provided by renewable energy generators.

1.3.47 Renewable energy generator

Any device producing electrical energy from a renewable source. For the purpose of this Standard, these are photovoltaic arrays, wind turbine generators and micro-hydro generators.

1.3.48 Renewable energy inverter

Unidirectional inverter with the ability to synchronise its a.c. output to an a.c. source or grid and that is used to connect a renewable energy generator to an a.c. bus or a.c. grid in an a.c. coupled system.

1.3.49 Shall

Indicates that a statement is mandatory.

1.3.50 Should

Indicates a recommendation.

1.3.51 Solar noon

The time at which the sun is at its highest point in the sky on that day.

1.3.52 Stand-alone power systems

Systems that are not connected to the power distribution network of an electricity distributor. Stand-alone systems are supplied with power from one, or more, of a number of sources including, but not limited to, a photovoltaic array, a wind turbine generator, a micro-hydro generator or an engine generator set.

1.3.53 Standard test conditions

Standard test conditions, for assessing the performance of photovoltaic modules are:

Irradiance = 1000 W/m²

Cell temperature = 25°C

Air mass = 1.5 spectral irradiance distribution

1.3.54 Stand-by load

The power consumption of a load when in stand-by mode.

1.3.55 State of charge (SOC)

The charge remaining in the battery at any point in time. State of charge is expressed as a percentage of the battery's rated capacity. (For example, the removal of 25 Ah from a battery rated at 100 Ah results in a 75% state of charge.)

NOTE: Battery capacity ratings depend on the rate of discharge.

1.3.56 Static head (for micro-hydro generators)

The difference in height between the water intake and the discharge point for reaction turbines and the water intake to the turbine for impulse turbines.

1.3.57 System output terminals

The system output terminals for the extra-low voltage (ELV) circuit(s) are the output side of the ELV protection and for the low voltage (LV) circuit(s) are the terminals for the conductors from the stand-alone system to the LV switchboard.

1.3.58 Sun path diagram

A diagram that shows the path of the sun across the sky, in terms of its azimuth and altitude angles at different times of the day, for selected days of the year, usually including the solstices and equinoxes.

1.3.59 Sunshine-hour data

The number of hours in a day for which the direct (beam) component of solar radiation is present.

1.3.60 Surge demand

The peak momentary apparent power level, which is typically present for 10 s or less (measured in VA).

1.3.61 Tilt angle

The angle between the horizontal plane and the plane of the photovoltaic module.

1.3.62 Unidirectional inverter

An inverter which operates with power flow from the d.c. side to the a.c. side only.

1.3.63 Vertical wind speed profile

The variation of wind speed with height.

1.3.64 Wind turbine generator

A device that converts the kinetic energy in the wind into electrical energy.

1.3.65 Wind speed frequency distribution

The statistical distribution of the frequency of occurrence of each wind speed.

1.3.66 Worst month

The month for which the energy available from renewable energy generators is lowest in comparison to the load for that month.

SECTION 2 SYSTEM DESIGN — GENERAL

2.1 OVERVIEW OF THE DESIGN PROCESS

2.1.1 General

There are a number of approaches to the design of stand-alone power systems. The approach recommended by this Standard is based on the following underlying principles:

- (a) The system is safe and meets regulatory requirements. Refer to AS/NZS 4509.1 and AS/NZS 3000.
- (b) The system meets the requirements of the user.
- (c) The provision of electrical energy is not considered in isolation, but is treated within the overall context of the provision of energy services.
- (d) The appropriate level of detail in design depends on the complexity and cost of the system.
- (e) The design guidelines laid out in this Standard are aimed at producing a robust design. This design will generally be conservative and may be further optimized to reduce cost to suit more specific conditions on a case by case basis.

2.1.2 Steps involved

There are a number of steps in the design process which are essential, though they cannot always be followed in sequential order. The following points can serve as a checklist:

- (a) Establishing design criteria—
 - (i) general design criteria;
 - (ii) assessment of energy services and energy source selection;
 - (iii) assessment of electrical demand; and
 - (iv) resource assessment.
- (b) System configuration.
- (c) Component sizing and selection—
 - (i) major component sizing and selection;
 - (ii) metering and control; and
 - (iii) protection, switching and isolation.
- (d) Installation design.
- (e) Costing and economic evaluation.
- (f) Documentation.

For small, low cost or simple systems, carrying out these steps may be trivial, or a step may be omitted. Additionally, the process may involve some degree of iteration. For example, if a chosen design proves to be over-budget, the system components may need to be re-sized, and other aspects of the design may need to be modified.

2.2 GENERAL DESIGN CRITERIA

The design of any system should be guided by a number of criteria, determined by the user's general preferences (e.g. lowest economic life cycle cost, lowest environmental impact) and by site constraints. Some of the major areas to be considered are—

- (a) budget constraints;
- (b) power quality (e.g. waveform quality or continuity of supply);
- (c) environmental impact (e.g. trimming or removal of trees for a PV system, civil works and diversion of water in a hydro system);
- (d) use of existing equipment;
- (e) acceptable extent of generating set (generating sets) running versus renewable energy contribution;
- (f) acceptable noise levels;
- (g) availability of spare parts and maintenance service;
- (h) site accessibility;
- (i) acceptable level of reliability and maintenance;
- (j) level of automation versus direct user control; and
- (k) aesthetics.

Reliability should be considered essential. However, the necessity for special design techniques to achieve very high levels of reliability will depend on the application.

2.3 ASSESSMENT OF ENERGY SERVICES AND ENERGY SOURCE SELECTION

2.3.1 General

The provision of electrical energy should be dealt with in the context of provision of all energy services to the dwelling or group of buildings. Such an integrated approach to the provision of energy services should yield the lowest cost outcome and can ensure lower overall energy consumption from non-renewable sources.

2.3.2 Identification of energy services

Typical services required within domestic dwellings include, but are not limited to —

- (a) water heating;
- (b) space heating;
- (c) space cooling;
- (d) refrigeration;
- (e) lighting;
- (f) cooking;
- (g) cleaning;
- (h) entertainment;
- (i) kitchen appliances;
- (j) power tools;
- (k) office equipment;
- (l) communication and information technology
- (m) water pumping; and
- (n) water treatment (e.g. softeners, purifiers, desalinators, etc.).

2.3.3 Matching energy sources to services

Energy sources for these services should be chosen on the basis of—

- (a) availability of energy sources and conversion technology;
- (b) an appropriate match between the energy source and the service and the efficiency of conversion (e.g. use gas for heating rather than electricity);
- (c) cost;
- (d) user preference; and
- (e) reliability.

Services deemed to be most appropriately supplied with electrical energy will form the load for the stand-alone power system.

The most important outcome of this approach is that heating services such as hot water, cooking and space heating generally are best supplied by sources that provide heat directly, rather than through conversion from electricity.

When excess renewable energy is available, consideration should be given to utilizing it for opportunity loads (e.g. for water heating or water pumping).

2.3.4 Typical sources of energy

For the services listed in Clause 2.3.2, in a non-urban area, a typical selection of energy sources and technologies may be, but not limited to —

- (a) water heating—solar, gas or wood or a combination;
- (b) space heating—solar, through passive or active solar and energy efficient design, supplemented by wood, gas or kerosene heating;
- (c) space cooling—energy efficient building design, assisted by fans, evaporative coolers (in dry climates), and refrigerative air conditioning only where necessary;
- (d) refrigeration—efficient electrical or gas units;
- (e) lighting—using daylight and efficient electrical;
- (f) cooking—wood, gas, electrical for microwave ovens and low energy usage items, e.g. toasters;
- (g) other—cleaning, entertainment, kitchen appliances, power tools and office equipment all require electrical energy; and
- (h) water pumping—may be performed by electrical energy from the stand-alone power system (including excess power), a self contained solar pumping system, a wind driven pump, petrol or diesel powered pumps.

Where a generating set is used and will be required to run for several hours every day, consideration should be given to the use of waste heat from the generating set for water heating.

NOTE: A worked example is shown in Appendix A.

2.4 COSTING AND ECONOMIC EVALUATION

2.4.1 Quotations

Quotations should include a specification of system performance as outlined in Section 5.

2.4.2 Evaluation of design options

Economic evaluation of different design options, including mains connection, should be made on the basis of a life cycle cost analysis using AS 3595, AS/NZS 4536 or similar methods.

The results of any such evaluation should be presented with an explicit statement of the discount rate, inflation rate, life cycle period and other parameters used in the analysis which are material to the outcome.

2.5 DOCUMENTATION

Documentation of the major parameters of the system design shall be provided to the user at the time of commissioning as set out in AS/NZS 4509.1.

SECTION 3 SYSTEM DESIGN — ELECTRICAL

3.1 ASSESSMENT OF ELECTRICITY DEMAND

3.1.1 Information required

The minimum amount of information required for design is—

- (a) design load energy (daily energy consumption);
- (b) maximum a.c. and d.c. demand; and
- (c) surge demand.

Where the daily design load energy equals or exceeds 1 kWh/d, seasonal variation of average daily energy demand is also required.

This information is to be drawn from a list of all electrical loads detailing supply type (a.c. or d.c.), real and apparent power consumption, usage time and surge demand.

NOTE: A worked example is provided in Appendix A and blank worksheets are provided in Appendix B.

3.1.2 Electrical energy efficiency measures

3.1.2.1 General

Consideration should be given to substituting more efficient appliances to reduce the power system component size and total costs.

Evaluation of the economic benefit of such a substitution, if required, should be performed by comparison of life cycle costs, as described in Clause 2.4.2.

3.1.2.2 Recommended measures

Measures which are recommended in most circumstances include—

- (a) high efficiency lights in place of incandescent lamps, except for fittings with low usage times or frequent on/off cycling or specialized task lighting;
- (b) efficient refrigeration, especially special purpose efficient d.c. refrigeration; and
- (c) power factor correction of significant a.c. loads with poor power factor.

3.1.2.3 Other measures to be considered

Other measures include the use of washing machines, dishwashers and other household appliances with a low energy consumption. The energy efficiency rating for the appliance (e.g. the kWh figures given on the Energy Star Rating label on the appliance) may be a useful guide. Washing machines, dishwashers and other devices that have built in heating elements are more likely to have a lower energy efficiency rating.

3.1.2.4 Stand-by loads

Many electronic or electronically controlled appliances maintain a small power consumption when the appliance is not in operation (i.e. on stand-by). Where these loads are supplied with power continuously, this may constitute a considerable additional load. This should be taken into account in the selection of appliances.

3.1.3 Demand management

Demand management may be applied to lower the maximum demand and to reduce component size and cost. This may be implemented by the system users or by automatic control. The extent of demand management that should be carried out will depend on a number of factors including—

- (a) size and usage times of individual loads;
- (b) budget constraints; and
- (c) user attitudes.

Typical demand management practices include staggering the time of operation of high power loads, so that they do not operate concurrently, and delaying or reducing usage of energy during periods of low resource availability, or scheduling high energy use to generating set run time or peak PV hours, where possible.

3.1.4 Demand assessment

3.1.4.1 General

Demand assessment needs to take into account whether the system is a d.c. or a.c. bus system and whether there is any correspondence in time between generation source and load.

3.1.4.2 Average daily energy consumption

The average daily energy consumption is determined as the sum of the energy consumption for each individual load (for all loads of either a.c. or d.c.) as follows:

$$\begin{array}{l} \text{design} \\ \text{load} \\ \text{energy} \end{array} = \text{sum of power} \times \text{usage time} \quad \dots 3.1.4.2(1)$$

where

$$\begin{array}{l} \text{design} \\ \text{load} \\ \text{energy} \end{array} = \text{daily energy consumed by all loads either d.c. or a.c., in watt hours (Wh)}$$

$$\begin{array}{l} \text{power} \\ \text{usage} \\ \text{time} \end{array} = \begin{array}{l} \text{power of an individual load, in watts (W)} \\ \text{average daily usage time of the individual load, in hours} \end{array}$$

Where the system is to supply both a.c. and d.c. loads, these are calculated separately.

This produces E_{dc} and E_{ac} as separate figures.

where:

$$\begin{array}{l} E_{dc} \\ E_{ac} \end{array} = \begin{array}{l} \text{design daily d.c. load energy, in watt hours (Wh)} \\ \text{design daily a.c. load energy, in watt hours (Wh)} \end{array}$$

For a d.c. bus design, the daily energy consumption is calculated at the d.c. bus, as follows:

$$E_{tot} = E_{dc} + \frac{E_{ac}}{\eta_{inv}} \quad \dots 3.1.4.2(2)$$

where

- E_{tot} = total design daily energy demand from the d.c. bus, in watt hours (Wh)
 η_{inv} = energy efficiency of the inverter when supplying the design a.c. load profile, dimensionless

The inverter efficiency factor is estimated based on the efficiency versus load curve of the inverter.

If the load profile and efficiency curve are both available then the weighted efficiency should be used as the inverter efficiency.

If only the efficiency curve but not the load profile is available then the efficiency at 50% power should be used as the inverter efficiency.

If only the maximum efficiency is available then 10% less than this value should be used as the inverter efficiency.

In other words a slightly conservative approach is recommended.

NOTES:

- 1 Stand-by loads should be included in estimates of daily energy consumption or, where it is not included, advice should be given to the user in regard to the operating conditions necessary to avoid stand-by energy consumption.
- 2 A worked example is provided in Appendix A and blank worksheets are provided in Appendix B.

For a.c. bus systems the E_{dc} and E_{ac} values are used separately.

3.1.4.3 Maximum demand

Where it cannot be measured directly, maximum demand should be estimated on the basis of a selection of loads which will typically include the load of highest power rating together with all other loads likely to be in use at the same time. The selection should be based on an understanding of load usage patterns and load management practices.

3.1.4.4 Surge demand a.c. loads

Surge demand should be based on a selection of loads which constitute the highest surge load condition. Where the starting of two or more loads is automatically controlled, such as for refrigeration, the calculation should account for concurrent surges from the largest two of these loads.

In the absence of more accurate information, the surge demand for an individual load can be estimated from the following equation:

$$\text{surge demand} = \frac{\text{power}}{pf \times \text{surge factor}} \quad \dots 3.1.4.4$$

where

- surge demand = surge demand, in volt amperes (VA)
 power = real power consumption when running, in watts (W)
 pf = power factor of the device when running, dimensionless
 surge factor = a factor which depends on the type of load

As a guide, use surge factor of 1 for resistive loads, 3 for universal motors (hand-held tools and most kitchen appliances), and 7 for induction motors.

NOTE: Electronic loads such as TVs can cause extremely high surges for very short periods after power up. This may be a problem for very small inverters if electronic loads are the major surge loads.

3.1.4.5 Surge demand d.c. loads

Where there are d.c. loads such as motors that may draw significant surge currents, the d.c. surge demand should be estimated. The main considerations that need to be considered are the cable sizing to minimize voltage drops during surge conditions and the batteries capability to sustain the surge. For battery considerations refer to Clause 3.4.7.4.

3.1.5 Seasonal variation

The seasonal variation in demand will have an influence on the optimum tilt angle for PV arrays, and on the performance of all systems, regardless of the type of generation source. Systems designed to supply a demand of 1 kWh/d or less may be designed without reference to seasonal variations in demand. Design of systems to supply more than 1 kWh/d should take seasonal variations into account, preferably based on data for each month of the year.

Typical causes of seasonal variation for various energy services are as follows:

- (a) Space heating—heating degree days per month.
- (b) Space cooling—cooling degree days per month.
- (c) Refrigeration—ambient temperature.
- (d) Lighting—night time hours.
- (e) Cooking—seasonal cooking habits.
- (f) Cleaning—little variation.
- (g) Entertainment—little variation.
- (h) Kitchen appliances—little variation.
- (i) Power tools—little variation, or dependent on seasonal work patterns.
- (j) Office equipment—little variation.
- (k) Water pumping—rainfall variation and ambient temperature for irrigation, household activity patterns for domestic supply.

3.1.6 Provision for growth

Provision for growth of energy demand should be made in agreement with the client.

3.2 RESOURCE ASSESSMENT

3.2.1 General

The choice of renewable energy source and sizing of generators depends on accurate knowledge of the resource. This is especially the case for wind and hydro resources which are highly site dependent.

3.2.2 Solar resource

3.2.2.1 Existing records

Various sources of long-term solar radiation data exist. Solar radiation data tables based on long-term pyranometer measurements provide the most reliable source of data, and have the convenience of presenting data for surfaces at various orientations and tilts. However, adjustments may need to be applied for sites some distance away from the measurement station. Satellite based measurements have the advantage of being available for virtually any location, however, the number of years of records may not be as great. Satellite data is usually only available as irradiation on the horizontal plane, and a suitable model must be used to generate data for the orientation and tilt angle of the array.

Maps showing average annual solar radiation or solar radiation for the worst month may be used for systems providing a design load of less than 1 kWh/d. It should be noted that these maps are prepared for one tilt angle only e.g. horizontal or latitude angle. The use of these maps is not recommended for systems over 1 kWh/d, unless no suitable long-term information for the site is available. The use of sunshine-hour data to estimate irradiation should be used only where reliable correlation with irradiation can be ascertained.

3.2.2.2 Adjustment for site conditions

Adjustment to data from the sources mentioned in Clause 3.2.2.1 should be made both for climatic variations from the measurement site to the installation site and shading, especially due to trees or built structures, at the PV array location. Shading should be avoided wherever possible due to the detrimental impact on array output.

Climatic variations will be influenced by such factors as distance from the coast and mountainous terrain. Rainfall records, vegetation and local knowledge of cloud cover and fogs may provide a qualitative indication of the correction factor to be applied.

Where shading may affect system performance and an accurate estimation of PV output is required, hourly analysis methods should be used to determine the impact on array output.

3.2.3 Wind resource

3.2.3.1 Existing records

Records of wind speed are kept by the Australian Bureau of Meteorology, the New Zealand Meteorological Service, NZ NIWA (National Institute of Water and Atmospheric Research), some agricultural research stations and mining operations. Reports from special purpose wind surveys may also be available from State or Federal energy authorities. Care should be taken with the use of surface wind analysis reports containing data from 9 a.m. and 3 p.m. only, as average daily wind speeds may be affected by diurnal variations not shown in this data. Where possible, the complete records (all hours) should be obtained.

Isovent maps may provide a very rough indication of the wind resource in the absence of more detailed measurements.

3.2.3.2 On-site measurements

The magnitude of the wind resource is very site specific, and on-site measurements are essential in many cases. On-site measurements should be carried out using data logging anemometers, for as long as is practically and economically possible. A period of 12 months of measurements should be considered minimum where long-term records from a nearby site are not available. Where the data is to be correlated with long-term data from a nearby site, a period of less than 12 months may be acceptable provided that it is at least long enough to reliably correlate wind speed for each of the major prevailing wind directions throughout the year. Short-term data should be used with great caution.

The anemometer should be sited as close as possible to the proposed installation site for the wind turbine, preferably at the proposed hub height of the turbine or at least at a height which will reduce ground effects to an acceptable level. A cleared site with a height of 10 m is typical. The site should be sufficiently clear of obstacles, such as buildings or trees, to ensure turbulence produced by obstacles does not affect the anemometer.

3.2.3.3 *Adjustment for site conditions*

Long-term data (over many years) from a nearby site should be used with care and must be adjusted according to differences between the measurement site and the installation site in terms of the effect of major geographical features, local terrain, exposure and the height of interest. Ideally, short-term measurements at the proposed installation site should be correlated with long-term data from the nearby site, to obtain a more accurate estimate of long-term wind speeds. Consideration should be given to the shading from growth of trees and possible future development of other buildings around the site.

Accurate assessment of the wind resource requires the application of expert knowledge and judgement and is beyond the scope of this Standard.

3.2.4 Hydro resource

3.2.4.1 *Existing records*

Stream flow or river discharge records may be held by water resources authorities.

3.2.4.2 *On-site measurements*

The magnitude of the hydro resource depends on two quantities. These are—

- (a) stream flow; and
- (b) static head.

Stream flow measurements may be made by a variety of methods.

Preliminary estimates of static head may be based on topographic maps. However, detailed design or performance estimates should be based on on-site measurements.

3.2.4.3 *Adjustment for site conditions*

Several methods for the estimation of stream flow are available, including the area-rainfall method, the flow correlation method, and variations on these two.

Where rainfall and hydrological conditions are similar for both the catchment area of the proposed installation site and a nearby site for which records exist, stream flow for the proposed installation site may be estimated to be proportional to the ratio between the catchment areas of the two sites. Where hydrology is similar but rainfall is known to be different, the stream flow may also be adjusted in proportion to the ratio between the rainfall at the two sites.

Where possible, flow measurements should be carried out a number of times over at least a one year period at the proposed installation site. These measurements may then be correlated with measurements taken at the recording station at the same time. If a reasonable correlation exists, this correlation may then be extrapolated over all years of records to obtain an estimate of long-term stream flow at the proposed installation site.

Accurate assessment of the hydro resource requires the application of expert knowledge and judgement and is beyond the scope of this Standard. Information for small watercourses should be used with great caution due to local variations, e.g. microclimate, hydrology.

3.3 SYSTEM CONFIGURATION

3.3.1 General

The system configuration should be chosen so as to satisfy the design criteria, to make the most cost-effective use of renewable energy resources, and to maximize the efficiency of operation of the system. Economic evaluation of different options, if required, should be carried out on the basis of life cycle costing.

3.3.2 Selection of generators

3.3.2.1 Generators

In selecting any generating source, the following factors shall be taken into account:

- (a) Installed cost and maintenance costs.
- (b) Environmental impacts.
- (c) Aesthetic and other user preferences.
- (d) Local regulations or constraints regarding use of the resource or installation of the generator and associated equipment.
- (e) Sized for efficient loading.

3.3.2.2 Renewable energy generators

In selecting renewable energy generators, the following additional factors shall be taken into account:

- (a) Time and cost of obtaining reliable resource data.
- (b) Adequacy of the renewable resource based on measured or estimated data.
- (c) Correlation with load on a daily, weekly and seasonal scale.
- (d) Where more than one renewable energy generator is used, the seasonal and short-term complementarity of the energy sources.

3.3.2.3 Internal combustion generating sets

- (a) The choice of fuel source for an internal combustion generating set includes, but is not limited to—
 - (i) distillate (diesel);
 - (ii) petrol;
 - (iii) bio-fuel
 - (iv) liquid petroleum gas; and
 - (v) liquefied natural gas.
- (b) Selection should be based on consideration of the following additional factors:
 - (i) Estimated monthly run time.
 - (ii) Fuel costs.
 - (iii) Use of the fuel on site for other purposes.
 - (iv) Noise levels emitted by the set, and required noise levels for the installation.

If run time exceeds 360 h/y, careful attention should be paid to operating and maintenance costs and the reliability of the set.

3.3.3 Common connection of generators

Where more than one generator is used, their outputs may be connected in common at the a.c. or d.c. bus.

In d.c. bus systems the renewable sources are generally connected to the d.c. bus (and battery) via individual regulators as shown in Figure 1A. D.C. loads are then connected to the d.c. bus and a.c. loads are connected to an inverter supplied from the d.c. bus.

In a.c. bus systems a bi-directional inverter connected to a battery bank establishes an a.c. bus. Renewable sources in this configuration are then connected via individual inverters to the a.c. bus. In this case the individual inverters act as the regulators for the renewable source and generally provide maximum power point regulation. Loads are generally supplied from the a.c. bus but d.c. loads may be supplied via a connection to the d.c. bus (i.e. battery).

Refer to Figure 1A for renewable energy generators connected at the d.c. bus.

Refer to Figure 1B for renewable energy generators connected at the a.c. bus.

When considering the design of any system the path the energy takes in travelling from the source to the load considering the need for intermediate storage for use at times when the resource is not available should be carefully considered. In both a.c. and d.c. bus systems the energy paths and the devices through which the energy passes needs to be carefully taken into account in calculating the subsystem efficiencies. Refer to Clause 3.4.2.2.

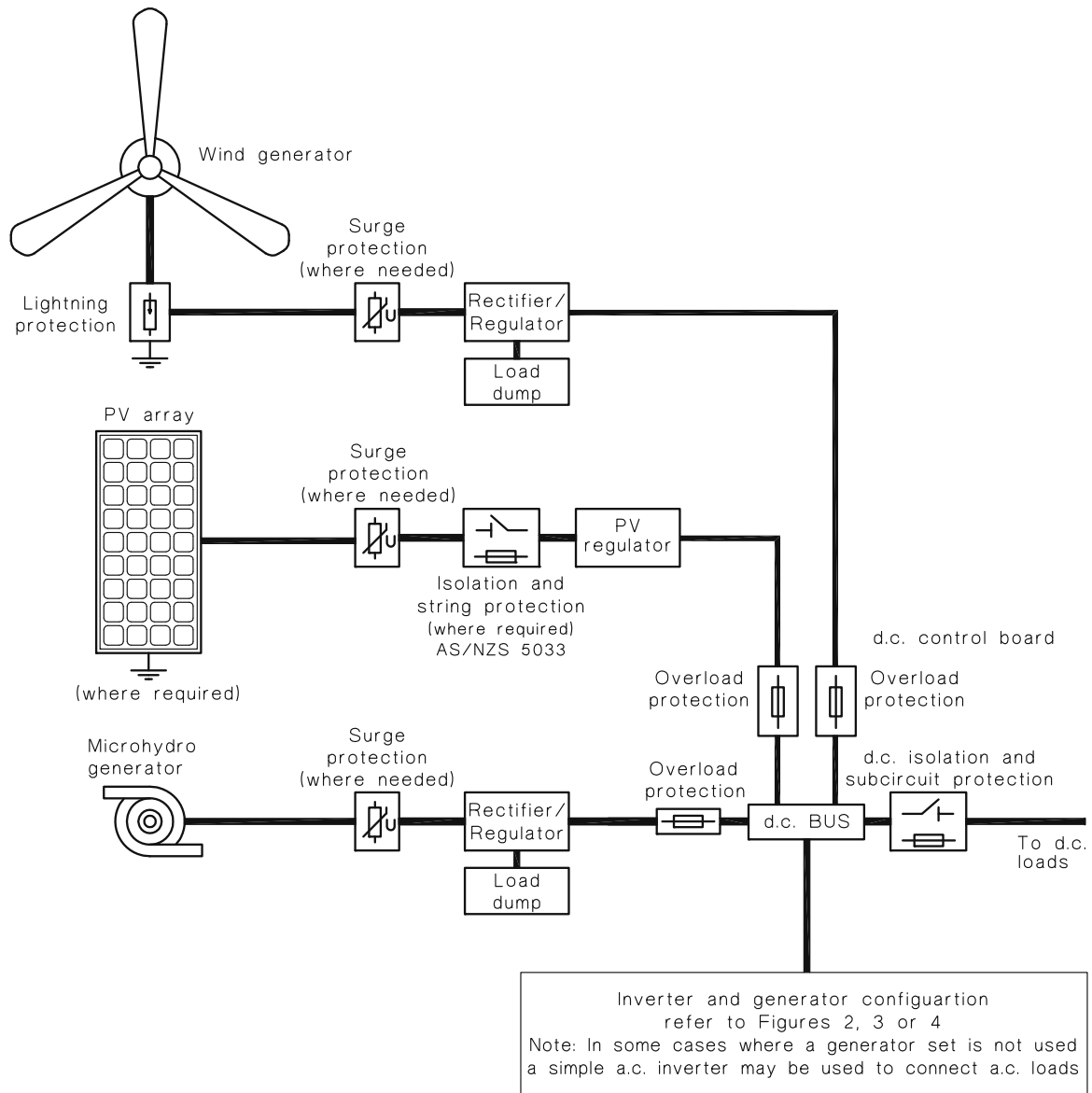


FIGURE 1A EXAMPLE OF D.C. COUPLED ENERGY INPUTS AND CONTROLS

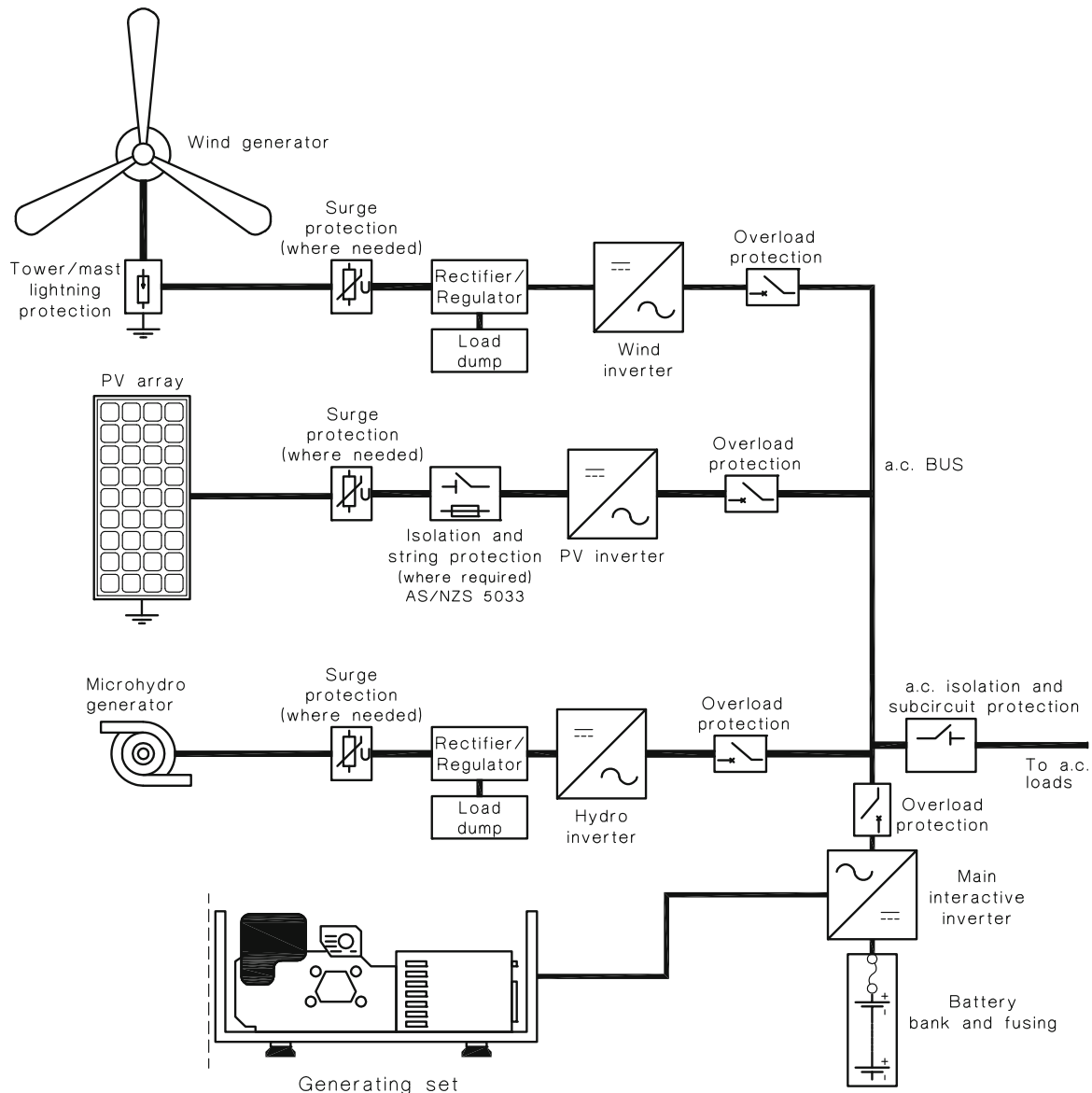


FIGURE 1B EXAMPLE OF A.C. COUPLED ENERGY INPUTS AND CONTROLS SWITCHBOARD DETAILS

3.3.4 Generating sets

3.3.4.1 General

Generating sets producing a.c. are commonly connected into the system in one of three ways, as set out in Clauses 3.3.4.2 to 3.3.4.4. The 'series configuration' and the 'switched configuration' are only applicable to d.c. bus systems. The 'parallel configuration' is applicable to both a.c. and d.c. bus systems. In the case of a.c. bus generator connections refer to Figure 1B.

3.3.4.2 Series configuration

The key feature of this configuration is that the output from the generating set is supplied only to the battery charger which then feeds the d.c. bus (refer to Figure 2). All a.c. load energy is provided by an inverter. This configuration is the least sophisticated and may be the lowest cost option. However because of the low efficiency of utilization of the generating set in supplying a.c. loads, it should be used only where the load is predominantly or entirely d.c., or in systems supplying less than 1 kWh/d.

3.3.4.3 Switched configuration

The key feature of this configuration is that the output from the generating set, when running, may supply both the battery charger and the a.c. loads directly (refer to Figure 3). When the generating set is not running, the a.c. loads will be switched to the inverter.

The switching may be done automatically, or manually by a changeover switch. In either case, it is essential that the changeover switch or contactor has a break-before-make action. Where a manual changeover switch is used, a switch with a 'centre-OFF' position is recommended. The battery charger, inverter and automatic changeover contactor may be incorporated into a single unit (inverter-charger).

If the inverter output is not synchronized before connection, a break in supply long enough to accommodate reverse voltages should be provided.

NOTE: A break of 20 ms may be adequate for most domestic situations however large inductive loads could require a considerably longer period. AS/NZS 3000 requires that all changeover devices have a voltage rating appropriate for the maximum out of phase voltage between contacts connected to different sources.

This configuration provides efficient utilization of the generating set power, but does require that a.c. loads are tolerant of short breaks in supply.

3.3.4.4 Parallel configuration

This configuration is applicable to either a.c. or d.c bus system designs.

The key feature of this configuration is the use of an interactive battery inverter, i.e. one which allows bi-directional power flow, and which is capable of synchronizing with, and supplying a.c. power in parallel with, a generating set (refer to Figure 4). A contactor, or contactors, under the control of the inverter, connects the generating set to the a.c. inverter output when the system is synchronised and the generator is required to be on-line. When operating in parallel with the generating set, the direction and magnitude of power flow through the inverter at any instant is controlled to ensure optimal or near optimal loading of the generating set and battery charging at the highest possible rate while at all times meeting the load demand.

This configuration provides the best utilization of the generating set, and the highest quality of output power (a sine waveform, without breaks in the supply voltage). It may also allow the use of greatly reduced battery size.

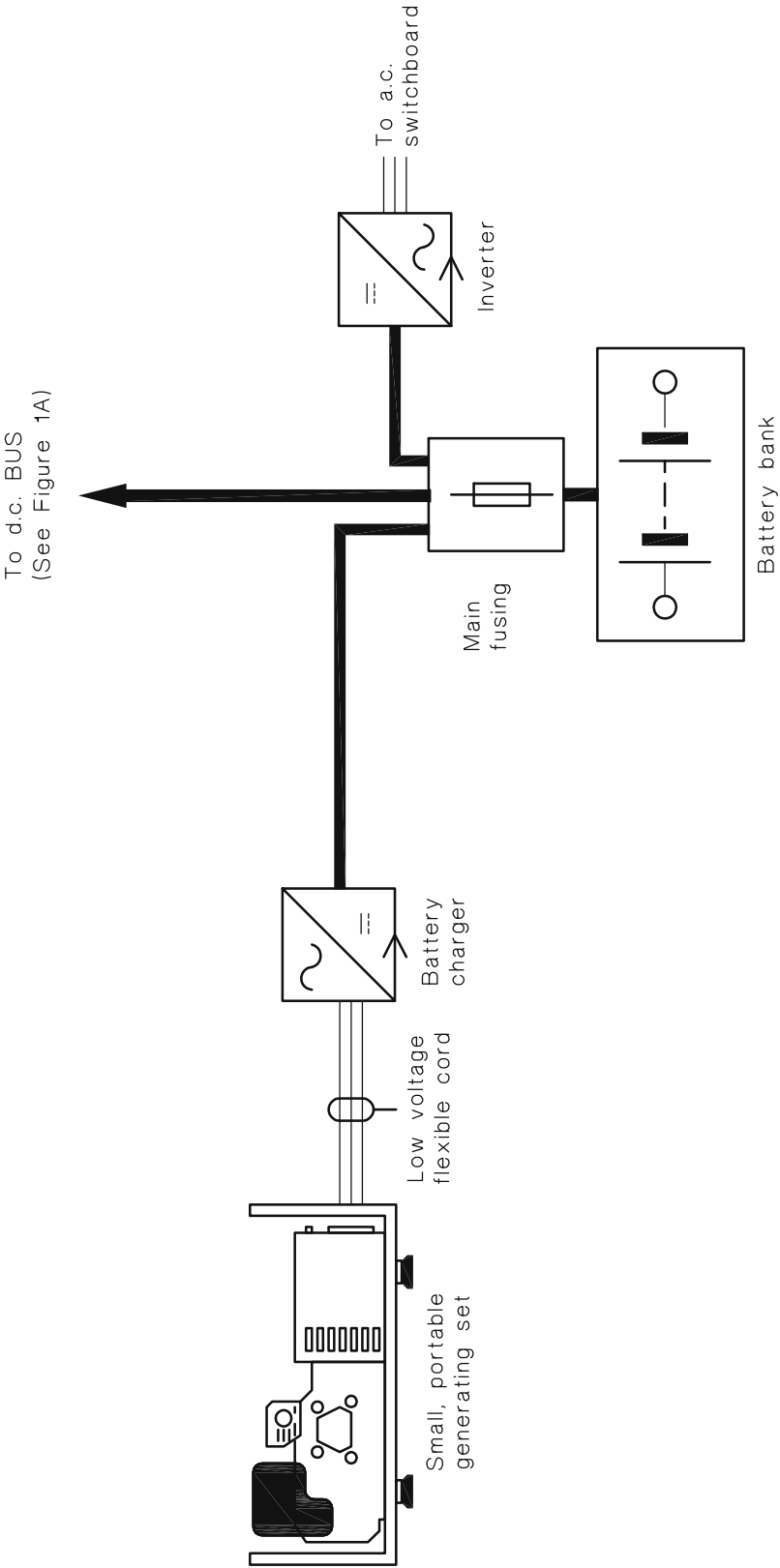
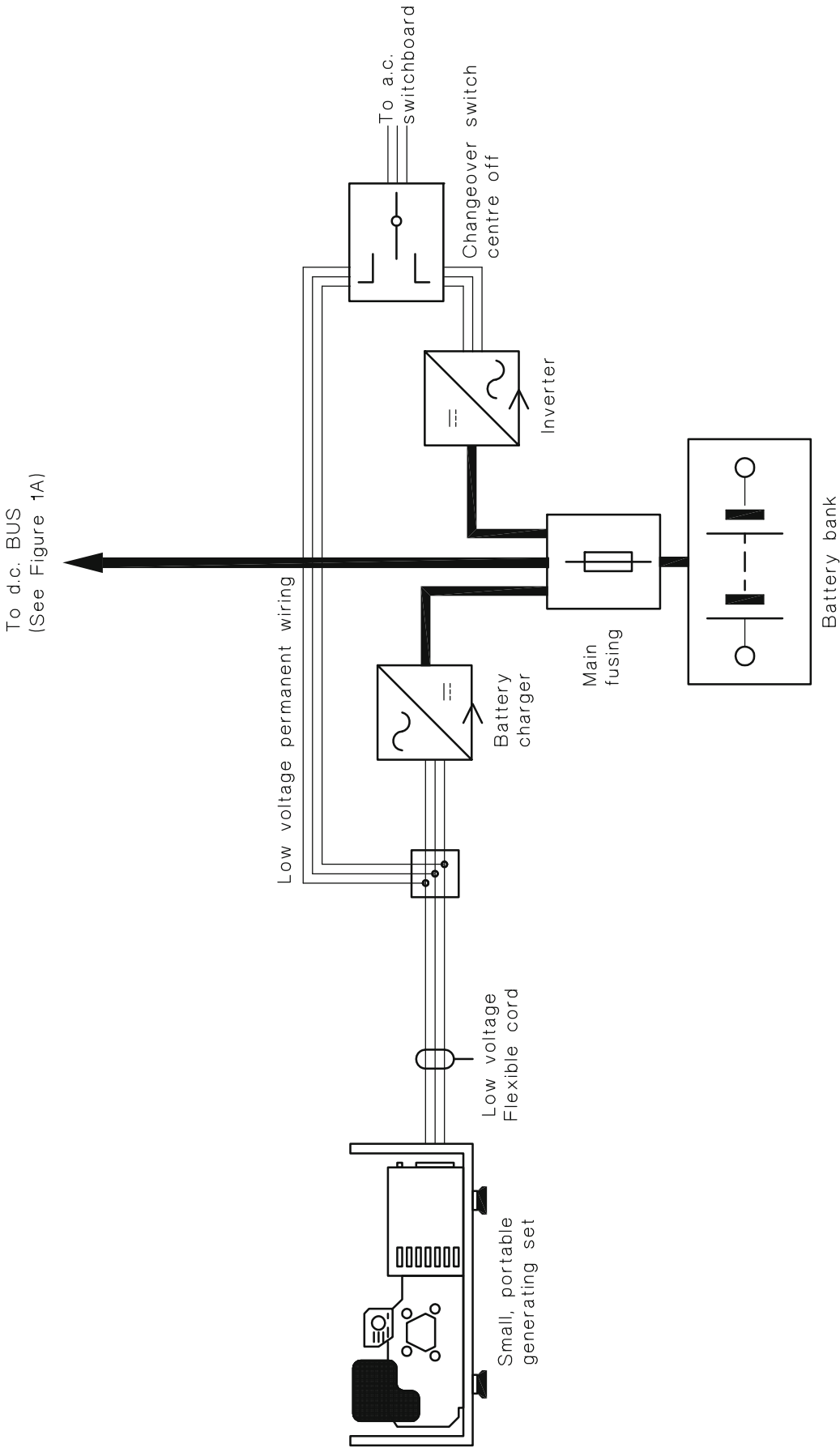


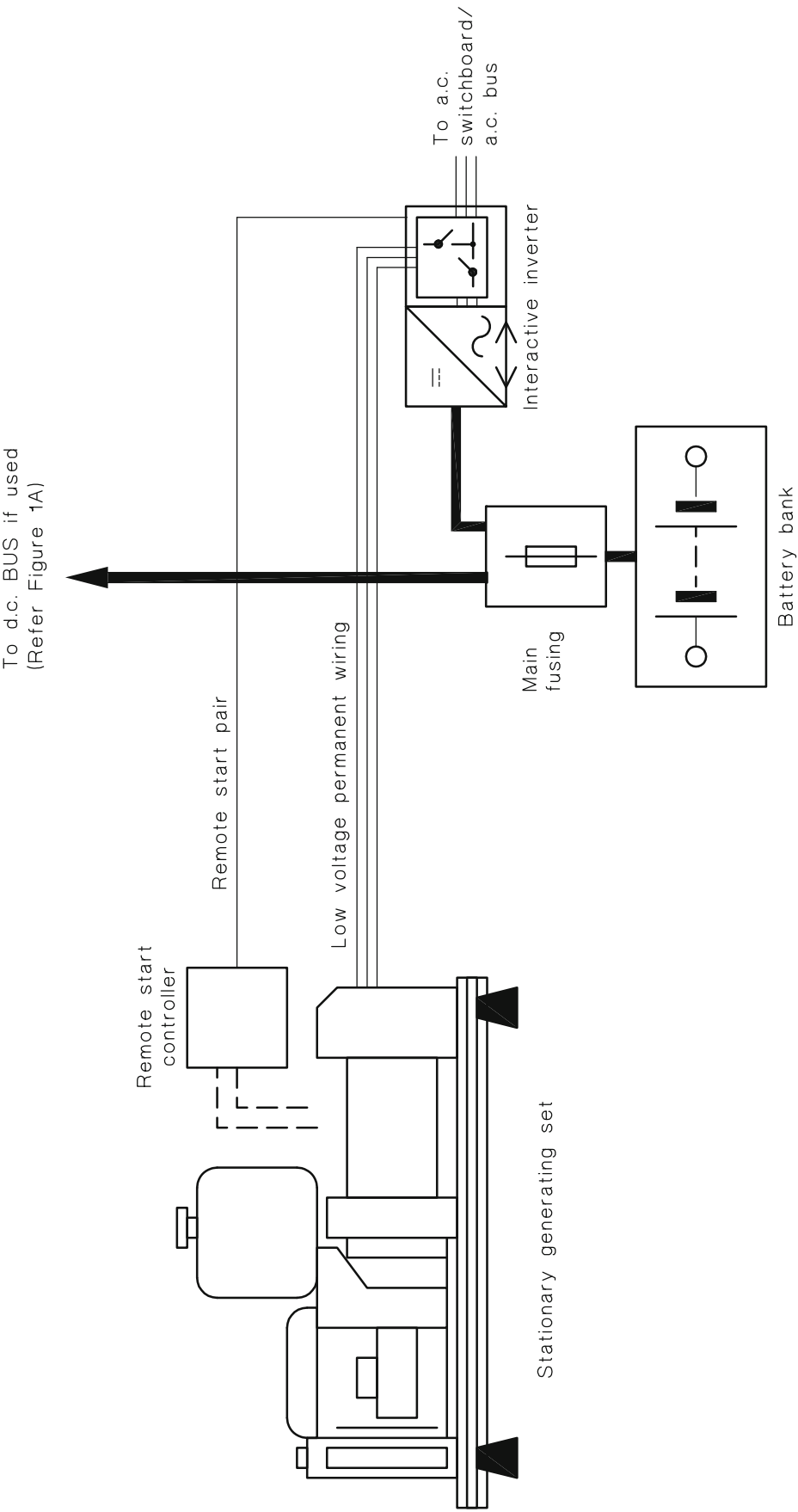
FIGURE 2 SERIES CONFIGURATION



NOTES:

- 1 Inverter/charger may be used in lieu of discrete inverter and battery charger.
- 2 Changeover switch to comply with the requirements of AS/NZS 3010 or AS 62310 series.

FIGURE 3 SWITCHED CONFIGURATION



NOTE: Back feeding protection for the generator may be needed on the inverter.

FIGURE 4 PARALLEL CONFIGURATION

3.4 COMPONENT SIZING AND SELECTION

3.4.1 System voltage selection (d.c.)

The following points shall be considered when deciding on the d.c. nominal system voltage—

- (a) limiting the current drawn under maximum demand conditions; and

NOTE: At high currents care must be taken to consider voltage drop in cables and battery sizes.

- (b) the availability of appropriately sized equipment, particularly batteries and inverters.

3.4.2 Renewable energy generator sizing and selection

3.4.2.1 General

The sizing of renewable energy generators is often influenced by a number of design criteria, including the available energy resource, acceptable generating set run time (if used), budget constraints and other factors. For systems in which the renewable energy fraction is less than 75%, other system features may be necessary to ensure satisfactory system performance (see Clause 3.5.2).

In system designs that allow for loads supplied directly from renewable generators without the need for intermediate battery storage, the appropriate sub-system efficiency should be chosen. Care should be exercised in design to allow for conditions when renewable resources may not be available and energy needs to be drawn from storage. In these cases subsystem efficiencies based on intermediate storage should be used.

3.4.2.2 Sub-system efficiencies

3.4.2.2.1 General

Design and performance calculations based on energy (Wh) should take into account energy losses in all equipment and cabling between the renewable energy generator and the d.c. distribution bus (including the battery).

3.4.2.2.2 D.C. bus systems

For any particular renewable energy generator, a renewable energy subsystem efficiency can be calculated as follows

$$\eta_{\text{renss}} = \eta_{\text{ren-batt}} \times \eta_{\text{reg}} \times \eta_{\text{batt}} \quad \dots 3.4.2.2(1)$$

where

- η_{renss} = the efficiency of the subsystem from a renewable energy generator to the d.c. bus, dimensionless
- $\eta_{\text{ren-batt}}$ = the energy transmission efficiency of the cabling between renewable energy generator and battery, dimensionless
- η_{reg} = the energy efficiency of the regulator, dimensionless
- η_{batt} = the energy efficiency (i.e. watt hour efficiency) of the battery, dimensionless

Design and performance calculations based on charge (Ah) should take into account the coulombic efficiency of the batteries.

3.4.2.2.3 A.C. bus systems

Where the loads are being supplied directly from the renewable generator (e.g. during the day directly from the solar array or at times of good wind via a wind turbine).

$$\eta_{\text{renss2}} = \eta_{\text{ren-load}} \times \eta_{\text{reninv}} \quad \dots 3.4.2.2(2)$$

where

$$\begin{aligned} \eta_{\text{renss2}} &= \text{Sub-system efficiency from the renewable energy generator to the load} \\ \eta_{\text{ren-load}} &= \text{energy transmission efficiency of the cabling between the renewable generator and the load} \\ \eta_{\text{reninv}} &= \text{energy efficiency of the renewable energy inverter} \end{aligned}$$

Where the loads are being supplied from the renewable source via intermediate battery storage:

$$\eta_{\text{renss3}} = \eta_{\text{ren-batt-load}} \times \eta_{\text{reninv}} \times \eta_{\text{inv(chg)}} \times \eta_{\text{batt}} \times \eta_{\text{inv(inv)}} \quad \dots 3.4.2.2(3)$$

where

$$\begin{aligned} \eta_{\text{renss3}} &= \text{sub-system efficiency from the renewable energy generator to the load} \\ \eta_{\text{ren-batt-load}} &= \text{energy transmission efficiency of the cabling between the renewable generator and the load via main inverter and battery} \\ \eta_{\text{reninv}} &= \text{energy efficiency of the renewable energy inverter} \\ \eta_{\text{batt}} &= \text{energy efficiency of the battery} \\ \eta_{\text{inv(inv)}} &= \text{energy efficiency of the interactive battery inverter in inverter mode} \\ \eta_{\text{inv(chg)}} &= \text{energy efficiency of the interactive battery inverter in charging mode} \end{aligned}$$

3.4.2.3 Systems under 1 kWh/d

Systems supplying less than 1 kWh/d may be designed on the basis of yearly average load and resource data, or where no generating set is included, data for the month of lowest resource availability.

3.4.2.4 Systems over 1 kWh/d

Design for systems supplying more than 1 kWh/d should take seasonal variations in load and resource data into account.

3.4.2.5 Systems without a generating set

Systems which rely entirely on renewable energy sources will be heavily affected by the variation in output from these sources. The sizing of both energy storage (see Clause 3.4.7) and renewable energy generators should therefore be greater than that required for systems incorporating a generating set. Consideration should be given to the degree of resource variability, and to the length of time over which poor resource availability is likely to persist. Generators should be sized to allow full recharge of the batteries from maximum depth of discharge in an acceptable time-frame, e.g. 14 days, as well as the capacity to provide an equalizing charge.

Where annual, monthly or worst month resource data is used for renewable energy generator sizing, an 'oversupply co-efficient', f_o , may be used in the design process to allow for the increase in size required. For the purposes of generator sizing, the design load should be first multiplied by the oversupply co-efficient. Typical values for f_o are given in Table 1. The appropriate value should be determined on the basis of the considerations mentioned above, as well as the nature of the load. Critical loads require a higher value of f_o than non-critical loads. Systems designed on the basis of annual resource data should use values of f_o at the higher end of the range given in Table 1.

Particular care should be taken with wind-only systems because of the great variability of the resource. Wind-only systems are generally not viable if wind droughts longer than a week or two occur (because of the cost of energy storage).

TABLE 1
TYPICAL VALUES FOR OVERSUPPLY COEFFICIENT

Renewable energy generator type	Oversupply coefficient, f_o
Photovoltaic array (wholly or principally)	1.3 to 2.0
Micro-hydro generator (wholly or principally)	1.15 to 1.5
Wind turbine generators	2 to 4

NOTE: The use of an oversupply coefficient for micro-hydro systems is only necessary if the resource is not reliable all year round.

3.4.2.6 Determination of worst month

The worst month may be determined by finding the month in which the ratio of renewable generator output to load energy is smallest. In a simplified calculation, the load may be taken as constant over all months in each season.

3.4.3 Photovoltaic array selection and sizing

3.4.3.1 Selection

PV modules and installation design shall comply with AS/NZS 5033.

3.4.3.2 General

Where appropriate measured data is not available, calculations of the daily energy output of photovoltaic modules should be based on manufacturer's specifications (including tolerances) and daily average irradiation on the inclined plane with derating for daily average cell temperature and module operating voltage. Allowance for soiling may also be made where this is deemed to be appropriate.

NOTE: Appendix A contains a worked example.

3.4.3.3 Module tilt angle

The tilt angle should be chosen so as to maximize the useable energy production of the array. The optimum angle depends on the site latitude, the variation in solar irradiation throughout the year, the variation in load throughout the year, and the variation in output from other renewable energy generators, if present. A minimum tilt angle of 10° is recommended under any circumstances, to ensure adequate self-cleaning.

Where the PV array is the only renewable energy generator in the system, Table 2 provides a first estimate of the optimum angle.

TABLE 2
APPROXIMATE OPTIMUM TILT ANGLE FOR PHOTOVOLTAIC POWER SYSTEMS FOR ARRAYS OF FIXED TILT

Latitude	Near optimum tilt angle		
	No seasonal load variation	Winter peaking load	Summer peaking load
5° to 25°	Lat to Lat +5°	Lat +5° to Lat +15°	Lat -5° to Lat +5°
25° to 45°	Lat +5° to Lat +10°	Lat +10° to Lat +20°	Lat to Lat +10°

In hybrid systems where the PV array is to be used in conjunction with some other renewable energy generator, the tilt angle should be chosen to maximize the seasonal complementarity of the array output with that of the other generators, in order to minimize the requirement for energy from a generating set.

3.4.3.4 *Module orientation*

An array with fixed orientation should be set up to face within $\pm 10^\circ$ of true north unless system or site requirements dictate otherwise. Where a single axis tracking system is used, the array should face within $\pm 10^\circ$ of true north when the array is at the midpoint of its range of axial movement.

3.4.3.5 *Irradiation data*

The irradiation data used should be appropriate for the tilt angle and orientation of the modules. In particular, data used for a module orientation greater than 5° from true north (dictated by installation constraints), or for modules mounted on a tracking system, should be adjusted for those conditions.

3.4.3.6 *Derating factors*

Allowance should be made for manufacturing tolerances on module output. For example, where tolerance is $\pm 5\%$ on output current or power, a derating factor of 0.95 should be applied to these quantities.

For temperature derating see Clauses 3.4.3.7 to 3.4.3.9.

Typical derating factors for soiling vary from 1.00 (no derating) to 0.90. The lower figure would apply at sites which are both dusty and where regular cleaning is impractical.

3.4.3.7 *PV cell temperature*

Cell temperature varies over the course of a day, under the influence of ambient temperature and irradiance, and will tend to be highest during periods of high irradiance. The daily average cell temperature can be estimated from the following equation:

$$T_{\text{cell,eff}} = T_{\text{a,day}} + 25 \quad \dots 3.4.3.7$$

where

$T_{\text{cell,eff}}$ = average daily effective cell temperature, in degrees Celsius

$T_{\text{a,day}}$ = daytime average ambient temperature for the month of interest, in degrees Celsius

3.4.3.8 *Output of photovoltaic array with standard switched regulator design*

Where the panel is to be connected through standard switched regulators (non-maximum power point tracking) the current output should be determined from the manufacturer's I-V curves or other specifications at the daily average cell operating temperature, daily average module operating voltage, and irradiance specified under standard operating conditions. Operating voltage should be determined taking into account the average voltage of the battery during the day, plus all voltage drops between the battery and the PV array. Typically, these will include cable and regulator drops. A typical average daily module operating voltage would be 14 to 14.5 V.

The derated output current of the module can be calculated as follows:

$$I_{\text{mod}} = I_{\text{T,V}} \times f_{\text{man}} \times f_{\text{dirt}}$$

where

I_{mod} = derated current output of the module, in amperes

$I_{\text{T,V}}$ = output current of the module at the average daily equivalent cell temperature, daily average module operating voltage, and irradiance specified under standard operating conditions, in amperes

f_{man} = derating factor for manufacturing tolerance, dimensionless

f_{dirt} = derating factor for dirt/soiling, dimensionless

The output of the array may then be calculated in terms of charge (Ah).

The average daily charge output of the array can be calculated as follows:

$$Q_{\text{array}} = I_{\text{mod}} \times H_{\text{tilt}} \times N_{\text{p}} \quad \dots 3.4.3.8(1)$$

where

Q_{array} = average daily charge output of the array, in ampere hours (Wh)

I_{mod} = derated current output of a module, in amperes (A)

H_{tilt} = daily irradiation on the tilted plane (i.e. on the plane of the array), in peak sun hours

N_{p} = number of parallel strings of modules in the array (an integer), dimensionless

3.4.3.9 Output of photovoltaic array with maximum power point tracking design

When a PV module is to be operated at its maximum power point, a temperature derating factor shall be applied. For crystalline silicon, this temperature derating factor can be calculated from Equation 3.4.3.9(1) or determined from manufacturer's data. For other technologies, refer to manufacturer's information.

The temperature derating factor can be calculated as follows:

$$f_{\text{temp}} = 1 \pm (\gamma \times (T_{\text{cell,eff}} - T_{\text{stc}})) \quad \dots 3.4.3.9(1)$$

where

f_{temp} = temperature derating factor, dimensionless

γ = power temperature co-efficient, in reciprocal degree Celsius (typically -0.005 for crystalline silicon)

$T_{\text{cell, eff}}$ = average daily effective cell temperature, in degrees Celsius

T_{stc} = cell temperature at standard test conditions, in degrees Celsius.

The derated output power of a module can be calculated as follows:

$$P_{\text{mod}} = P_{\text{stc}} \times f_{\text{man}} \times f_{\text{temp}} \times f_{\text{dirt}} \quad \dots 3.4.3.9(2)$$

where

P_{mod} = derated output power of the module, in watts

P_{stc} = rated output power of the module under standard test conditions, in watts

f_{temp} = temperature derating factor, dimensionless

f_{man} = derating factor for manufacturing tolerance, dimensionless

f_{dirt} = derating factor for dirt/soiling, dimensionless

The average daily energy output of a photovoltaic array can then be calculated as follows:

$$E_{\text{pv}} = P_{\text{mod}} \times H_{\text{tilt}} \times N \quad \dots 3.4.3.9(3)$$

where

E_{pv} = design daily energy from the photovoltaic array, in watt hours (Wh)

P_{mod} = derated power output of a module, in watts (W)

H_{tilt} = daily irradiation on the tilted plane, in peak sun hours

N = number of modules in the array (an integer), dimensionless

3.4.3.10 Array sizing for d.c. bus PV-only systems

3.4.3.10.1 D.C. bus systems with standard switched regulators

The number of modules required for a PV array where this is the sole energy source can be calculated from Equation 3.4.3.10(1) is for systems with standard switched regulators and Equation 3.4.3.10(2) for systems with standard regulators with maximum power point tracking:

$$N_{\text{p}} = \frac{E_{\text{tot}} \times f_{\text{o}}}{V_{\text{dc}} \times I_{\text{mod}} \times H_{\text{tilt}} \times \eta_{\text{coul}}} \quad \dots 3.4.3.10(1)$$

where

N_{p} = number of parallel strings of modules in the array (rounded up to the next whole number), dimensionless

E_{tot} = total design daily energy demand, in watt hours (Wh)

f_{o} = oversupply co-efficient, dimensionless

V_{dc} = nominal d.c. voltage, in volts (V)

I_{mod} = derated output current of the module, in amperes (A)

H_{tilt} = daily irradiation on the tilted plane, in peak sun hours

η_{coul} = coulombic efficiency of the battery, dimensionless

3.4.3.10.2 D.C. bus systems with maximum power point tracking (MPPT) regulators

The number of modules required for a PV array where this is the sole energy source can be calculated from Equation 3.4.3.10(2) for systems containing regulators with maximum power point tracking:

$$N_p = \frac{E_{\text{tot}} \times f_o}{P_{\text{mod}} \times H_{\text{tilt}} \times \eta_{\text{pvss}} \times N_s} \quad \dots 3.4.3.10(2)$$

where

- N_p = number of parallel strings of modules in the array (rounded up to the next whole number), dimensionless
- E_{tot} = total design daily energy demand, in watt hours (Wh)
- f_o = oversupply co-efficient, dimensionless
- P_{mod} = derated power output of a module, in watts (W)
- H_{tilt} = daily irradiation on the tilted plane, in peak sun hours
- N_s = number of series connected modules per string (an integer)
- η_{pvss} = efficiency of PV subsystem, dimensionless
- $\eta_{\text{pv-batt}} \times \eta_{\text{reg}} \times \eta_{\text{batt}}$

where

- $\eta_{\text{pv-batt}}$ = energy transmission efficiency from the photovoltaic array to the battery (i.e. from the effect of cable losses)
- η_{reg} = the energy efficiency of the regulator
- η_{batt} = the energy efficiency (i.e. watt-hour efficiency) of the battery

3.4.3.11 Array sizing for a.c. bus PV only systems

The number of modules required for a PV array where this is the sole energy source can be calculated from Equation 3.4.3.11(1) for a.c. bus systems where loads are supplied directly i.e. where the loads are being provided during the day directly from the solar array.

$$N_2 = \frac{E_{\text{tot2}} \times f_o}{P_{\text{mod}} \times H_{\text{tilt}} \times \eta_{\text{pvss2}}} \quad \dots 3.4.3.11(1)$$

where

- N_2 = number of modules in the array (rounded up to the next whole number), dimensionless required to supply loads directly
- E_{tot2} = total design daily energy demand, in watt hours (Wh) supplied directly to the loads from the renewable source
- f_o = oversupply co-efficient, dimensionless
- P_{mod} = derated power output of a module, in watts (W)
- H_{tilt} = daily irradiation on the tilted plane, in peak sun hours
- η_{pvss2} = sub-system efficiency from the PV energy generator to the load, dimensionless
- $\eta_{\text{pv-load}} \times \eta_{\text{pvinv}}$