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Reconfirmed 2017

Australian/New Zealand Standard™

Stand-alone power systems

Part 2: System design

STANDARDS Australia

STANDARDS NEW ZEALAND PAEREWA AOTEAROA

AS/NZS 4509.2:2010

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This Standard was issued in draft form for comment as DR AS/NZS 4509.2.

STANDARDS AUSTRALIA/STANDARDS NEW ZEALAND

RECONFIRMATION
OF
AS/NZS 4509.2:2010
Stand-alone power systems
Part 2: System design

RECONFIRMATION NOTICE

Technical Committee EL-042 has reviewed the content of this publication and in accordance with Standards Australia procedures for reconfirmation, it has been determined that the publication is still valid and does not require change.

Certain documents referenced in the publication may have been amended since the original date of publication. Users are advised to ensure that they are using the latest versions of such documents as appropriate, unless advised otherwise in this Reconfirmation Notice.

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Stand-alone power systems

Part 2: System design

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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—

Projects Manager, EL-042
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SYDNEY NSW 2001

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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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) × [(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 M J/m^2, kWh/m^2 and peak sun hours (PSH).

NOTE: 1 kWh/m^2 ≡ 1 PSH ≡ 3.6 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/m^2
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:

$$\text{design load energy} = \text{sum of power} \times \text{usage time} \qquad \ldots 3.1.4.2(1)$$

where

design load energy = daily energy consumed by all loads either d.c. or a.c., in watt hours (Wh)

power = power of an individual load, in watts (W)

usage time = average daily usage time of the individual load, in hours

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:

E_{dc} = design daily d.c. load energy, in watt hours (Wh)

E_{ac} = design daily a.c. load energy, in watt hours (Wh)

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

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

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:

$$\text{surge demand} = \frac{\text{power}}{pf \times \text{surge factor}} \qquad \text{. . . 3.1.4.4}$$

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.

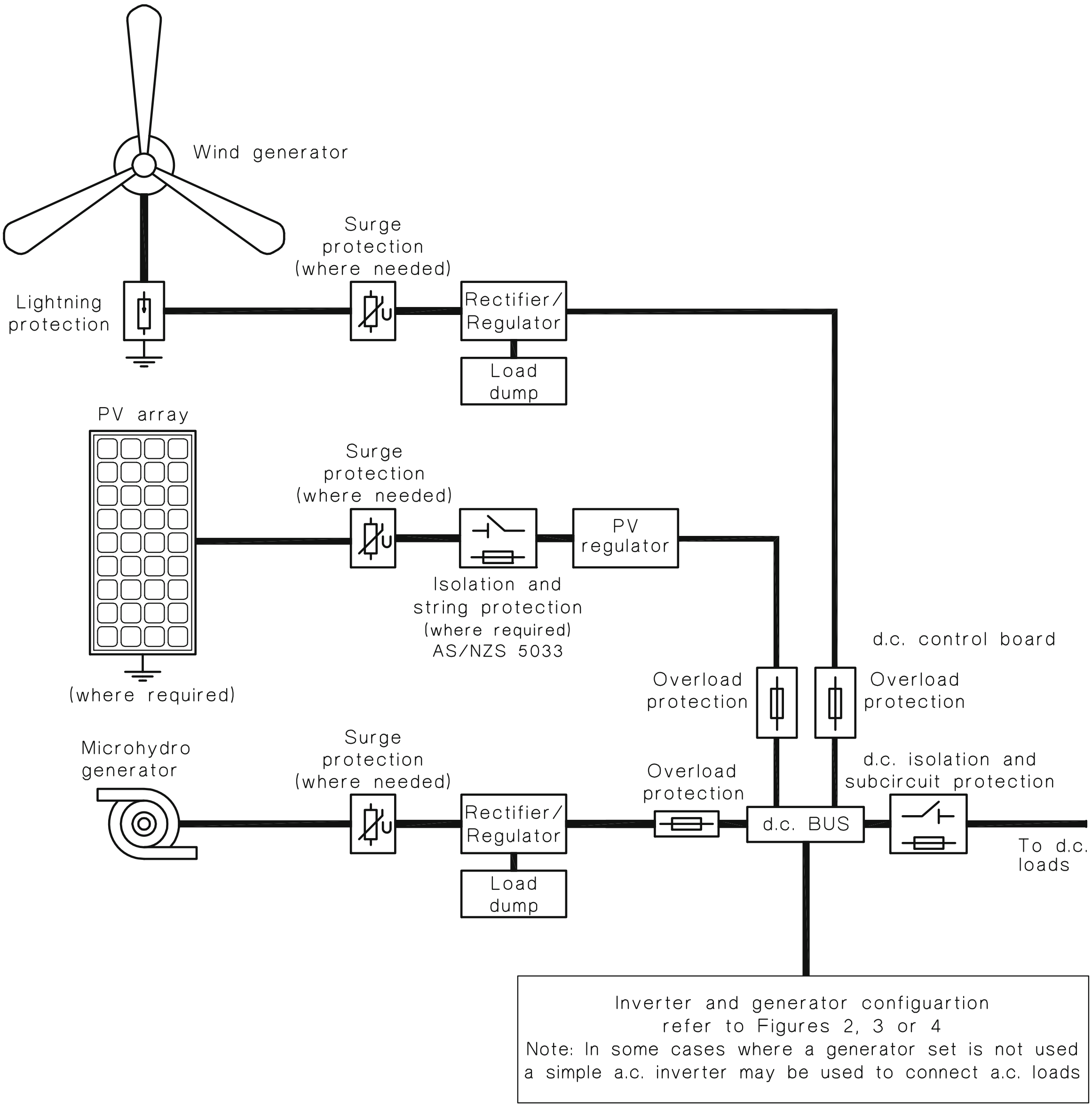


FIGURE 1A EXAMPLE OF D.C. COUPLED ENERGY INPUTS AND CONTROLS

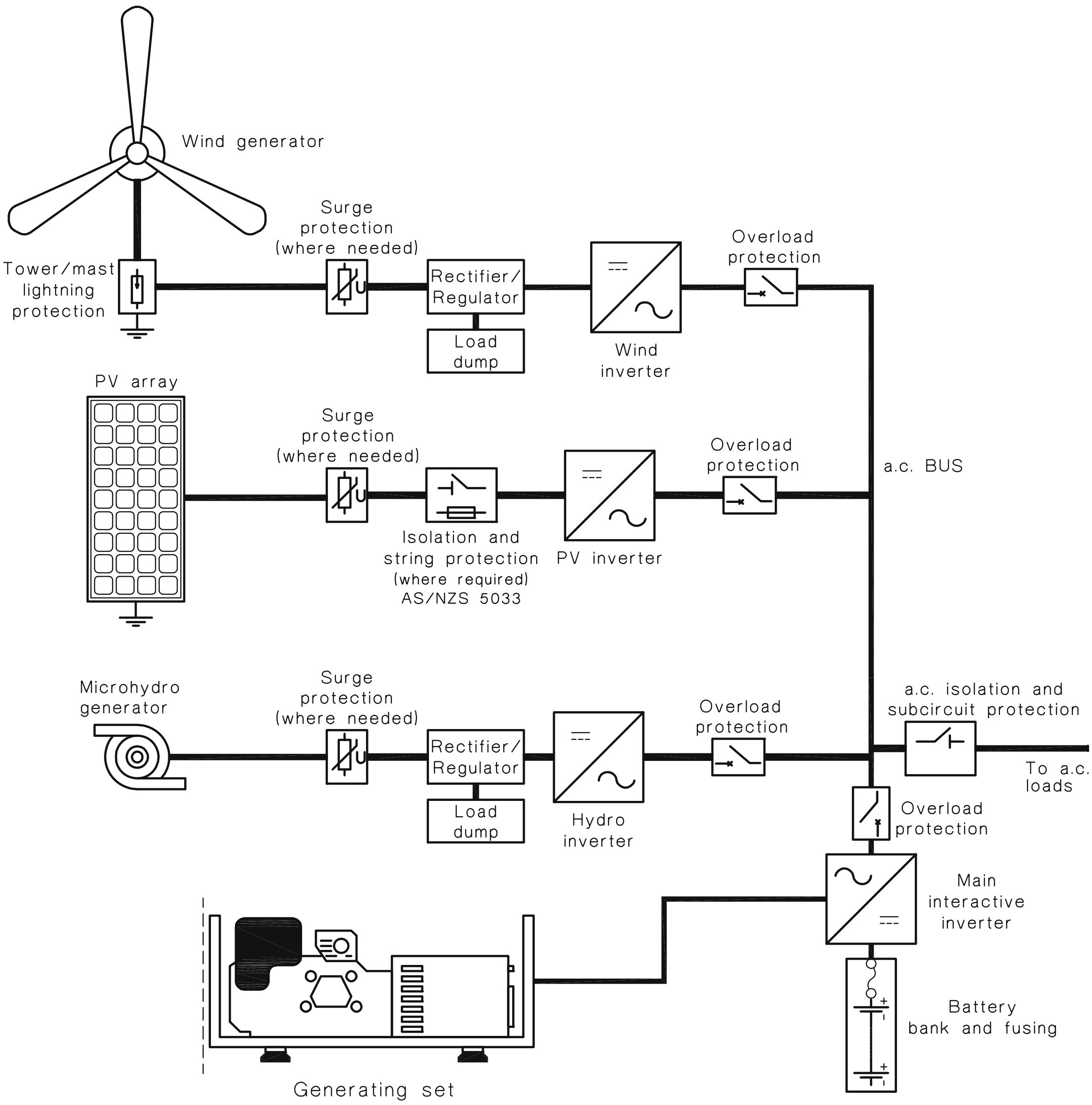


FIGURE 1B EXAMPLE OF A.C. COUPLED ENERGY INPUTS AND CONTROLS SWITCHBOARD DETAILS

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.

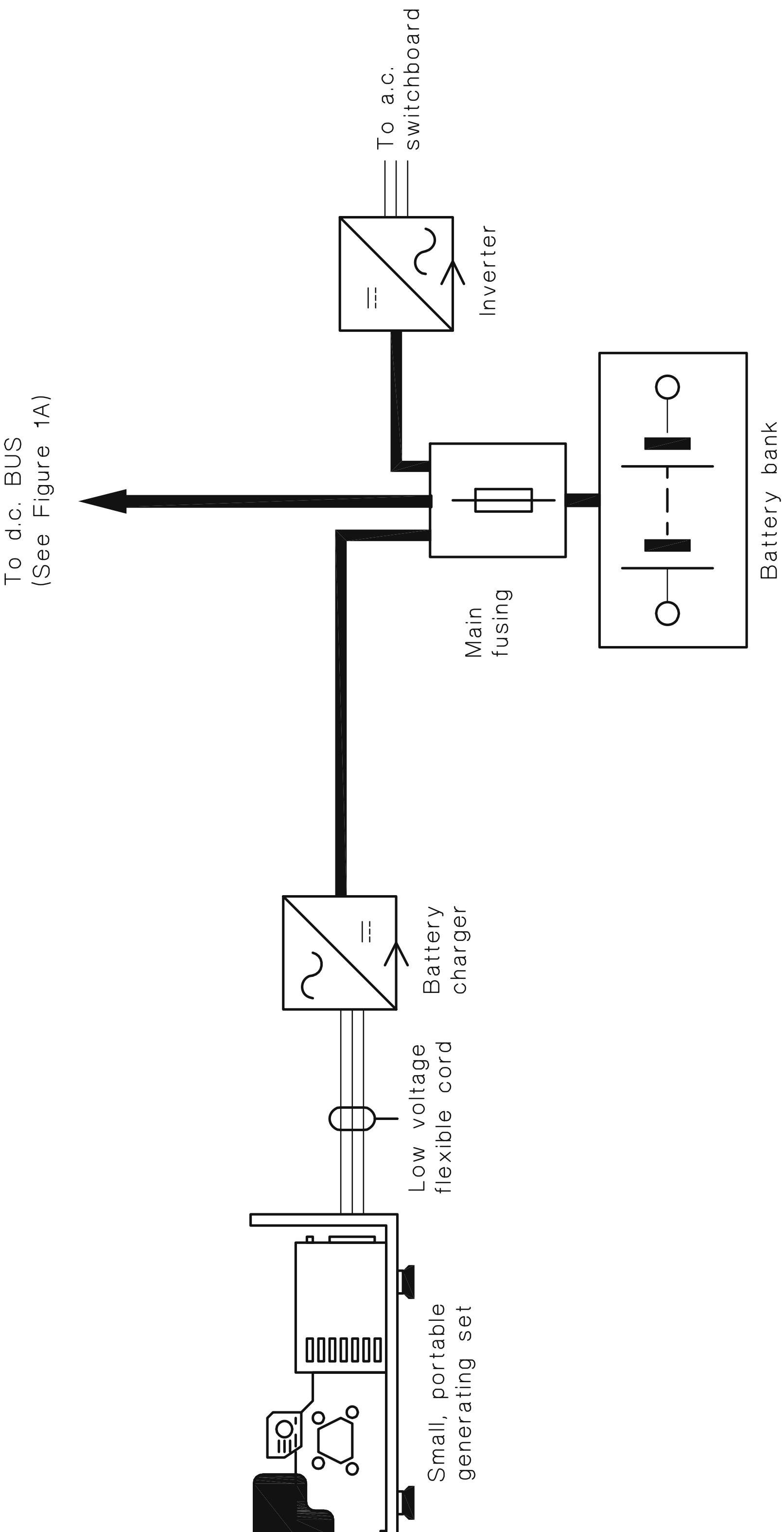
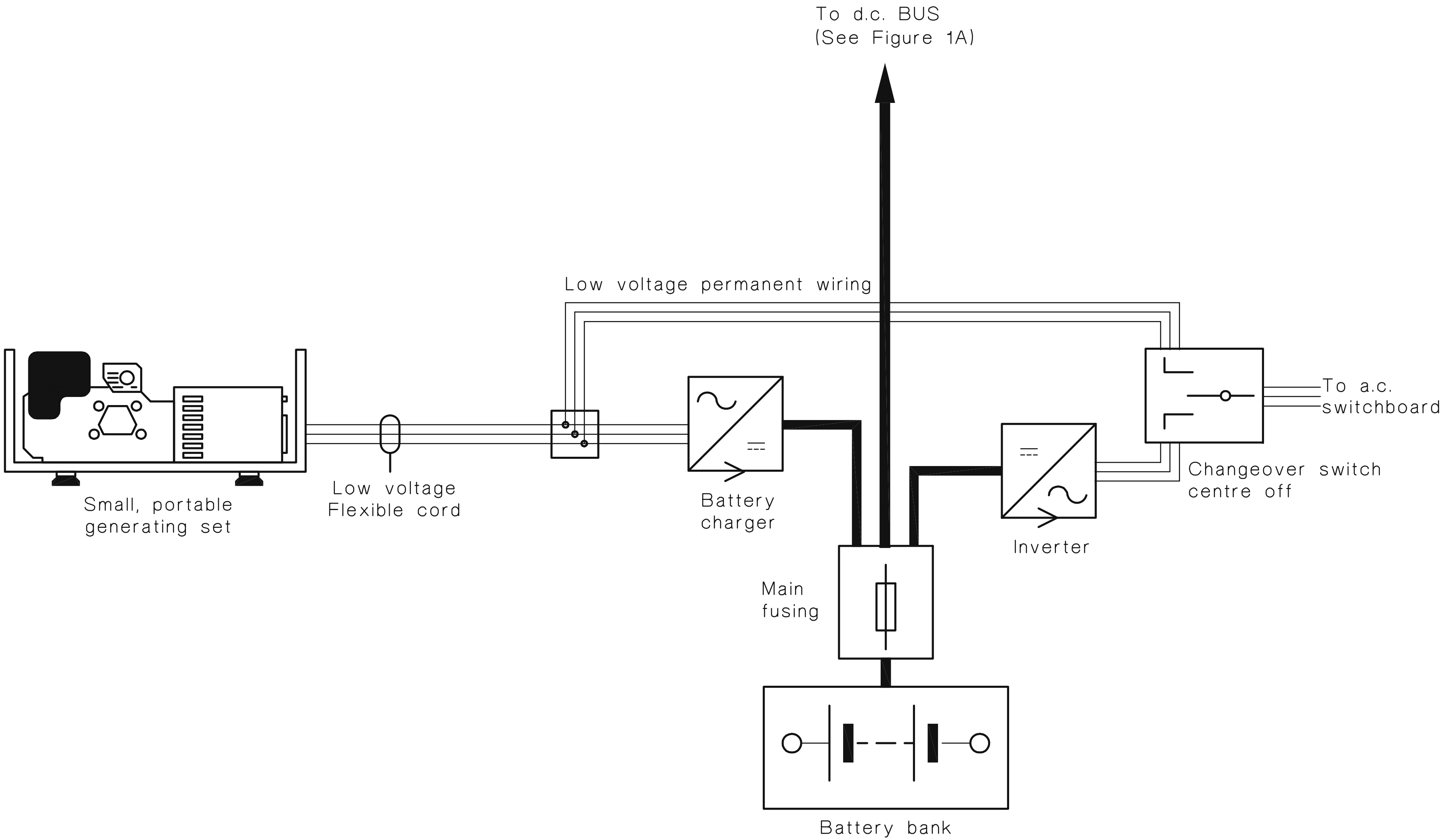


FIGURE 2 SERIES CONFIGURATION

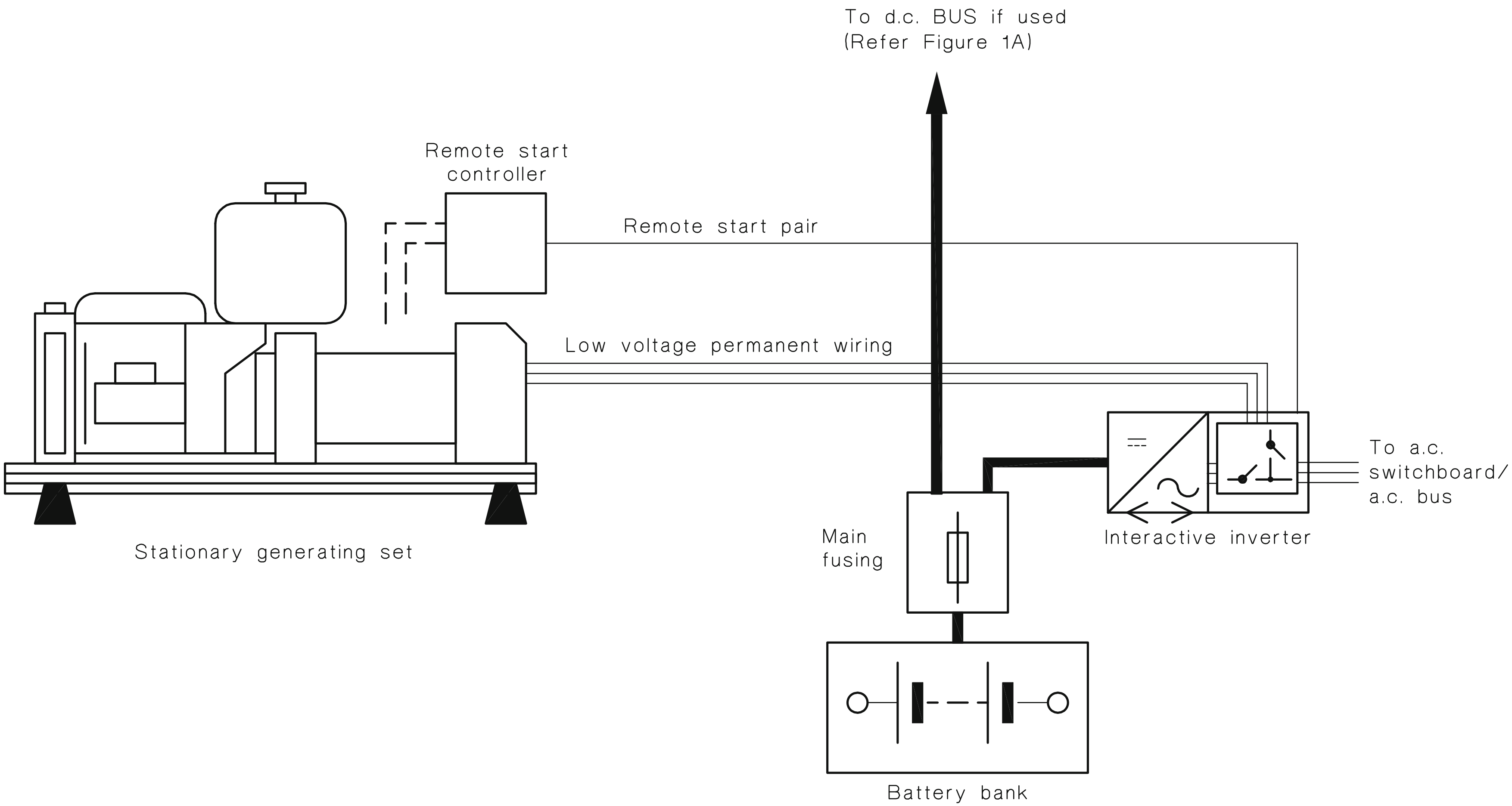


NOTES:

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

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

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).

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

where

η_{renss2} = Sub-system efficiency from the renewable energy generator to the load

$\eta_{ren\text{-}load}$ = energy transmission efficiency of the cabling between the renewable generator and the load

η_{reninv} = energy efficiency of the renewable energy inverter

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

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

where

η_{renss3} = sub-system efficiency from the renewable energy generator to the load

$\eta_{ren\text{-}batt\text{-}load}$ = energy transmission efficiency of the cabling between the renewable generator and the load via main inverter and battery

η_{reninv} = energy efficiency of the renewable energy inverter

η_{batt} = energy efficiency of the battery

$\eta_{inv(inv)}$ = energy efficiency of the interactive battery inverter in inverter mode

$\eta_{inv(chg)}$ = energy efficiency of the interactive battery inverter in charging mode

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 ±10° of true north unless system or site requirements dictate otherwise. Where a single axis tracking system is used, the array should face within ±10° 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 ±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:

$$T_{\mathrm{cell,eff}} = T_{\mathrm{a,day}} + 25 \qquad \ldots 3.4.3.7$$

where

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

$T_{\mathrm{a,day}}$ = 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:

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

where

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

$I_{T,V}$ = 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:

$$Q_{array} = I_{mod} \times H_{tilt} \times N_p \qquad \text{. . . 3.4.3.8(1)}$$

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:

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

where

f_{temp} = temperature derating factor, dimensionless

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

$T_{cell,\,eff}$ = 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:

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

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:

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

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:

$$N_p = \frac{E_{tot} \times f_o}{V_{dc} \times I_{mod} \times H_{tilt} \times \eta_{coul}} \quad \ldots 3.4.3.10(1)$$

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:

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

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

= $\eta_{pv\text{-}batt} \times \eta_{reg} \times \eta_{batt}$

where

$\eta_{pv\text{-}batt}$ = 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.

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

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

= $\eta_{pv\text{-}load} \times \eta_{pvinv}$

where

$\eta_{pv\text{-}load}$ = energy transmission efficiency of the cabling between the PV generator and the load

η_{pvinv} = energy efficiency of the PV inverter

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(2) for a.c. bus systems loads supplied indirectly via storage in the battery:

$$N_3 = \frac{E_{tot3} \times f_o}{P_{mod} \times H_{tilt} \times \eta_{pvss3}} \quad \ldots 3.4.3.11(2)$$

where

N_3 = number of modules in the array (rounded up to the next whole number), dimensionless required to supply loads via intermediate battery storage

E_{tot3} = total design daily energy demand, in watt hours (Wh) supplied to the loads via intermediate battery storage.

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_{pvss3} = sub-system efficiency from the PV generator to the load

= $\eta_{pvbatt\text{-}load} \times \eta_{pv\text{-}inv} \times \eta_{inv\text{-}chg} \times \eta_{batt} \times \eta_{inv(inv)}$

where

$\eta_{pv\text{-}batt\text{-}load}$ = energy transmission efficiency of the cabling between the PV generator and the load via main inverter and battery

η_{pvinv} = energy efficiency of the PV inverter

$\eta_{inv(chg)}$ = energy efficiency of the main battery inverter in charging mode

η_{batt} = energy efficiency of the battery

$\eta_{inv(inv)}$ = energy efficiency of the main battery inverter in inverter mode.

In a.c. systems, the oversupply co-efficient f_0 is typically 1 because there will generally be a fuel generator (genset) in the system. In reality the daytime load energy will be partly supplied directly by the PV array and also via the batteries, while the night time loads will be supplied via the batteries. The above two Equations 3.4.3.11(1) and 3.4.3.11(2) provide the two extremes in the number of modules required in an array. The actual requirement will fall between the lower and higher number of modules.

If the design is to be conservative, then Equation 3.4.3.11(2) should be used.

When undertaking the load analysis, an estimate could be calculated of the daily load energy that could be supplied directly by the array (E_{tot2}) and the amount that needs to be supplied via battery storage (E_{tot3}). Care has to be taken to allow for system operation when there is a lack of renewable energy input where the system has no ability to supply loads directly. Two calculations of the number of modules required could be performed based on Equations 3.4.3.11(1) and 3.4.3.11(2) where the final number of modules required will be:

$$N_{\text{total}} = N_2 + N_3 \qquad \text{. . . 3.4.3.11(3)}$$

where

N_{total} = Total number of modules in the array (rounded up to the next whole number), dimensionless required to supply loads

N_2 = number of modules in the array (rounded up to the next whole number), dimensionless required to supply loads directly

N_3 = number of modules in the array (rounded up to the next whole number), dimensionless required to supply loads via intermediate battery storage

3.4.4 Wind turbine sizing and selection

The following factors should be taken into account in calculating the required size or expected performance of wind turbines:

(a) The system load and losses in the charging subsystem.

(b) Seasonal or monthly average wind speeds and wind speed frequency distributions at the site.

(c) Vertical wind speed profile and tower height.

(d) Terrain roughness and turbulence.

(e) Power versus wind speed characteristic of the wind turbine generator.

Energy output depends strongly on the match between the power versus wind speed characteristic and the wind speed frequency distribution at the site, and may be a more important factor than the rated power output of the machine at its rated wind speed. This is especially the case in low wind speed areas where a low cut-in wind speed is crucial to adequate performance. Energy output from a wind turbine generator should be determined by use of the power versus wind speed characteristic of the machine, based on the wind speed frequency distribution at the site.

In some cases, the turbine manufacturer may specify an annual energy output based on an average annual wind speed and a particular wind speed distribution (often a Weibull distribution). Such specifications should be used only in the absence of more detailed (e.g. monthly) wind speed data and where the wind speed frequency distribution is known to be, or is likely to be, of the appropriate shape.

η_{windss} = efficiency of wind subsystem, dimensionless (refer to Equation 3.4.2.2)

= $\eta_{wind\text{-}batt} \times \eta_{reg} \times \eta_{batt}$ for d.c. coupled systems supplying loads where all the energy assessment has been centralised at the d.c. bus

= $\eta_{wind\text{-}cable} \times \eta_{invwind} \times \eta_{inv(inv)} \times \eta_{batt} \times \eta_{inv(chg)}$ for a.c. coupled systems supplying load via intermediate battery storage

= $\eta_{wind\text{-}cable} \times \eta_{invwind}$ for a.c. coupled systems supplying a.c. load directly

where

$\eta_{wind\text{-}batt}$ = energy transmission efficiency from the wind turbine to the battery (i.e. from the effect of cable losses)

η_{reg} = the energy efficiency of the regulator (d.c. coupled systems)

η_{batt} = the energy efficiency (i.e. watt-hour efficiency) of the battery

$\eta_{wind\text{-}cable}$ = energy transmission efficiency from the wind turbine to the battery, i.e from the effect of a.c. and d.c. cable losses

$\eta_{invwind}$ = the energy efficiency of the wind turbine inverter (a.c. coupled systems)

$\eta_{inv(inv)}$ = energy efficiency of the main battery inverter in inverter mode

$\eta_{inv(chg)}$ = energy efficiency of the main battery inverter in charging mode

3.4.5 Micro-hydro generator sizing

The following factors should be taken into account in calculating the size and performance of micro-hydro generators:

(a) Flow rate.

(b) Total dynamic head, including losses due to pipe fouling with age.

(c) Turbine and electrical generator efficiency.

(d) Seasonal variations in stream flow where these will affect the flow available to the turbine.

NOTE: Local regulations may limit the amount of water available for generation purposes.

The power output of a micro-hydro generator can be determined from manufacturer's data sheets or calculated as follows:

$$P_{hyd} = Q \times g \times h_{net} \times \eta_{turb} \times \eta_{mech} \times \eta_{gen} \quad \ldots 3.4.5$$

where

P_{hyd} = electrical output power of the hydro generator, in watts (W)

Q = flow rate through the turbine, in kilograms per second (the density of water is very close to 1 kg/L in most operating situations) (kg/s)

g = gravitational acceleration, 9.8 metres per second squared (m/s^2)

h_{net} = net head, in metres (m)

η_{turb} = efficiency of the turbine at the specified flow rate and head, dimensionless

η_{mech} = efficiency of the mechanical transmission between turbine and electrical generator, dimensionless

η_{gen} = efficiency of the electrical generator, dimensionless

η_{hydss} = efficiency of hydro subsystems, dimensionless, (refer to Equation 3.4.2.2)

= $\eta_{hyd\text{-}batt} \times \eta_{reg} \times \eta_{batt}$ for d.c. coupled systems systems supplying loads where all the energy assessment has been centralised at the d.c. bus

= $\eta_{hyd\text{-}cable} \times \eta_{invhyd} \times \eta_{inv(inv)} \times \eta_{batt} \times \eta_{inv(chg)}$ for a.c. coupled systems supplying load via intermediate battery storage.

= $\eta_{hyd\text{-}cable} \times \eta_{invhyd}$ for a.c. coupled systems supplying a.c. load directly

where

$\eta_{hyd\text{-}batt}$ = energy transmission efficiency from the hydro generator to the battery (i.e. from the effect of cable losses)

η_{reg} = the energy efficiency of the regulator (d.c. coupled systems)

η_{batt} = the energy efficiency (i.e. watt-hour efficiency) of the battery

$\eta_{hyd\text{-}cable}$ = energy transmission efficiency from the hydro generator to the hydro inverter, i.e from the effect of cable losses

η_{invhyd} = the energy efficiency of the hydro turbine inverter (a.c. coupled systems)

$\eta_{inv(inv)}$ = energy efficiency of the main battery inverter in inverting mode

$\eta_{inv(chg)}$ = energy efficiency of the main battery inverter in charging mode

3.4.6 Renewable energy fraction

The renewable energy fraction is made up of contributions from each of the renewable energy generators which are used in the system. For each renewable energy generator, a fraction can be defined for the design conditions. This is often expressed as a percentage.

Where PV array sizing calculations are based on watt hours, the following Equation may be used:

$$\text{Solar fraction} = f_{pv} = \frac{E_{pv} \times \eta_{pvss}}{E_{tot}} \qquad \text{. . . 3.4.6(1)}$$

Where array sizing calculations are based on ampere hours, the following Equation can be used:

$$\text{Solar fraction} = f_{pv} = \frac{I_{mod} \times H_{tilt} \times N_p \times V_{dc} \times \eta_{coul}}{E_{tot}} \qquad \text{. . . 3.4.6(2)}$$

Other fractions can be calculated as follows:

$$\text{Wind fraction} = f_{wind} = \frac{E_{wind} \times \eta_{windss}}{E_{tot}} \qquad \text{. . . 3.4.6(3)}$$

$$\text{Hydro fraction} = f_{hyd} = \frac{E_{hyd} \times \eta_{hydss}}{E_{tot}} \qquad \text{. . . 3.4.6(4)}$$

$$\text{Renewable energy fraction} = f_{ren} = f_{pv} + f_{wind} + f_{hyd} \qquad \text{. . . 3.4.6(5)}$$

where

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

η_{pvss} = the efficiency of the photovoltaic subsystem, dimensionless

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

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

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

N_p = number of parallel strings in the array (an integer), dimensionless

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

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

E_{wind} = design daily energy from wind turbines, in watt hours (Wh)

η_{windss} = efficiency of the wind subsystem, dimensionless

E_{hyd} = design daily energy from hydro-electric sources, in watt hours (Wh)

η_{hydss} = efficiency of the hydro-electric subsystem, dimensionless

Fractions of approximately 90% or above should be treated with some caution, as some generated energy may not be used and weather variations within the month may reduce the actual fraction. A calculated solar or wind fraction of greater than 100% does not guarantee sufficient energy generated to meet the load at all times.

3.4.7 Battery sizing and selection

3.4.7.1 *Battery selection*

Batteries used for stand-alone power systems should be of a type suitable for the duty and operating environment they will experience. The following factors should be considered:

(a) Cycle life under deep cycling duty.

(b) Calendar life.

(c) Maintenance.

(d) Rate of gassing and overcharge requirement.

(e) Self discharge.

(f) Energy efficiency.

(g) Discharge rate capability.

(h) Performance over the expected ambient temperature range.

(i) Ease and safety of transport, installation and activation.

(j) Purchase, disposal and maintenance costs.

Batteries with different characteristics or ages should not be used in the same battery bank.

NOTE: Problems often occur if batteries are used in parallel strings. It is strongly recommended that the number of parallel strings be minimized and that the battery manufacturer is consulted when parallel strings cannot be avoided.

3.4.7.2 *Battery sizing—general*

Batteries should be capable of meeting both the power and energy requirements of the system. In systems where more than 3 days of autonomy is required, the energy storage capacity of the battery is likely to be the limiting factor in determining battery size. In systems where less than 36 h of autonomy is required, the power output capability of the battery may be the limiting factor in determining battery size.

The major design parameters to be considered in the sizing of batteries are as follows:

(a) Number of days of autonomy (dependent on energy sources available, system configuration and climatic conditions).

(b) Daily and maximum depth of discharge (DOD_{max}) (to be chosen with consideration of cycle life characteristics).

(c) Daily energy demand from the d.c. bus.

(d) Maximum power demand.

(e) Surge demand.

(f) Maximum charging current.

An appropriate discharge rate should be used when selecting or specifying the capacity of batteries. This discharge rate should consider the maximum load and the duration of the load. For example, for a system with where the average load power requirement is low, a suitable discharge rate for the battery may be the 100 h rate. The capacity of the battery at this discharge rate is denoted as C_{100}. However if a significant fraction of the load energy is drawn at a higher rate, it may be necessary to select the battery capacity at a higher discharge rate, e.g. 10 h rate or 20 h rate.

3.4.7.3 *Battery sizing-energy storage*

Batteries for energy storage should be sized according to the following equation:

$$C_x = \frac{E_{tot}}{V_{dc}} \times \frac{T_{aut}}{DOD_{max}} \qquad \text{. . . 3.4.7.3}$$

where

C_x = battery capacity, specified for an appropriate discharge rate x, in ampere hours (Ah)

E_{tot} = total design daily energy demand from the d.c. bus, in watt hours (Wh)

T_{aut} = number of days of autonomy

V_{dc} = nominal voltage of the d.c. bus (i.e. battery voltage), in volts (V)

DOD_{max} = design maximum depth of discharge of the battery, expressed as a percentage

3.4.7.4 *Battery sizing—maximum or surge demand*

When sizing batteries, consult the manufacturer's data sheets for maximum demand and surge capabilities.

3.4.7.5 *Daily depth of discharge*

For systems where the battery is sized for several days of autonomy, and the generating set does not run every day, the average daily depth of discharge of the battery should be calculated from the following equation:

$$DOD_d = \frac{E_{tot}}{V_{dc} \times C_x} \qquad \text{. . . 3.4.7.5}$$

where

DOD_d = daily depth of discharge of the battery, expressed as a percentage

E_{tot} = total daily energy demand from the d.c. bus, in watt hours (Wh)

V_{dc} = nominal voltage of the d.c. bus (i.e. battery voltage), in volts (V)

C_x = battery capacity, specified for an appropriate discharge rate, x, in ampere hours (Ah)

For systems where the generating set runs every day, the daily depth of discharge should be calculated based on knowledge of the expected load profile (at least approximately) and the generating set running times.

3.4.7.6 *Determining suitable number of days of autonomy*

The number of days of autonomy should be determined in consultation with the user. The following factors should be considered:

(a) Acceptable level of loss of load probability

(b) The intermittency of the renewable energy source.

(c) The presence of firm (available on demand) generation such as a generating set.

(d) The average daily depth of discharge as to afford satisfactory battery life.

(e) The energy source to battery storage ratio as to ensure acceptable re-charge times and regular charge to full cycles to satisfy battery manufacturer's recommendations.

Examples of typical number of days of autonomy for various applications:

System	Autonomy (d)	Typical considerations
100% Hydro	1.5	Average daily depth of discharge
System with automatic generating set control	2	Reliability of auto start
System with manual generating set control	2 to 3	User
PV, wind, or hybrid systems without generating set	4 to 5	Probability of number of consecutive days of low solar irradiation Probability of number of consecutive days of no wind

3.4.7.7 *Systems with automatic generating set control (hybrid systems)*

In hybrid systems with automatic generating set control, the battery may be sized for 3 days or less of energy storage, provided generating set starting components will perform reliably under a frequent start/stop duty cycle.

3.4.7.8 *Capacity derating for operating temperature*

The available capacity of a battery is affected by the electrolyte temperature, generally decreasing with decreasing temperature. Temperature variations within cells vary more slowly than the ambient air temperature because of their large thermal mass. Therefore the battery capacity should be derated, based on the monthly minimum daily average air temperature.

Typical figures for lead acid batteries discharging at the 100 h rate and 20 h rate (C_{100} and C_{20}) are shown in Figure 5.

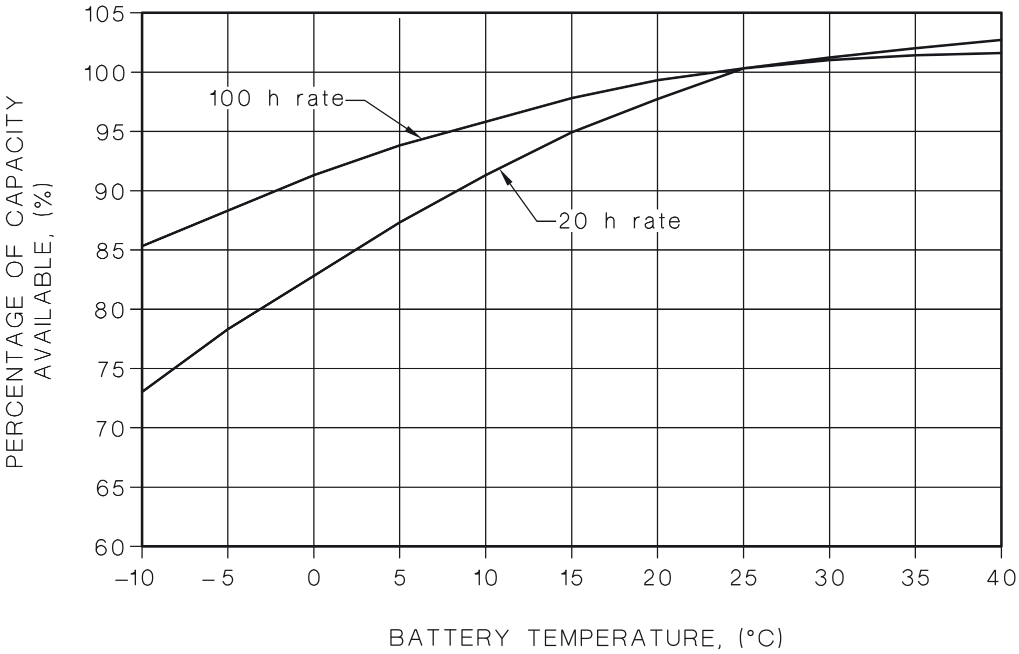


FIGURE 5 TYPICAL BATTERY CAPACITY CORRECTION FACTOR AS A FUNCTION OF TEMPERATURE FOR C_{100} AND C_{20} DISCHARGE RATES

3.4.8 Regulator sizing and selection

3.4.8.1 *General*

Regulators should be used to control battery charging from renewable energy sources in all systems covered by this Standard.

3.4.8.2 *Photovoltaic regulators*

Regulators for photovoltaic arrays should be capable of carrying 125% of the array short-circuit current. Regulators shall withstand the open circuit voltage of the array at the lowest expected operating temperature.

Large arrays may need to be split into sub-arrays. Considerations are—

(a) the availability of high current regulators;

(b) improved fault tolerance; and

(c) more staged battery charging.

3.4.8.3 *Wind turbine regulators*

Regulators for use with wind turbine generators should be capable of carrying the maximum current and voltage output of the generator and may require a dump facility for excess energy.

3.4.8.4 *Micro-hydro regulators*

Regulators for use with micro-hydro generators should be capable of carrying the maximum current and the open circuit voltage of the generator that is possible at the turbine site. This should be determined having regard to peak stream flows and possible failure of voltage clamping devices located at the generator.

3.4.8.5 *Battery charging regimes*

Battery charging methods and voltage regulation settings should be chosen to suit the batteries and the duty cycle they experience. The primary source of information for correct regulator settings should be the battery manufacturer. Guidelines may also be provided by the manufacturer of the regulator or other charging equipment (e.g. inverter or battery charger).

Typical charging methods, and voltages (based on electrolyte temperature of 20°C) are listed in Table 3.

TABLE 3

TYPICAL CHARGING METHODS AND REGULATOR SETTINGS

Battery type	Charging method	Cell volts		
		Float V	Voltage V	Equalize V
Flooded lead acid	Absorption charge after a period below gassing voltage; then float charge; equalize charge after prolonged low SOC	2.25 to 2.30	2.35 to 2.50	2.50 to 2.60
Sealed (valve regulated) lead acid	Absorption change after a period below gassing voltage; then float charge. Absorption voltage is generally below gassing voltage.	2.25 to 2.30	2.35 to 2.40	none
Nickel cadmium	High float charge only, boosting optional; equalize charge periodically, but not essential	1.45 to 1.55	—	1.55 to 1.65

3.4.8.6 *Temperature compensation*

Battery charging voltages should be temperature compensated according to the electrolyte temperature, by a factor appropriate for the battery type.

3.4.9 Inverter sizing and selection

3.4.9.1 *Inverter selection*

The following factors should be considered in the selection of inverters:

(a) Maximum and surge demand and their match to the inverter's ratings at expected maximum ambient temperature. If a high demand condition is likely to persist for an extended period, allowance should be made for this when applying maximum demand calculations to inverter sizing.

(b) Account for load growth or uncertainty.

(c) Waveform quality (harmonic distortion compared to a pure sine wave).

(d) Power efficiency.

(e) Earthing arrangements.

(f) No-load and stand-by power consumption.

(g) D.C. operating voltage range.

(h) Voltage and frequency regulation.

(i) Power factor handling range.

(j) Performance with 'problem loads' (e.g. half wave loads or other loads which draw large harmonic currents).

(k) Electromagnetic interference (C-tick).

(l) System configuration.

(m) Soft start capability.

(n) Control of operating parameters.

(o) Protection (thermal, electrical).

(p) Load profile.

(q) Inverter isolation and bonding.

(r) Power rating at expected high ambient temperatures

(s) Ingress Protection (IP) rating

(t) Ventilation requirements

For general domestic use, sinewave inverters with electromagnetic interference levels within the limits specified by AS/NZS 1044 are recommended.

Inverter ratings are limited by heat dissipation within the equipment, which is a function of the output current. Sizing should therefore be based on apparent power (volt-amperes), rather than real power. Where apparent power is not known for each load, it may be estimated from the real power consumption divided by an assumed power factor of 0.8.

3.4.9.2 *Unidirectional inverters*

In systems that use a unidirectional inverter, the inverter should be capable of supplying both the maximum and surge demand that will be placed on it by the load.

3.4.9.3 *Inverter-chargers*

Inverter-chargers should be sized in the same manner as unidirectional inverters, with the additional constraint that the device should provide a charge rate adequate to allow recharging of the batteries from the design maximum depth of discharge, in an acceptable time.

3.4.9.4 *Interactive battery inverters*

Interactive battery inverters should be sized in conjunction with the generating sets. The combined ratings of the inverter and generating set should be capable of supplying both the maximum demand and surge demand that will be placed on them by the load.

While a smaller inverter rating may suffice in a parallel system compared to a switched system, the inverter should also be capable of supplying the demand that will be placed on it when the generating set is not running or not yet paralleled. This consideration relates to the inverter power rating, as well as to the programming of generating set start and stop parameters with respect to the expected load profile.

3.4.10 Battery charger sizing and selection

3.4.10.1 *Selection*

The following factors should be considered in the selection of battery chargers:

(a) Charging method appropriate for the battery type (constant voltage for lead acid cells and constant current for NiCd cells).

(b) Voltage regulation (if any).

(c) Output current limiting.

(d) Battery manufacturer's recommended charge characteristics.

(e) Output current ripple content.

(f) High efficiency.

(g) Power factor

(h) Electromagnetic interference levels to AS/NZS 1044.

In systems where the generating set provides a large fraction of the total annual energy demand, battery chargers with the following characteristics are recommended:

(i) Electronic voltage regulation.

(ii) Current limited output.

(iii) Battery manufacturer's recommended charge characteristic.

(iv) Efficiency greater than 80% at full load.

3.4.10.2 *Sizing*

Battery chargers should be typically sized at the 10 h rate. Charging rates and voltages should be to manufacturer's recommendations.

The following Equation can be used to estimate the required size:

$$I_{bc} = 0.1 \times C_{10} \qquad \ldots 3.4.10.2$$

where

I_{bc} = maximum charge current of the battery charger, in amperes (A)

C_{10} = 10 h rate capacity of the battery, in ampere hours (Ah)

NOTE: This does not imply that the battery can be fully recharged in 10 hours.

3.4.10.3 *Battery charger input power*

Where measurements or specifications of the maximum input power or power factor of the battery charger are not available, they can be estimated as follows:

$$S_{bc} = \frac{I_{bc} \times V_{bc}}{\eta_{bc} \times pf_{bc}} \qquad \ldots 3.4.10.3$$

where

S_{bc} = maximum apparent input power to the battery charger under conditions of maximum output current and typical maximum charge voltage, in volt amperes (VA)

I_{bc} = maximum charge rate of the battery charger, in amperes (A)

V_{bc} = typical maximum charge voltage of the battery charger at maximum output current, in volts (V)

η_{bc} = energy conversion efficiency of the battery charger, dimensionless

pf_{bc} = power factor of the battery charger, dimensionless

NOTES:

1 V_{bc} is typically 2.3 to 2.4 V per cell multiplied by the number of cells in series for lead acid batteries.

2 η_{bc} is typically 0.8 to 0.95. The lower end of this range applies to smaller, cheaper units, while the higher end applies to more sophisticated units, especially those utilizing high frequency pulse width modulation techniques.

3 Typical power factor of the battery charger is 0.8 to 1.0.

3.4.11 Generating set sizing and selection

3.4.11.1 *Sizing—general*

Generating set sizing has two primary requirements—

(a) that the alternator is capable of supplying the continuous and surge load apparent power (in volt amperes); and

(b) that the engine is capable of providing the real power requirements of the alternator.

The generating set should be able to meet these requirements under any operating conditions normally experienced at the site. Care should be taken to avoid excessively oversizing the generating set as light loading may be detrimental to the unit (refer to manufacturer's data).

3.4.11.2 *Series system*

In series systems, the generating set should be sized to meet the power requirements of the battery charger, with an additional design margin. The following Equation can be used:

$$S_{gen} = S_{bc} \times f_{go} \qquad \text{. . . 3.4.11.2}$$

where

S_{gen} = apparent power rating of the generating sets, in volt amperes (VA)

S_{bc} = maximum apparent input power to the battery charger under conditions of maximum output current and typical maximum charge voltage, in volt amperes (VA)

f_{go} = generating set over-size factor, dimensionless

NOTE: Typical value for the generating set over-size factor is 1.1

3.4.11.3 *Switched system*

In switched systems, the generating set should be sized to meet the requirements of the battery charger along with the maximum and surge demand during battery charging, plus an additional design margin. The following equations can be used:

$$S_{gen} = (S_{bc} + S_{max,chg}) \times f_{go} \qquad \text{. . . 3.4.11.3(1)}$$

$$S_{gen} = \frac{(S_{bc} + S_{sur,chg}) \times f_{go}}{A_s} \qquad \text{. . . 3.4.11.3(2)}$$

where

S_{gen} = apparent power rating of the generating sets, in volt amperes

S_{bc} = maximum apparent input power to the battery charger under conditions of maximum output current and typical maximum charge voltage, in volt amperes (VA)

$S_{max,chg}$ = maximum a.c. demand during battery charging, in volt amperes (VA)

$S_{sur,chg}$ = a.c. surge demand during battery charging, in volt amperes (VA)

f_{go} = generating set over-size factor, dimensionless

A_s = ratio of instantaneous current to continuous current output of the alternator (the alternator surge ratio)

NOTES:

1 Typical value for the generating set over-size factor is 1.1.

2 Refer to manufacturer's data for alternator surge ratio values. Typical value is 2 to 3, however the ability of a generating set to supply a surge also depends on its inertia, as well as governing and voltage regulation. Small generating set may be limited to surges of very short duration by these factors. Where load surges are of longer duration, the alternator surge ratio should be taken as 1. Methods to reduce the magnitude of the surge may be useful in this case.

3.4.11.4 *Parallel and a.c. bus systems*

The generator should be sized so:

(a) the ratings of generating set and inverter combined meet both the maximum demand and surge demand, plus an additional design margin;

(b) sufficient energy can be provided to the system taking into account generator run times;

(c) the generating set will be sufficiently loaded so it runs efficiently;*

(d) the battery can be re-charged from the generating set within reasonable time.†

Care should be taken to ensure generating sets selected for parallel systems have adequate voltage regulation and speed governing due to the limited tolerance on voltage and frequency in bi-directional inverters. This may be of particular concern with very small generating sets.

The following equations may be used, and the selected generating set should meet or exceed the ratings:

$$S_{gen} = (S_{max} - S_{inv,30\,min}) \times f_{go} \qquad \ldots 3.4.11.4(1)$$

and

$$S_{gen} = \frac{(S_{sur} - S_{inv,sur}) \times f_{go}}{A_s} \qquad \ldots 3.4.11.4(2)$$

where

S_{gen} = apparent power rating of the generating sets, in volt amperes

S_{max} = maximum a.c. load demand, in volt amperes

$S_{inv,30\,min}$ = 30 min apparent power rating of the inverter at the expected maximum ambient air temperature, in volt amperes

f_{go} = generating set over-size factor, dimensionless

S_{sur} = a.c. surge load demand, in volt amperes

$S_{inv,sur}$ = surge rating of the inverter at the expected maximum ambient temperature, in volt amperes

A_s = ratio of instantaneous current to continuous current output of the alternator (the alternator surge ratio)

NOTES:

1 Typical value for the generating set over-size factor is 1.1.

2 Refer to manufacturer's data for alternator surge ratio values. Typical value is 2 to 3, however the ability of a generating set to supply a surge also depends on its inertia, as well as governing and voltage regulation. Small generating sets may be limited to surges of very short duration by these factors. Where load surges are of longer duration, the alternator surge ratio should be taken as 1. Methods to reduce the magnitude of the surge may be useful in this case.

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* Refer to the generating set manufacturer's documentation for the maximum efficiency operating point. Typically this will be in the range of 80% - 90% of rated power. To minimise fuel and maintenance costs the generating set should not be operated at less than 50% of its rated power

† The re-charge time is related to the selected battery storage size. It is recommended that generating set, charger and battery bank are sized so the re-charge time from maximum depth of discharge using only the generating set and no load on the systems does not exceed 10h.

3.4.11.5 *Derating for operating conditions*

The output of both the engine and the alternator should be derated for temperature, altitude and humidity as per the manufacturer's specifications (examples are shown in Table 4). Derating factors are cumulative.

TABLE 4

EXAMPLES OF DERATING FACTORS FOR GENERATING SETS

Air temperature		Derate 2.5% for every 5°C above 25°C
Altitude		Derate 3% for every additional 300 m above 300 m altitude
Humidity	**Air temperature between 30°C and 40°C**	Derate 0.5% for every 10% above 60% humidity
	Air temperature between 40°C and 50°C	Derate 1.0% for every 10% above 60% humidity
	Air temperature above 50°C	Derate 1.5% for every 10% above 60% humidity

NOTE: When performing generating set sizing calculations, the derating factors should be added to the required size specification.

3.4.11.6 *Generating sets run time*

The nominal generating set run time will vary according to a number of system design parameters, including the system configuration. Where monthly or seasonal variation in energy demand or renewable resources is significant, it may be desirable to calculate figures for each month or season. For systems where the majority of generating set running is used to recharge batteries, the nominal generating set run time may be calculated from the following equations, which take into account the renewable energy fraction, and the time required for equalizing charges. In systems where a substantial proportion of generating set output is supplied direct to loads, the calculation is more complex, and should be considered on a case by case basis.

If $f_{ren} < 1$,

$$T_{gen} = \frac{(1 - f_{ren}) \times E_{tot} \times 30}{I_{bc} \times V_{dc} \times \eta_{coul}} + \frac{T_{eq,run} \times 30}{T_{eq}} \quad \text{. . . 3.4.11.6(1)}$$

otherwise,

$$T_{gen} = \frac{T_{eq,run} \times 30}{T_{eq}} \quad \text{. . . 3.4.11.6(2)}$$

where

f_{ren} = renewable energy fraction (see Clause 3.4.6), dimensionless

T_{gen} = nominal generating set run time, in hours per month

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

I_{bc} = maximum charge rate of the battery charger, in amperes

V_{dc} = nominal voltage of the d.c. bus, in volts

η_{coul} = coulombic charge efficiency of the battery

T_{eq} = design equalization period (i.e. time between equalizing charges), in days

$T_{eq,run}$ = equalization run-on time, in hours

It should be noted that this is a nominal value only. The actual run time of the generating set will vary from this value (being typically longer) because of various factors, including—

(a) system configuration;

(b) battery charging regime;

(c) weather conditions; and

(d) the way the generating set is controlled, including—

  (i) the co-incidence of generating set run time and system load;

  (ii) use of the generating set to supply specific high power loads; and

  (iii) the battery SOC at the time the generator is started.

3.4.12 Cable sizing

Cables shall be sized to satisfy both their voltage drop requirement and their current carrying capacity limitation. Extra-low voltage (ELV) wiring is normally sized to limit the voltage drop, except in the case of high current, short cable runs. Battery bank to inverter cabling is the most common exception, where the current carrying capacity of the cable is normally the limiting factor.

Where parallel battery strings are used, cabling should be arranged so the current paths through each string are of equal length and equal cross-sectional area (i.e. between common connection points). This is to ensure the voltage drop is the same for each string.

See Table 5 for recommended maximum voltage drop losses.

NOTE: Appendix C gives a worked example of a cable sizing calculation and Appendix D gives an example of circuit protection sizing.

TABLE 5

RECOMMENDED MAXIMUM VOLTAGE DROP

d.c.voltage drops	
Photovoltaic	Less than 5%
Wind and micro-hydro generators:	Less than 10% at rated output
Battery bank to d.c.loads	Less than 5%

NOTES:

1 Voltage drop requirements for ELV circuits in AS/NZS 3000 should not be used

2 For some situations overall cost effectiveness will lead to larger voltage drops.

a.c.voltage drops	
Source to load	Less than 5%

NOTE: For a.c. bus systems manufacturer's recommendations should be followed regarding voltage drops between system sources

3.5 METERING AND CONTROL

3.5.1 Metering

Each system should be equipped with metering of the following system variables:

(a) Battery voltage (measured at the battery terminals).

(b) Input current (from each generator).

(c) 'Hours run' meter for the generating sets.

Additional meters such as load current ammeters and ampere hour or kilowatthour meters may also be useful.

3.5.2 Control

3.5.2.1 *Automatic*

Automatic control of starting and stopping of the generating set is recommended for systems supplying loads of over 3 kWh/d, where the renewable energy fraction is less than 75%.

3.5.2.2 *Manual override*

Where automatic control of the generating set is fitted, provision shall be made for manual override of these controls for starting and stopping the generating sets. Provision shall also be made to disable the automatic controls to enable maintenance on the generating set to be carried out safely.

3.6 ELECTRICAL PROTECTION

3.6.1 General

Electrical protection shall be in accordance with AS/NZS 3000, AS/NZS 3010, AS/NZS 5033 and AS/NZS 4509.1. All connections and wiring should be protected from inadvertent contact and mechanical damage by insulated enclosures, barriers, conduits or ducts.

Where an a.c. bus system design is used and the system is distributed on multiple buildings, the inverter installations remote from the main system shall comply with AS 4777.

NOTES:

1 See Appendix D for circuit protection sizing and Clause 3.6.6 for battery overcurrent protection.

2 Protection of systems using transformerless inverters is not covered by this Standard.

3.6.2 Generating set overcurrent protection

All outgoing circuits from a generating set shall be provided with overcurrent protection which, if not located on the alternator itself, should be located as close as practicable to the alternator.

3.6.3 Generating set isolation

All outgoing circuits from a generating set shall be provided with an isolating device which, if not located on the alternator itself, should be located as close as practicable to the alternator. This isolation may take the form of a main switch, combined circuit-breaker/main switch or a changeover switch with an intermediate OFF position.

3.6.4 Wiring

Wiring shall be protected from short-circuit and overload by high rupturing capacity (HRC) fuses or appropriate type circuit breakers (a.c. or d.c.), sized to limit the current below the maximum current carrying capacity of any part of the connected circuit.

All fuses and circuit breakers shall be labelled to indicate the circuits protected.

The wiring from the battery terminals to the overload protection is usually not electrically protected (due to practical constraints) and should be as short as possible with special attention paid to its mechanical protection.

3.6.5 Discrimination

The operation of protection equipment on any circuit should not affect any other section of the installation.

Circuit protection equipment should be graded to protect the installation.

Rewirable and auto type fuses shall not be used for circuit protection or as main battery fuses.

3.6.6 Battery overcurrent protection

The output conductors of the battery bank shall be protected against overcurrent, by HRC fuses or d.c. rated circuit breakers, as follows:

(a) Where the battery bank is electrically floating (i.e. neither side of the battery is earthed), protection shall be provided in both positive and negative battery leads.

(b) Where one side of the battery bank is earthed, protection shall be provided in the unearthed battery lead.

The protection should be mounted as close as practicable to the battery terminals (keeping battery leads as short as possible) while offering no possibility for spark ignition of any hydrogen emitted from the batteries during charging. Refer to AS/NZS 4509.1 requirements

Ideally, the battery bank should comprise a single string of cells of the correct ampere hour capacity and of the same type of battery.

Where multiple strings of cells are used, each string should be separately protected (see Figure 6).

Additionally, the strings should be connected to equalize cable resistance in each string.

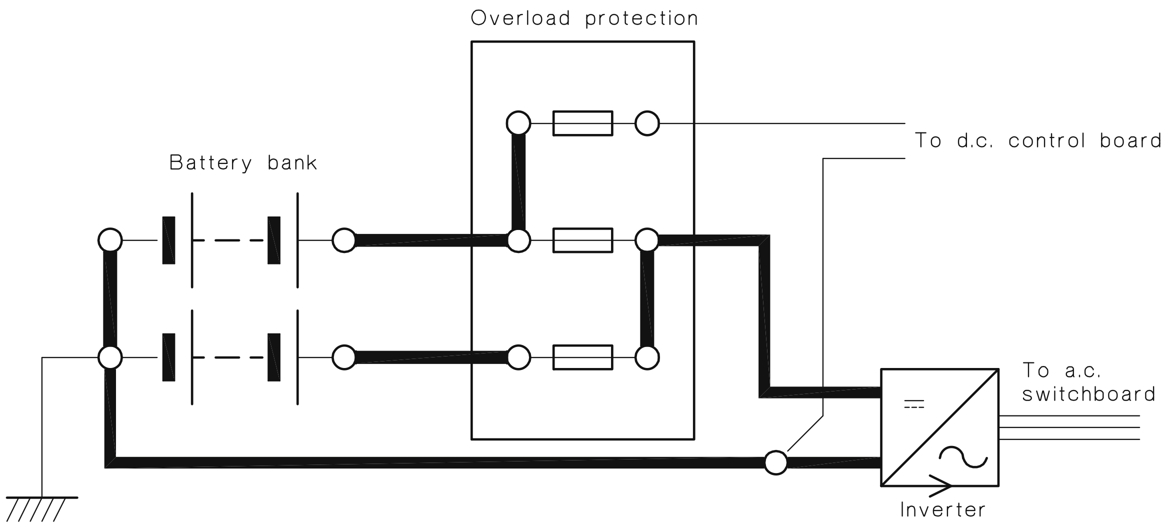
3.6.7 Battery isolation

The battery bank shall be able to be readily isolated from the power system.

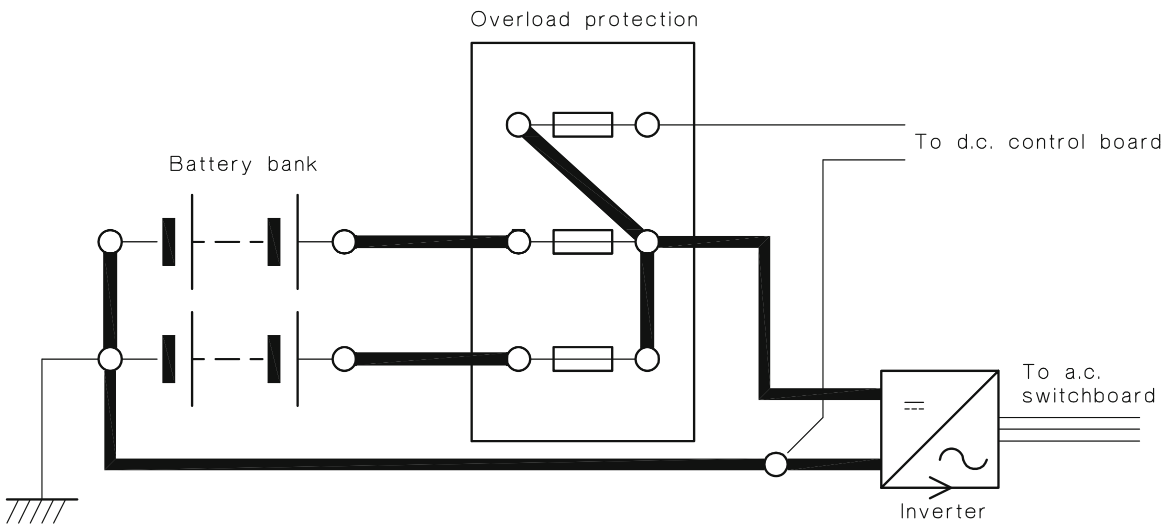
One solution is the ‘Disconnector Fuse’ which enables quick disconnection. A multi-fuse unit can also provide the main protection for any d.c. loads required (see Figures 6, 7 and 8).

NOTE: See Appendix D for sizing method and example.

Where it is necessary to isolate battery strings without interrupting power supply, the schemes shown in Figures 7 and 8 may also be implemented with separate fusing and isolation for each string.



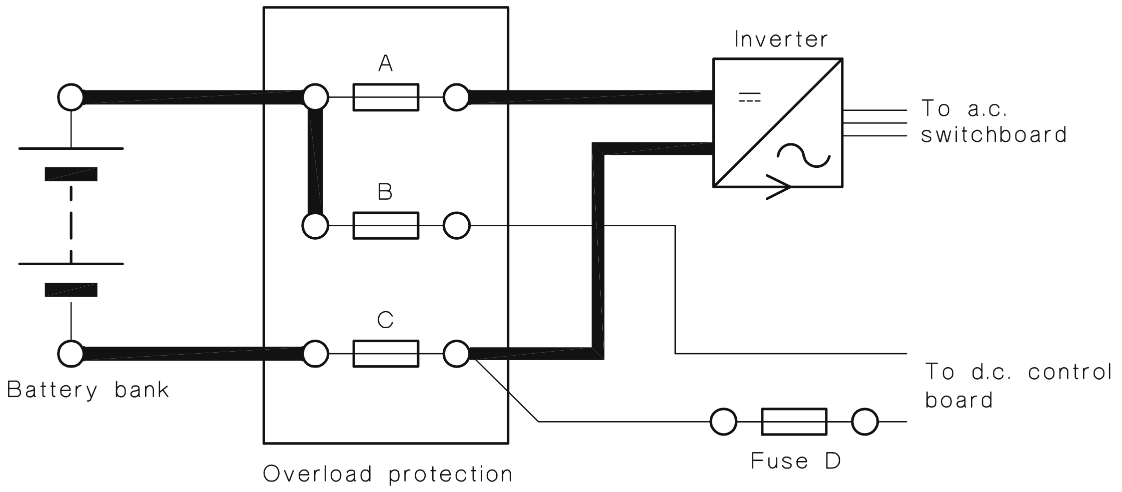
(a)



(b)

NOTE: Both cabling and fusing for each string should be sized to cope with the full load requirement.

FIGURE 6 TWO CONFIGURATIONS FOR USING A 3 POLE SWITCH-FUSE FOR CONNECTION OF TWO BATTERY STRINGS WITH D.C. LOAD PROTECTION (EARTHED D.C. SUPPLY)

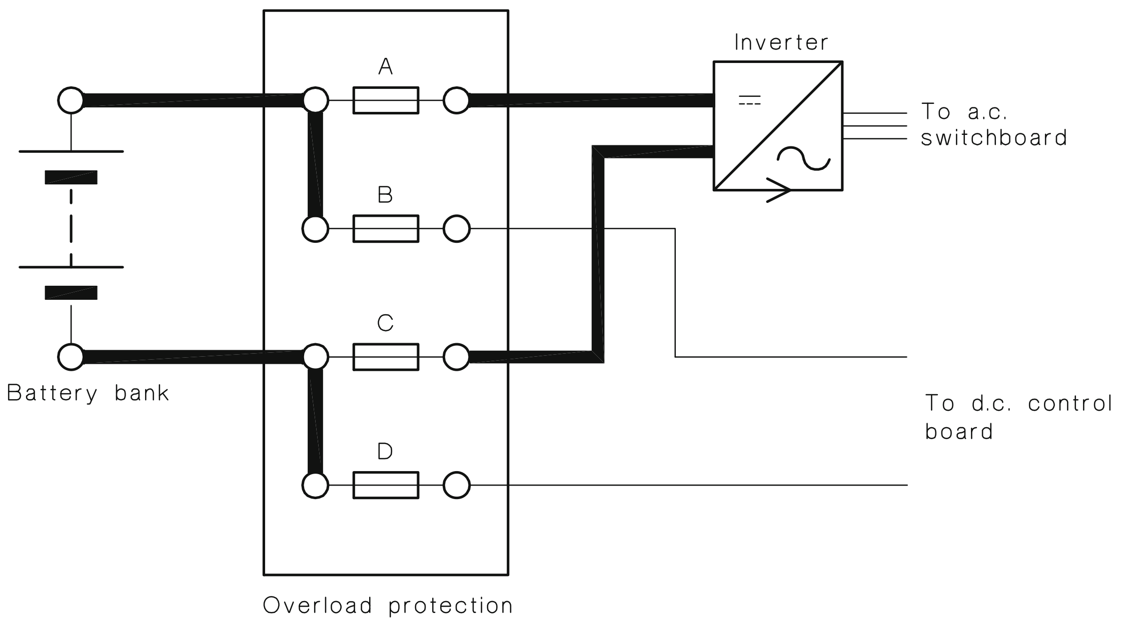


NOTES:

1 Fuse D should be adjacent to Fuse C.

2 The wiring from Fuse C to Fuse D is not electrically protected (due to practical constraints) and should be as short as possible with special attention paid to its mechanical protection.

FIGURE 7 USING A 3-POLE SWITCH-FUSE FOR INVERTER AND D.C. LOAD PROTECTION



NOTES:

1 Fuses A and C are sized for inverter continuous and surge supply current.

2 Fuses B and D are sized for the d.c. load maximum demand current or maximum charging current, whichever is greater.

FIGURE 8 USING A 4-POLE SWITCH-FUSE FOR INVERTER AND D.C. LOAD PROTECTION

3.7 SWITCHING AND ISOLATION

3.7.1 Switch selection

All switches used on the d.c. side shall be selected on the basis of d.c. current ratings and fault current requirements.

3.7.2 Isolation

Provision shall be made for each generating source to be electrically isolated from the system. Suitable isolating devices include appropriately rated fuses, circuit-breakers and switches.

3.8 LIGHTNING PROTECTION

3.8.1 General

The system equipment should be protected against lightning surge, where necessary, in accordance with AS/NZS 1768.

The use of metal oxide varistors (MOV) is recommended and it is recommended that expert advice should be sought in lightning prone areas.

NOTES:

1 Gas discharge protection devices/surge protectors are not recommended as they may not self extinguish on a d.c. circuit.

2 For information on lightning protection, see Appendix E.

3.8.2 Photovoltaic regulator

Lightning protection may be required in lightning prone areas. This should take the form of—

(a) metal oxide varistors at the entry point to the equipment area; and

(b) isolation equipment or metal oxide varistors, or both, at the photovoltaic regulator (these may be incorporated in the regulation equipment).

3.8.3 Wind generator

Lightning protection will normally be required and this should take the form of—

(a) adequate tower earthing;

(b) metal oxide varistors at the tower and the entry point to the equipment area; and

(c) isolation equipment or metal oxide varistors, or both, at the wind generator regulator (these may be incorporated in the regulation equipment).

3.8.4 Micro-hydro regulator

Lightning protection may be required in lightning prone areas or where aerial cable runs are used. This should take the form of—

(a) metal oxide varistors at the entry point to the equipment area; and

(b) isolation equipment or metal oxide varistors or both, at the micro-hydro regulator (these may be incorporated in the regulation equipment).

SECTION 4 SYSTEM DESIGN—MECHANICAL AND CIVIL WORKS

4.1 GENERAL

4.1.1 Standards

All structures shall be constructed to appropriate local statutory requirements and Standards.

4.1.2 Environmental impact

All civil works should be carried out in such a way as to minimize the environmental impacts, especially in regard to soil erosion and damage to vegetation.

4.2 PHOTOVOLTAIC ARRAY

4.2.1 Array siting

The photovoltaic array should be located where it will be unshaded for at least 4 h before and after solar noon (the time when the sun is highest in the sky), during all seasons. Where appropriate, vegetation causing significant shading should be removed. Where this is not possible or desirable, allowance should be made for reduced irradiation in array output calculations. (See Clause 3.4.3.)

In d.c. coupled systems, consideration shall also be given to minimizing the length of cable run to the battery.

4.2.2 Structures for PV array mounting

PV array mounting structures should comply with AS/NZS 1170.2.

The lightning risk index should be determined and appropriate protection provided, where required.

NOTE: For information on lightning protection, see Appendix E.

4.3 WIND TURBINE GENERATORS

4.3.1 Siting

Providing that the general location has an adequate wind resource, factors to consider in the selection of the wind turbine site include—

(a) suitable geography, (e.g. siting on flat or raised land);

(b) distance from the dwelling, (e.g. typically within several hundred metres); and

(c) terrain clear of obstacles (trees and built structures).

4.3.2 Tower height

The height of the tower should be high enough to raise the turbine above turbulence caused by obstacles in the vicinity. Additional height for the purpose of gaining access to higher wind speeds is usually justified through the increase in energy obtained.

4.3.3 Tower design

Wind turbine towers shall be designed to comply with AS/NZS 1170.2. Where a tower other than that supplied by the manufacturer is to be used, care should be taken to ensure the resonant behaviour of the tower will not cause excessive vibration under the normal range of operating conditions.

The choice of tower type (self-supporting or guyed) should take into account the cost, the area of level ground suitable for locating guy anchors, and accessibility of the turbine for maintenance.

4.4 MICRO-HYDRO TURBINE

4.4.1 Micro-hydro siting

In selecting a site for a micro-hydro turbine the following points should be considered:

(a) Obtaining the maximum static head.

(b) Being within a suitable distance for transmission of electrical power to the dwelling.

(c) Accessibility of the site.

The likely flood level for the site should be assessed, in order to either locate the turbine above flood level, or, where the turbine-generator will withstand flooding, make provision for adequate protection from floodwaters and flood-borne debris.

Any local regulations regarding diversion of water from the watercourse should be met.

4.4.2 Pipe

Pipes used for the penstock or draught tube (if present) should be of a construction sufficient to withstand the hydraulic pressures that will be experienced in all operational conditions. This includes the static head as well as any transient conditions caused by flow regulation at the turbine, blockages or air pockets.

All pipes should be anchored at regular intervals and at all elbows, to ensure secure fixing under all operating conditions.

The penstock should be laid in such a way as to prevent the formation of air pockets which may reduce the performance of the turbine or, where this is not possible, air release valves should be installed at appropriate points.

4.4.3 Water intake

The penstock inlet should be located at a suitable natural pond or small dam, and fitted with a filter. The filter should be of such construction as to withstand flood conditions, and should resist blockage to an extent that will prevent reduction of turbine performance.

4.4.4 Civil works

All civil works should be of adequate construction to withstand flooding, where such works are below flood level. This includes dams, pipes and their anchors, filters and turbine mounting or housing.

4.5 GENERATING SETS

4.5.1 Accommodation

The following recommendations apply to generating set accommodation:

(a) Generating set accommodation should allow for an adequate air flow for combustion and cooling sufficient to maintain the air temperature around the generating set within manufacturer's specified operating temperatures, during normal operating conditions.

(b) The generating set should be easily accessible for maintenance purposes.

(c) The generating set accommodation should be constructed in such a way as to reduce noise emission from the body of the engine to an acceptable level (refer Clause 4.7.4).

(d) Attention should be given to the orientation of the air discharge outlet with respect to any prevailing wind.

4.5.2 Exhaust system

The discharge end of the exhaust pipe should be fitted with some form of weather protection or otherwise arranged so as to prevent entry of rain into the exhaust system and it should not point directly into any area likely to be occupied or used by people (e.g. a window in the residence).

The exhaust system should include a muffler to reduce noise emissions to an acceptable level (refer Clause 4.7.4). The back pressure created by the exhaust pipe and muffler should not exceed the specifications for correct operation of the engine.

4.5.3 Vibration

All piping, ducting or cable connections between the engine or alternator and any fixed point should include flexible sections to withstand the vibration experienced under all operating conditions for the expected life of the generating sets. The mounting of the generating set should include adequate vibration isolation.

4.6 BATTERY

4.6.1 Battery enclosure

The battery installation shall be designed in accordance with the requirements of AS/NZS 4509.1 and the batteries should be located in accordance with the manufacturer's recommendations.

Consideration should also be given to the following:

(a) Localized heat sources should not be present e.g. direct sunlight, generators, battery proximity to walls exposed to direct sunlight.

(b) Extreme ambient temperatures should be avoided because low temperatures decrease battery capacity and high temperatures shorten battery life.

(c) The battery bank location should preclude contamination of the natural environment, damage to equipment and injury to personnel in the event of electrolyte spillage.

(d) The battery bank should not be located near combustible material or near metal objects capable of falling across the battery terminals and causing a short-circuit.

(e) The size of the enclosure should allow for sufficient clearance to provide access for installation, maintenance, handling equipment and safety equipment.

(f) In New Zealand, the battery enclosure or stand shall protect the batteries from damage due to seismic (earthquake) activity and it shall comply with NZS 4219.

(g) In Australia, the battery stand or supports shall comply with AS 1170.4.

(h) The supporting surface of the enclosure should have adequate structural strength to support the battery bank weight and its support structure.

(i) The enclosure should be resistant to the effects of electrolyte, either by the selection of materials used or by appropriate coatings. Provision should be made for the containment of any spilled electrolyte. Acid resistant trays in which the batteries sit should be capable of holding electrolyte equal to the capacity of at least one cell of the battery bank.

(j) Any enclosure doors should allow unobstructed exit.

4.6.2 Ventilation

All battery installations, for both vented and valve regulated (sealed) batteries, shall have natural ventilation or be force-ventilated.

NOTES:

1 Although valve regulated (gel and absorptive glass mat) cells use internal oxygen-recombination to suppress most hydrogen gas evolution, under conditions of overcharge significant amounts of hydrogen gas can be emitted, constituting a hazard.

2 See AS 4086.2 for the calculation of exhaust ventilation rate, method of ventilation and sizing of ventilation apertures.

4.6.3 Arrangement of ventilation

The following recommendations apply to the arrangement and layout of the ventilation system:

(a) Exhaust air should not pass over other electrical devices.

(b) Battery enclosures should be provided with ventilation holes, grilles or vents so that air sweeps across the battery. To avoid stratification of the airflow, it is recommended that ventilation inlets and outlets consist of—

  (i) a number of holes spaced evenly along the enclosure; or

  (ii) a slot running along the side of the room or enclosure.

(c) Battery enclosures should be designed to prevent the formation of pockets of gas.

(d) Ventilation outlets should be at the highest level of the battery enclosure.

(e) Ventilation inlets should be at a low level in the battery enclosure. Inlets should be no higher than the top of the battery cells, and fitted with a coarse screen to prevent the entry of vermin.

(f) To ensure airflow does not bypass the battery, ventilation inlets and outlets should be located on opposite sides of the enclosure.

Where mechanical ventilation is used, the fan shall be positioned on the inlet and below the battery tops and designed to create airflow through the enclosure. An airflow sensor shall be incorporated to initiate an alarm if the ventilation fan fails.

4.6.4 Alarms

For the protection of the battery bank, it is desirable to have an indication of high or low battery voltage. In stand-alone power systems these may take the form of the system voltmeter in combination with high and low volt alarms in any inverter or system controller, or a low volt d.c. cut-off incorporated in the PV regulator.

In any case, where a low battery voltage load disconnect is not available, a dedicated cut-off unit should be fitted.

4.7 NOISE CONTROL

4.7.1 General

Steps should be taken to ensure noise produced by any of the system components is of an acceptably low level. The components of most concern in this respect are—

(a) generating set;

(b) wind turbines; and

(c) inverters and other electronic equipment using high frequency power conversion techniques.

In critical situations, the advice of a specialist should be sought. Reference should be made to AS 1359.109 for noise limits for rotating machines.

NOTE: Information on the prediction, measurement and assessment of sound from both horizontal and vertical wind turbine generators can be obtained from NZS 6808.

4.7.2 Assessment of noise annoyance

In cases where local authorities have guidelines or by-laws specifying maximum acceptable noise levels, these should be referred to. Where no such guidelines or by-laws exist, the following factors should be considered:

(a) Equipment noise levels which are less than 5 dB above the background noise level are unlikely to cause annoyance in any circumstances.

(b) Irregular or inconsistent noises are generally more annoying than steady noises.

(c) The annoyance value of any noise is subjective, and depends on the kind of activities being carried out in the area in question and the listener's expectations.

4.7.3 Principles of noise attenuation

Application of the following principles may be of use in attenuating noise to acceptable levels:

(a) Sound levels are reduced by 6 dB for every doubling of distance from the noise source.

(b) Generally sparse vegetation provides little sound attenuation whereas 10 m depth of thickly wooded forest could provide a reduction of 10 dB.

(c) Solid barriers are most effective. Small openings in walls, around doors and in other barriers allow significant noise to pass through.

(d) Sound propagation is affected by wind speed and direction and will be higher in the downwind direction.

(e) Low frequency sound diffracts (bends) around corners more than high frequency sound.

(f) Low frequency sound can be attenuated only by distance, and by the use of massive (i.e. heavy construction) barriers between the source and the listener.

(g) Sound may be easily reflected off solid barriers, especially mid and high frequency sound.

(h) The use of sound absorbing material (e.g. sound batts) as a lining on walls or other barriers may provide benefit in two ways—

    (i) by reducing reverberation, especially in enclosures of solid construction such as brick; and

    (ii) by reducing transmission of sound through the wall or barrier, especially through walls of lightweight construction.

4.7.4 Noise reduction methods for specific items of equipment

4.7.4.1 *Generating sets*

Generating set produce noise covering a wide range of frequencies, with low frequencies predominating. Sound is emitted from two sources—the engine body, and the exhaust pipe outlet.

Exhaust noise can be reduced by the following means:

(a) Using a muffler of adequate noise reduction grade.

(b) Pointing the exhaust away from any residence.

(c) Ensuring that there is no direct sound path to any residence.

Noise from the engine body can be reduced by any or all of the following means, as appropriate:

(i) Locate the generating set as far as possible from any residence, preferably not upwind of the residence in the prevailing wind direction.

(ii) Locate the generating set so there is no direct sound path from the generating set to any residence (erect a barrier if necessary).

(iii) Enclose the generating set in a soundproof enclosure or room (taking care to ensure adequate cooling air is available to the engine). Heavy construction is preferred, or light construction with sound absorbing lining.

(iv) Ensure proper sealing around doors and other openings.

(v) For permanent openings in an enclosure (e.g. for cooling air inlet or discharge), incorporate some form of attenuation (e.g. cowl or louvre, preferably acoustically lined, or air attenuator/silencer).

(vi) Use a generating set with integral noise reducing enclosure.

NOTES:

1 Confining generating set run times to daytime only will reduce the level of noise attenuation required.

2 Noise levels are dependent on fuel type, engine operating speed and load. Fuel types, in order of increasing noise levels, are gas, petrol, diesel.

4.7.4.2 *Wind turbines*

Wind turbines may produce noise from two sources-turbine blades gearboxes. There are few options available to reduce noise levels, due to constraints in the system design and turbine siting. The main considerations when minimizing noise levels are—

(a) choice of machine; and

(b) location of turbine—as far as possible or practicable from the residence, and downwind in the prevailing wind direction from the residence, if possible.

NOTES:

1 Background noise levels at windy sites will be elevated by the noise of the wind blowing through vegetation and over built structures.

2 NZS 6808 gives a method of assessing the noise from wind turbines.

4.7.4.3 *Inverters and other electronic equipment*

Noise produced by inverters or electronic equipment is generally of mid to high frequencies. Noise levels may be of concern where equipment is located within a residence. In such a case, the equipment may be housed in an enclosure of adequate construction to attenuate noise to the required level. In small enclosures, care should be taken to ensure the equipment will have an adequate flow of cooling air.

SECTION 5 SYSTEM PERFORMANCE

Performance specifications should be based on the equations and other considerations outlined in Sections 2, 3 and 4.

Major system parameters which should be specified (for annual, seasonal or monthly periods, as appropriate to the basis of the design) are—

(a) design d.c. load energy and design a.c. load energy;

(b) load management strategies or conditions necessary for performance as specified;

(c) maximum and surge demand;

(d) average daily energy output of each renewable energy generator under design conditions;

(e) expected contribution to the load from each generator under design conditions, as a percentage;

(f) nominal generating set run time under design conditions;

(g) renewable energy resource data used for design calculations including adjustments for site conditions and design parameters (e.g. PV array tilt angle and orientation, wind turbine tower height);

(h) system voltage; and

(i) ratings of major components.

APPENDIX A

WORKED EXAMPLE FOR SIZING OF A PV SYSTEM WITH A D.C. BUS

(Informative)

A1 INTRODUCTION

A1.1 General

Tables A1 to A11 provide data that comprises a worked example showing one method of using the information on PV system sizing set out in this Standard. Users should note that other methods may be equally applicable.

The worksheets used in this worked example show the application of the design guidelines to stand-alone systems with the following qualifications:

(a) Battery size based on several days autonomy.

(b) PV array as the only renewable energy input.

(c) PV array regulators are not maximum power point tracking.

(d) Generating set, if present, does not run every day.

A1.2 Basis used for this worked example

This worked example is based on the provision of electricity to a house in rural south-east Queensland (with a latitude of 27.5°S). The design process encompasses an analysis of energy services, an assessment of electrical loads, the selection and sizing of major components and the calculation of major performance parameters.

A2 CALCULATIONS

A2.1 Rounding

The data used in this worked example is taken from a computer based spreadsheet. Values shown in the following tables are rounded-off to an appropriate number of decimal places. Manual calculations using these values may give slightly different results.

A2.2 Treatment of percentage values

Quantities shown as percentages are treated as fractional quantities in the calculations.

TABLE A1

TYPICAL ENERGY SERVICES AND ENERGY SOURCE SELECTION

Energy service	Energy source	Comments
Water heating	Solar + gas boosting	Most appropriate energy source Minimum environmental impact Lowest cost at remote site
Space heating	Energy efficient house design, wood heating	Most appropriate energy source Lowest cost
Space cooling	Energy efficient house design	
Refrigeration	Electric (d.c.)	d.c. chosen for efficiency reasons
Lighting	Electric (d.c.)	Preference for fluorescent lamps. Some incandescent lamps for low use areas
Cooking	Gas stove, some electric appliances (e.g. microwave oven)	Only available option Efficiency produces lowest energy requirements Lowest system cost
Cleaning, entertainment, kitchen appliances, office equipment	Efficient electric	Only available option Efficiency produces lowest energy requirements Lowest system cost
Power tools	Electric	Only available option
Water pumping	Efficient electric	Lowest cost
Water and waste treatment	None	

NOTE: Refer to Clause 2.3 for selection principles. The choices of energy sources and the reasons given apply to this specific worked example and may not apply in all situations.

TABLE A2

D.C. LOADS

(1)	(2)	(3)	(4a)	(5a)	(4b)	(5b)	(6)	
Appliance	Number	Power	Winter or dry season		Summer or wet season		Contribution to maximum demand	Comments
			Usage time	Energy	Usage time	Energy		
		W	h	Wh	h	Wh	W	
Fluorescent lamp	3	40	4	480	3	360	120	Assumes all lamps may be on at the same time as any other appliance.
Compact fluorescent lamps	3	15	5	225	3	135	45	Assumes all lamps may be on at the same time as any other appliance.
Incandescent lamps	3	60	0.25	45	0.25	45	60	These lamps have low usage time, and are unlikely to be on at the same time. Only one lamp is considered for maximum demand purposes.
Refrigerator	1	70	—	800	—	1100	70	Refrigerator running time is unknown, but manufacturer's specs show 900 Wh daily energy consumption for 20°C ambient, and 70 W max. power consumption.
Daily load energy: d.c. loads (Wh)			(DC7a) →	1550	(DC7b) →	1640		
Maximum d.c. demand (W)						(DC8) →	295	

NOTES:

1 Columns (1) to (4a,b) contain data obtained from the user or field survey. Where practicable, power consumption data should be from actual measurements.

2 Columns (5a,b) = Column (2) × Column (3) × Columns (4a,b).

3 Column (6) = n × Column (3) if these items contribute to the maximum demand scenario,
where
n = the number of items specified in Column (2) which actually contribute to the maximum demand.

4 Cell (DC7a,b) = Sum of Columns (5a,b), as appropriate.

5 Cell (DC8) = Sum of Column (6).

6 In cases where large loads are known to occur during certain months (e.g. during harvesting), this worst case load situation should be considered explicitly.

TABLE A3

A.C. LOADS

(1)	(2)	(3)	(4a)	(5a)	(4b)	(5b)	(6)	(7)	(8)	(9a)	(9b)	
			Winter or dry season		Summer or wet season					Contribution to surge demand		
Appliance	No.	Power	Usage time	Energy	Usage time	Energy	p.f.	Contribution to max. demand	Surge factor	(potential)	(design)	Comments
		W	h	Wh	h	Wh		VA		VA		
TV	1	80	3	240	1.5	120	0.8	100			100	Contribution to max. Demand is based on an assumed power factor of 0.8.
Stereo	1	20	3	60	3	60						Stereo power usage is an estimate based on measurements of other stereo systems. Nameplate rating is likely to be excessive.
Computer	1	120	3	360	3	360	0.8	150			150	Contribution to max. Demand is based on an assumed power factor of 0.8.
Blender	1	150	0.083	13	0.083	13						Usage time is based on 5 minutes per day (i.e. $\frac{5}{60}$ hour per day).
Vacuum cleaner	1	1000	0.071	71	0.071	71	0.8	1250	3	3750	3750	Usage time is based on 1 hour per fortnight (i.e. 1/14 hour per day). Surge demand is taken as 3 times the running demand (assuming running power factor of 0.8), which is typical for universal motors (i.e. $\frac{1000 \times 3}{0.8}$).
Washing machine	1	300	0.32	96	0.32	96						Usage time is based on 3 loads per week at 0.75 hour per load (i.e. $\frac{3 \times 0.75}{7}$ hour per day).
Electric drill	1	600	0.071	43	0.071	43						Usage time is based on 1 hour per fortnight (i.e. $\frac{1}{14}$ hour per day).
Iron	1	1200	0.14	168	0.14	168						Usage time is based on 1 hour per week (i.e. $\frac{1}{7}$ hour per day).
Water Pump	1	300	3	900	1.5	450	0.7	429	7	3000	429 (See Note 11)	Usage time estimated is based on water usage requirements. Surge is taken as 7 times the running demand, which is typical for induction machines.
Daily Load Energy: a.c. Loads (Wh)			(AC10a)	1951	(AC10b)	1381						Only one of vacuum, washing machine, drill, iron to be used at any one time
½ hour maximum demand - (VA)							(AC11)	1929				
Surge demand - (VA)										(AC12) →	4429	

(*continued*)

NOTES TO TABLE A3:

1 Columns (1) to (4a), (4b) and (6) contain data obtained from the user or field survey.

2 Columns (5a,b) = Column (2) × Column (3) × Columns (4a,b).

3 Column (7) = if the item contributes to the maximum demand,

where

n = the number of items specified in Column (2) which actually contribute to the maximum demand.

4 Column (8) is the ratio of apparent power during start-up surge to that when running, and depends on the type of load. As a guide, use 1 for resistive loads, 3 for universal motors (hand-held tools and most kitchen appliances), and 7 for induction motors.

5 Column (9a) = Column (7) × Column (8).

6 Column (9b) = Column (9a) if the item's surge contributes to the surge demand (usually the item with largest surge), or Column (7) if the item's running power contributes to surge demand.

7 Cells (AC10a,b) = Sum of Columns (5a,b).

8 Cell (AC11) = Sum of Column (7).

9 Cell (AC12) = Sum of Column (9b).

10 Values in Columns 7 and 8 may need consideration of load diversity.

11 It is assumed that, since the vacuum cleaner is manually started and infrequently used, a starting surge concurrent with the pump is unlikely. Since the pump has smaller surge, its continuous running demand is used instead.

12 In cases where large loads are known to occur during certain months (e.g. harvesting), this worst case load situation should be considered explicitly.

TABLE A4
MISCELLANEOUS SYSTEM DESIGN INFORMATION

Item	Symbol	Source[1]	Ref.	Value	Units	Refer Clause	Notes
Summer/wet months			M1	Oct, Nov, Dec, Jan, Feb, Mar			
Winter/dry months			M2	Apr, May, Jun, Jul, Aug, Sep			
Average inverter efficiency	η_{inv}	Manufacturer's data	M3	85%		3.1.4.1	This is less than the peak efficiency quoted in manufacturer's specifications.
Design load energy – winter/dry	E_{tot}	$\frac{AC10a}{M3} + DC7a$	M4	3846	Wh	3.1.1 3.1.4.1	
Design load energy – summer/wet	E_{tot}	$\frac{AC10b}{M3} + DC7b$	M5	3265	Wh	3.1.1 3.1.4.1	
Design tilt angle		Design decision	M6	45°		3.4.3.4	
Maximum demand at d.c. bus (approximately)		$\frac{AC11 \times 0.8}{M3} + DC8$	M7	2110	W	3.1.4.2	pf of 0.8 is assumed
Nominal system voltage	V_{dc}	Design decision	M8	24	V	1.3.36 3.4.1	
Approximate d.c. current at maximum demand		$\frac{M7}{M8}$	M9	88	A	3.4.1	
System configuration		Design decision	M10	Switched		3.3.1 3.3.3	

1 Values for AC10a, AC10b and AC11 are from Table A3. Values for DC7a, DC7b and DC8 are from Table A2.

TABLE A5
SELECTION OF DESIGN MONTHS

Solar radiation data source: Australian Solar Radiation Data Handbook

Measurement location: Brisbane, latitude 27.5°S

Ref.	Item (units)	Source	Value												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
DM1	Irradiation on tilted plane (kWh/m^2 or PSH)	From resource data[1] and M6	5.5	5.5	5.6	5.3	4.8	4.9	4.9	5.7	6.2	5.4	5.1	5.2	5.5
DM2	Load (kWh/d)	From M1, M2, M4 and M5[2]	3.26	3.26	3.26	3.85	3.85	3.85	3.85	3.85	3.85	3.26	3.26	3.26	3.56
DM3	Ratio $\frac{\text{Resource}}{\text{Load}}$	$\frac{\text{DM1}}{\text{DM2}}$	1.68	1.68	1.72	1.38	1.25	1.27	1.27	1.48	1.61	1.65	1.56	1.59	1.54
DM4	Worst and best months	Select after inspecting DM3[3]			Best		Worst								

1 In this example, the site was considered to have no appreciable difference in irradiation compared to the measurement location and hence no adjustment was required. See Clause 3.2.2.

2 Values for M1, M2, M4 and M5 are from Table A4.

3 Refer Clause 3.4.2.6.

TABLE A6

INVERTER SIZING AND SELECTION (SEE CLAUSE 3.4.9)

Item	Symbol	Source	Ref.	Value	Units	Refer Clause	Notes
Inverter ½ hour maximum demand	$S_{\mathrm{inv,30min}}$	AC11[1]	IN1	1929	VA	1.3.32 3.1.4.2	
Inverter surge demand	$S_{\mathrm{inv,sur}}$	AC12[1]	IN2	4429	VA	1.3.59 3.1.4.3	
Safety factor		Design decision	IN3	10%		3.1.6 3.4.9.1	Typically 10%
Suggested inverter ½ hour maximum rating		(1+IN3) × IN1	IN4	2121	VA	3.4.9.1 1.3.32	
Suggested inverter surge rating		(1+IN3) × IN2	IN5	4872	VA	3.4.9.1 1.3.59	
Waveform quality required		Design decision	IN6	Sine		2.2 3.4.9.1	Depends on the customer's requirements
Inverter type		Design decision, also depends on M10[2]	IN7	Standard		3.3.3 3.4.9	Depends on system configuration
Selected inverter		Brand and model	IN8	INV 2k-24		3.4.9.1	
Selected inverter ½hour max. rating		From manufacturer's specifications	IN9	2300	VA	3.4.9.1	
Selected inverter continuous rating		From manufacturer's specifications	IN10	2000	VA	3.4.9.1	
Selected inverter surge rating		From manufacturer's specifications	IN11	5100	VA	3.4.9.1	

1 Values for AC11 and AC12 are from Table A3.

2 Value for M10 is from Table A4.

TABLE A7

BATTERY SIZING AND SELECTION (SEE CLAUSE 3.4.7)

Item	Symbol	Source	Ref.	Value	Units	Refer Clause	Notes
Design load energy for battery sizing		The larger of M4[1] or M5[1]	B1	3846	Wh	3.4.7.3	Load energy for season with highest load.
Design load Ah for battery sizing		$\frac{B1^{1}}{M8}$	B2	160	Ah		
Target number of days of autonomy	T_{aut}	Design decision	B3	5	d	1.3.2 3.4.7.2 3.4.7.6	
Maximum DOD	DOD_{max}	Design decision	B4	70%		1.3.13 3.4.7.2	
Nominal battery discharge rate	C_{100}	Design decision	B5	100	h rate	3.4.7.2	Due to spread of loads
Minimum mean daily temperature		From climatic data	B6	15	°C	3.4.7.7	Coldest month may not necessarily be design month.
Temperature correction factor		From graph or table	B7	0.98		3.4.7.7	
Required battery capacity		$\frac{B2 \times B3}{B4 \times B7}$	B8	1168	Ah	3.4.7.3	
Selected cell/block		Brand and model	B9	XYZ 500B		3.4.7.1	See comments for B14
Selected cell/block capacity at nominal discharge rate		From manufacturer's specifications	B10	500	Ah	3.4.7.2	
Selected cell/block voltage		From manufacturer's specifications	B11	2	V		
Number of strings in parallel		$\frac{B8}{B10}$ rounded off	B12	2		3.4.7.1	The number of parallel battery strings should be minimized.
Number of cells/blocks in series		$\frac{M8}{B11}$	B13	12			
Capacity of battery bank at nominal discharge rate	C_{100}	B10 × B12	B14	1000	Ah		The selected cells provide a capacity slightly less than that required for 5 days autonomy. This design decision is made on economic grounds assuming that slightly less autonomy is acceptable to the client. C_{100} used in this example.
Days of autonomy for selected battery		$\frac{B4 \times B14 \times B7}{B2}$	B15	4.3	d		
Nominal daily DOD	DOD_{d}	$\frac{B2}{B14}$	B16	16%		3.4.7.5	
Design equalization period	T_{eq}	Design decision	B17	14	d	3.4.11.6	This is the time between equalization charges when using a generating sets.
Equalization run-on time	$T_{eq,run}$	Design decision	B18	3	h	3.4.11.6	This is the time required to provide an equalizing charge from the generating sets.

1 Values for M4, M5 and M8 are from Table A4.

2 These calculations assume that the battery size is not limited by power output capability (refer Clause 3.4.7.2).

TABLE A8-1

PHOTOVOLTAIC ARRAY AND REGULATOR SIZING AND SELECTION (PART 1)

Item	Symbol	Source	Ref.	Value	Units	Refer Clause	Notes
Oversupply co-efficient	f_o	Design decision	PV1	1		3.4.2.5	Equals 1 if the system includes a generating sets.
Nominal battery efficiency (coulombic)	η_{coul}	From manufacturer's specifications	PV2	90%		1.3.8 3.4.2.2 3.4.3.11.1	Approximately 90% to 95% is typical for lead acid batteries. This depends strongly on the charging regime used.
Selected module		Brand and model	PV3	XYZ 80			
Nominal module power	P_{stc}	From manufacturer's specifications	PV4	80	W		
Nominal module voltage		From manufacturer's specifications	PV5	12	V		
Module short-circuit current	I_{sc}	From manufacturer's specifications	PV6	5.2	A		
Module current at 14 V at operating temp.	$I_{T,V}$	From manufacturer's specifications	PV7	4.8	A	3.4.3.9	In areas where module operating temperatures significantly exceed NOCT, manufacturer's data should be consulted to determine the current in such conditions. Module current can be significantly diminished by high temperatures due to changes in the IV curve.
Manufacturer's tolerance on current output		From manufacturer's specifications	PV8	5%		3.4.3.7	
Derating factor for soiling	f_{dirt}	Design decision	PV9	95%		3.4.3.7	Depends on site conditions

NOTE: This work-sheet assumes the use of standard (switched) regulators only, not maximum power point tracking regulators.

TABLE A8-2

PHOTOVOLTAIC ARRAY AND REGULATOR SIZING AND SELECTION (PART 2)

Item	Symbol	Source[1]	Ref.	Worst month	Best month	Annual average	Units	Refer Clause	Notes
Irradiation on tilted plane	H_{tilt}	From DM1	PV10	4.8	5.6	5.5	h	3.2.2	
Design load energy for array sizing		From DM2	PV11	3846	3265	3555	Wh		
Design load Ah		$\frac{PV11}{M8}$	PV12	160	136	148	Ah		
Required array output		$\frac{PV12}{PV2}$	PV13	178	151	165	Ah		
Daily charge (Ah) output per module		(1-PV8) × PV7 × PV9 × PV10	PV14	20.8	24.3	23.7	Ah	3.4.3.9	
Number of parallel strings required		$\frac{PV13 \times PV1}{PV14}$	PV15	8.6	6.2	6.9		3.4.3.11	
Number of parallel strings used	N_p	Design decision, based on PV15 data	PV16	7				3.4.3.11 3.1.6	
Nominal solar fraction for design month	f_{sol}	$\frac{PV16}{PV15}$	PV17	82%	112%	101%		1.3.46 3.4.6	Solar fractions of approximately 90% or above, should be treated with some caution.

1 Values for DM1 and DM2 are from Table A5. Value for M8 is from Table A4.

TABLE A8-3

PHOTOVOLTAIC ARRAY AND REGULATOR SIZING AND SELECTION (PART 3)

Item	Symbol	Source[1]	Ref.	Value	Units	Refer Clause	Notes
Number of series modules per string	N_s	$\frac{\text{M8}}{\text{PV5}}$	PV18	2			
Total number of modules in array	N	PV16 × PV18	PV19	14			
Regulator current rating required		PV6 × PV16 × 1.25	PV20	45.5	A	3.4.8.2	
Selected regulator		Brand and model	PV21	REG 30-Deluxe		3.4.8.2	Large arrays may need to be split into sub-arrays. Considerations are— (a) availability of high current regulators; (b) improved fault tolerance; and (c) more staged battery charging.
Regulator current rating		From manufacturer's specifications	PV22	30	A	3.4.8.2	
Number of regulators/sub-arrays required		$\frac{\text{PV20}}{\text{PV22}}$, rounded up	PV23	2			

1 Value for M8 is from Table A4.

TABLE A9

BATTERY CHARGER SIZING AND SELECTION (SEE CLAUSE 3.4.10)

Item	Symbol	Source	Ref.	Value	Units	Refer Clause	Notes
10 h rate capacity of selected cell/block		From manufacturer's specifications	BC1	380	Ah	3.4.10.2	For parallel system; Values BC1 to BC4 may be used as a check against inverter charging capacity.
10 h rate capacity of battery bank	C_{10}	BC1 × B12[1]	BC2	760	Ah	3.4.10.2	
10 h charge rate for battery Bank	I_{10}	$\frac{\text{BC2}}{10}$	BC3	76	A	3.4.10.2	
Recommended max. charging current		From manufacturer's specifications	BC4	100	A		
Selected battery charger		Brand and model	BC5	ABC 75-24		3.4.10.1	For parallel systems, the inverter also performs battery charging.
Selected charger capacity	I_{bc}	From manufacturer's specifications	BC6	75	A		For parallel systems, these cells are determined by the inverter's charging capacity, or that portion of the charging capacity that is used.
Selected charger nominal efficiency	η_{bc}	From manufacturer's specifications	BC7	70%			
Selected charger nominal power factor	pf_{bc}	From manufacturer's specifications	BC8	0.8			
Max. charge voltage at typical max. output current	V_{bc}	Typically 2.4 V per cell × B13[1]	BC9	28.8	V	3.4.7.4 3.4.10.3	
Battery charger max. apparent power	S_{bc}	$\frac{\text{BC6} \times \text{BC9}}{(\text{BC7} \times \text{BC8} \times 1000)}$	BC10	3.9	kVA	3.4.10.3	

1 Values for B12 and B13 are from Table A7.

TABLE A10

GENERATING SET SIZING AND SELECTION (SEE CLAUSE 3.4.11)

Item	Symbol	Source[1]	Ref.	Value	Units	Refer Clause	Notes
Alternator surge ratio		Typically 2.5	G1	250%		3.4.11.3 3.4.11.4	
Generating set oversize factor	f_{go}	Minimum and typical 10%	G2	1.1		3.4.11.2 3.4.11.4	
Maximum ambient temperature during operation		See note	G3	45	°C	3.4.11.5	Maximum ambient temperature should account for temperature rise within the generating set enclosure (if any), as well as climate.
Derating factor for temperature		From manufacturer's specifications	G4	0.5%	per °C above reference	3.4.11.5	Data from Table 4 may be used in the absence of manufacturer's data.
Reference temperature		From manufacturer's specifications	G5	25	°C	3.4.11.5	
Derating for temperature		If G3>G5, then 1-(G3-G5) × G4, otherwise 1	G6	0.9		3.4.11.5	
Max. humidity		From manufacturer's specifications	G7	50%		3.4.11.5	Data from Table 4 may be used in the absence of manufacturer's data.
Derating factor for humidity		From manufacturer's specifications	G8	1.0%	per 10% above reference	3.4.11.5	
Reference humidity		From manufacturer's specifications	G9	60%		3.4.11.5	
Derating for humidity		If G7>G9, then $\{1-\frac{(G7-G9)\times G8}{0.1}\}$, otherwise 1	G10	1		3.4.11.5	For consistency, humidity has been treated as a fraction (see Clause A2.2)
Altitude		Depends on location	G11	500	m	3.4.11.5	
Derating factor for altitude		From manufacturer's specifications	G12	1%	per 100 m above reference	3.4.11.5	Data from Table 4 may be used in the absence of manufacturer's data.
Reference altitude		From manufacturer's specifications	G13	300	m	3.4.11.5	
Derating for altitude		If G11>G13, $1-\frac{(G11-G13)\times G12}{100}$	G14	0.98		3.4.11.5	
Total derating factor for temperature, humidity and altitude		G6 × G10 × G14	G15	0.88		3.4.11.5	

(*continued*)

TABLE A10 *(continued)*

Item	Symbol	Source[1]	Ref	Value	Units	Refer Clause	Notes
Series system:							
Suggested minimum generating set rating	S_{gen}	$\dfrac{\text{BC10} \times \text{G2}}{\text{G15}}$	G16	4.8	kVA	3.4.11.2	
OR							
Switched system:							
Apparent power to run loads while charging		See note	G17	1.8	kVA	3.4.11.3	Equals some portion of maximum demand, depending on load management considerations. In this example, the vacuum cleaner, water pump and television are on (i.e. computer is excluded). See Table A3.
Load surge while charging		See note	G18	6.8	kVA	3.4.11.3	Equals some portion of surge demand, depending on load management considerations. In this example, the vacuum has the highest surge and the water pump and television are taken at running demand (computer is excluded). See Table A3.
Required generating set rating (based on maximum demand calculations)		$\dfrac{(\text{BC10} + \text{G17}) \times \text{G2}}{\text{G15}}$	G19	7.1	kVA	3.4.11.3	
Required generating set rating (based on surge calculations)		$\dfrac{(\text{BC10} + \text{G17}) \times \text{G2}}{\text{G1} \times \text{G15}}$	G20	5.3	kVA	3.4.11.3	
Suggested min generating set rating	S_{gen}	The larger of G19 and G20	G21	7.1	kVA	3.4.11.3	
OR							
Parallel system:	*Parallel system calculations are not considered in this worked example since a different inverter would be required.*						
Minimum generating set rating (based on maximum demand calculations)		$\dfrac{(\text{AC11} - \text{IN9}) \times \text{G2}}{\text{G15} \times 1000}$	G22	N/A	kVA	3.4.11.4	Not applicable as value is negative.
Minimum generating set rating (based on surge calculations)		$\dfrac{(\text{AC12} - \text{IN11}) \times \text{G2}}{\text{G1} \times \text{G15} \times 1000}$	G23	N/A	kVA	3.4.11.4	
Minimum generating set rating (based on battery charging requirements)		$\dfrac{\text{BC10} \times \text{G2}}{\text{G15}}$ + allowance for load	G24	N/A	kVA	3.4.11.4	Not applicable as data in Table A9, cells BC5 to BC10 must have appropriate data from interactive inverter specifications
Suggested min. generating set rating	S_{gen}	The largest of G22, G23 and G24	G25	N/A	kVA	3.4.11.4	

NOTE: Use of cells G16 to G25 is dependent on system configuration (refer cell M10 in Table A4).

(*continued*)

TABLE A10 *(continued)*

Item	Symbol	Source[1]	Ref.	Value	Units	Refer Clause	Notes
Generating set selection							
Selected generating sets		Make and model	G26	XYZ 6.5			There may be a minimum size restriction for generating set in parallel systems. See Clause 3.4.11.4, Note.
Generating set rating		From manufacturer's specifications	G27	6.5	kVA		
Monthly generating set run time (see Clause 3.4.11.6)							
Generating set run time for equalizing charge		$\dfrac{B18 \times 30}{B17}$	G28	6.5	hours per month	3.4.11.6	
Worst month							
Generating set run time required for maintaining full SOC		If $PV17_{worst} < 100\%$, then $\dfrac{(1 - PV17_{worst}) \times PV11_{worst} \times 30}{BC6 \times PV2 \times M8}$, otherwise 0	G29	13	hours per month	3.4.11.6	
Nominal generating set run time	T_{gen}	G29 + G28	G30	19.5	hours per month	3.4.11.6	This is a nominal figure only. Actual operating conditions will affect.
Best month							
Generating set run time required for maintaining full SOC		If $PV17_{best} < 100\%$, then, $\dfrac{(1 - PV17_{best}) \times PV11_{best} \times 30}{BC6 \times PV2 \times M8}$, otherwise 0	G31	0	hours per month	3.4.11.6	
Nominal generating set run time	T_{gen}	G31 + G28	G32	6.5	hours per month	3.4.11.6	This is a nominal figure only. Actual operating conditions will affect.

1 Values for AC11 and AC12 are from Table A3. Values for M8 is from Table A4. Values for IN9 and IN11 are from Table A6. Values for B17 and B18 are from Table A7. Values for PV2, $PV11_{best}$, $PV11_{worst}$, $PV17_{best}$ and $PV17_{worst}$ are from Table A8. Values for BC6 and BC10 are from Table A9.

TABLE A11

BATTERY VENTILATION (FROM AS 4086.2)

Item	Symbol	Source[1]	Ref	Value	Units	Notes
Maximum charge rate of battery (from all sources)		BC6 + PV7 × PV16	V1	108.6	A	
Minimum exhaust ventilation rate		0.003 × V1 × M8	V2	78.2	L/s	
Minimum vent area for natural ventilation		100 × V2	V3	782	cm^2	

1 Value for M8 is from Table A4. Value for BC6 is from Table A9. Values for PV7 and PV16 are from Table A8.

APPENDIX B
BLANK WORKSHEETS FOR PV SYSTEM SIZING

(Informative)

Tables B1 to B11 are non-copyright and may be reproduced.

TABLE B1

TYPICAL ENERGY SERVICES AND ENERGY SOURCE SELECTION

Energy service	Energy source	Comments
Water heating		
Space heating		
Space cooling		
Refrigeration		
Lighting		
Cooking		
Cleaning, entertainment, kitchen appliances, office equipment		
Power tools		
Water pumping		
Water and waste treatment		

NOTE: Refer to Clause 2.3 for selection principles.

TABLE B2

D.C. LOADS

(1)	(2)	(3)	(4a)	(5a)	(4b)	(5b)	(6)	Comments
			Winter or dry season		Summer or wet season		Contribution to maximum demand	
Appliance	Number	Power	Usage time	Energy	Usage time	Energy		
		W	h	Wh	h	Wh	W	
Daily load energy: d.c. loads (Wh)			(DC7a) →		(DC7b) →			
Maximum d.c. demand (W)						(DC8) →		

NOTES:

1 Columns (1) to (4a,b) contain data obtained from the user or field survey. Where practicable, power consumption data should be from actual measurements.

2 Columns (5a,b) = Column (2) × Column (3) × Columns (4a,b).

3 Column (6) = n × Column (3) if these items contribute to the maximum demand scenario,
where
n = the number of items specified in Column (2) which actually contribute to the maximum demand.

4 Cell (DC7a,b) = Sum of Columns (5a,b), as appropriate.

5 Cell (DC8) = Sum of Column (6).

6 In cases where large loads are known to occur during certain months (e.g. during harvesting), this worst case load situation should be considered explicitly.

TABLE B3

A.C. LOADS

(1)	(2)	(3)	(4a)	(5a)	(4b)	(5b)	(6)	(7)	(8)	(9a)	(9b)	
Appliance	**No.**	**Power**	**Winter or dry season**		**Summer or wet season**		**p.f.**	**Contribution to max. demand**	**Surge factor**	**Contribution to surge demand**		**Comments**
			Usage time	**Energy**	**Usage time**	**Energy**				**(potential)**	**(design)**	
		W	**h**	**Wh**	**h**	**Wh**		**VA**		**VA**		
Daily Load Energy: a.c Loads (Wh)			(AC10a)		(AC10b)							
½ hour maximum demand (VA)							(AC11)					
Surge demand (VA)										(AC12) →		

NOTES TO TABLE B3:

1 Columns (1) to (4a), (4b) and (6) contain data obtained from the user or field survey.

2 Columns (5a,b) = Column (2) × Column (3) × Columns (4a,b).

3 Column (7) = $\frac{n \times \text{Column (3)}}{\text{Column (6)}}$ if the item contributes to the maximum demand,

where

n = the number of items specified in Column (2) which actually contribute to the maximum demand.

4 Column (8) is the ratio of apparent power during start-up surge to that when running, and depends on the type of load. As a guide, use 1 for resistive loads, 3 for universal motors (hand-held tools and most kitchen appliances), and 7 for induction motors.

5 Column (9a) = Column (7) × Column (8).

6 Column (9b) = Column (9a) if the item's surge contributes to the surge demand (usually the item with largest surge), or Column (7) if the item's running power contributes to surge demand.

7 Cells (AC10a,b) = Sum of Columns (5a,b).

8 Cell (AC11) = Sum of Column (7).

9 Cell (AC12) = Sum of Column (9b).

10 Values in Columns 7 and 8 may need consideration of load diversity.

11 In cases where large loads are known to occur during certain months (e.g. harvesting), this worst case load situation should be considered explicitly.

TABLE B4

MISCELLANEOUS SYSTEM DESIGN INFORMATION

Item	Symbol	Source[1]	Ref.	Value	Units	Refer Clause	Notes
Summer months			M1				
Winter months			M2				
Average inverter efficiency	η_{inv}	Manufacturer's data	M3			3.1.4.1	
Design load energy - winter	E_{tot}	$\frac{\text{AC10a}}{\text{M3}} + \text{DC7a}$	M4		Wh	3.1.1 3.1.4.1	
Design load energy - summer	E_{tot}	$\frac{\text{AC10b}}{\text{M3}} + \text{DC7b}$	M5		Wh	3.1.1 3.1.4.1	
Design tilt angle		Design decision	M6			3.4.3.3	
Maximum demand at d.c. bus (approximately)		$\frac{\text{AC11} \times 0.8}{\text{M3}} + \text{DC8}$	M7		W	3.1.4	
Nominal system voltage	V_{dc}	Design decision	M8		V	1.3.36 3.4.1	
Approximate d.c. current at maximum demand		$\frac{\text{M7}}{\text{M8}}$	M9		A	3.4.1	
System configuration		Design decision	M10			3.3.1 3.3.3	

1 Values for AC10a, AC10b and AC11 are from Table B3.
Values for DC7a, DC7b and DC8 are from Table B2.

TABLE B5

SELECTION OF DESIGN MONTHS

Solar radiation data source:

Measurement location:

Ref.	Item (units)	Source	Value												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
DM1	Irradiation on tilted plane (kWh/m^2 or PSH)	From resource data and M6													
DM2	Load (kWh/d)	From M1, M2, M4 and M5[1]													
DM3	Ratio $\frac{\text{Resource}}{\text{Load}}$	$\frac{\text{DM1}}{\text{DM2}}$													
DM4	Worst and best months	Select after inspecting DM3[2]													

1 Values for M1, M2, M4 and M5 are from Table B4

2 Refer Clause 3.4.2.6.

TABLE B6

INVERTER SIZING AND SELECTION (SEE CLAUSE 3.4.9)

Item	Symbol	Source	Ref.	Value	Units	Refer Clause	Notes
Inverter ½ hour maximum demand	$S_{\text{inv,30min}}$	AC11[1]	IN1		VA	1.3.32 3.1.4.2	
Inverter surge demand	$S_{\text{inv,sur}}$	AC12[1]	IN2		VA	1.3.59 3.1.4.3	
Safety factor		Design decision	IN3			3.1.6 3.4.9.1	
Suggested inverter ½ hour maximum rating		(1+IN3) × IN1	IN4		VA	3.4.9.1 1.3.36	
Suggested inverter surge rating		(1+IN3) × IN2	IN5		VA	3.4.9.1 1.3.59	
Waveform quality required		Design decision	IN6			2.2 3.4.9.1	Depends on the customer's requirements
Inverter type		Design decision, also depends on M10[2]	IN7			3.3.3 3.4.9	Depends on system configuration
Selected inverter		Brand and model	IN8			3.4.9.1	
Selected inverter ½hour max. rating		From manufacturer's specifications	IN9		VA	3.4.9.1	
Selected inverter continuous rating		From manufacturer's specifications	IN10		VA	3.4.9.1	
Selected inverter surge rating		From manufacturer's specifications	IN11		VA	3.4.9.1	

1 Values for AC11 and AC12 are from Table B3.

2 Value for M10 is from Table B4.

TABLE B7

BATTERY SIZING AND SELECTION (SEE CLAUSE 3.4.7)

Item	Symbol	Source	Ref.	Value	Units	Refer Clause	Notes
Design load energy for battery sizing		The larger of M4[1] or M5[1]	B1		Wh	3.4.7.3	Load energy for season with highest load.
Design load Ah for battery sizing		$\frac{\text{B1}^{1}}{\text{M8}}$	B2		Ah		
Target number of days of autonomy	T_{aut}	Design decision	B3		Days	1.3.2 3.4.7.2 3.4.7.6-9	
Maximum DOD	DOD_{max}	Design decision	B4			1.3.13 3.4.7.2	
Nominal battery discharge rate	C_{100}	Design decision	B5		h rate	3.4.7.2	
Minimum mean daily temperature		From climatic data	B6		°C	3.4.7.10	Coldest month may not necessarily be design month.
Temperature correction factor		From graph or table	B7			3.4.7.10	
Required battery capacity		$\frac{\text{B2} \times \text{B3}}{\text{B4} \times \text{B7}}$	B8		Ah	3.4.7.3	
Selected cell/block		Brand and model	B9			3.4.7.1	
Selected cell/block capacity at nominal discharge rate		From manufacturer's specifications	B10		Ah	3.4.7.2	
Selected cell/block voltage		From manufacturer's specifications	B11		V		
Number of strings in parallel		$\frac{\text{B8}}{\text{B10}}$ rounded off	B12			3.4.7.1	The number of parallel battery strings should be minimized.
Number of cells/blocks in series		$\frac{\text{M8}}{\text{B11}}$	B13				
Capacity of battery bank at nominal discharge rate	C_{100}	B10 × B12	B14		Ah		
Days of autonomy for selected battery		$\frac{\text{B4} \times \text{B14} \times \text{B7}}{\text{B2}}$	B15		days		
Nominal daily DOD	DOD_{d}	$\frac{\text{B2}}{\text{B14}}$	B16			3.4.7.5	
Design equalization period	T_{eq}	Design decision	B17		days	3.4.11.6	This is the time between equalization charges when using a generating sets.
Equalization run-on time	$T_{\text{eq,run}}$	Design decision	B18		h	3.4.11.6	This is the time required to provide an equalizing charge from the generating sets.

NOTES:

1 Values for M4, M5 and M8 are from Table B4

2 These calculations assume that the battery size is not limited by power output capability (refer Clause 3.4.7.2).

TABLE B8-1

PHOTOVOLTAIC ARRAY AND REGULATOR SIZING AND SELECTION (PART 1)

Item	Symbol	Source	Ref.	Value	Units	Refer Clause	Notes
Oversupply co-efficient	f_o	Design decision	PV1			3.4.2.5	Equals 1 if the system includes a generating sets
Nominal battery efficiency (coulombic)	η_{coul}	From manufacturer's specifications	PV2			1.3.8 3.4.2.2	Approximately 90% to 95% is typical for lead acid batteries. This depends strongly on the charging regime used.
Selected module		Brand and model	PV3				
Nominal module power	P_{stc}	From manufacturer's specifications	PV4		W		
Nominal module voltage		From manufacturer's specifications	PV5		V		
Module short-circuit current	I_{sc}	From manufacturer's specifications	PV6		A		
Module current at 14 V at operating temp.	$I_{T,V}$	From manufacturer's specifications	PV7		A	3.4.3.8	In areas where module operating temperatures significantly exceed NOCT, manufacturer's data should be consulted to determine the current in such conditions. Module current can be significantly diminished by high temperatures due to changes in the IV curve.
Manufacturer's tolerance on current output		From manufacturer's specifications	PV8			3.4.3.6	
Derating factor for soiling	f_{dirt}	Design decision	PV9			3.4.3.6	Depends on site conditions

NOTE: This work-sheet assumes the use of standard (switched) regulators only, not maximum power point tracking regulators.

TABLE B8-2

PHOTOVOLTAIC ARRAY AND REGULATOR SIZING AND SELECTION (PART 2)

Item	Symbol	Source[1]	Ref.	Worst month	Best month	Annual Average	Units	Refer Clause	Notes
Irradiation on tilted plane	H_{tilt}	From DM1	PV10				h	3.2.2	
Design load energy for array sizing		From DM2	PV11				Wh		
Design load Ah		$\frac{PV11}{M8}$	PV12				Ah		
Required array output		$\frac{PV12}{PV2}$	PV13				Ah		
Daily charge (Ah) output per module		(1-PV8) × PV7 × PV9 × PV10	PV14				Ah	3.4.3.8	
Number of parallel strings required		$\frac{PV13 \times PV1}{PV14}$	PV15					3.4.3.10	
Number of parallel strings used	N_p	Design decision, based on PV15 data	PV16					3.4.3.10 3.1.6	
Nominal solar fraction for design month	f_{sol}	$\frac{PV16}{PV15}$	PV17					1.3.46 3.4.6	Solar fractions of approximately 90% or above, should be treated with some caution.

1 Values for DM1 and DM2 are from Table B5. Value for M8 is from Table B4.

TABLE B8-3

PHOTOVOLTAIC ARRAY AND REGULATOR SIZING AND SELECTION (PART 3)

Item	Symbol	Source[1]	Ref.	Value	Units	Refer Clause	Notes
Number of series modules per string	N_s	$\frac{M8}{PV5}$	PV18				
Total number of modules in array	N	PV16 × PV18	PV19				
Regulator current rating required		PV6 × PV16 × 1.25	PV20		A	3.4.8.2	
Selected regulator		Brand and model	PV21			3.4.8.2	Large arrays may need to be split into sub-arrays. Considerations are: (a) availability of high current regulators; (b) improved fault tolerance; and (c) more staged battery charging.
Regulator current rating		From manufacturer's specifications	PV22		A	3.4.8.2	
Number of regulators/sub-arrays required		$\frac{PV20}{PV22}$, rounded up	PV23				

1 Value for M8 is from Table B4.

TABLE B9

BATTERY CHARGER SIZING AND SELECTION (SEE CLAUSE 3.4.10)

Item	Symbol	Source	Ref.	Value	Units	Refer Clause	Notes
10 h rate capacity of selected cell/block		From manufacturer's specifications	BC1		Ah	3.4.10.2	For parallel system; Values BC1 to BC4 may be used as a check against inverter charging capacity.
10 h rate capacity of battery bank	C_{10}	BC1 × B12[1]	BC2		Ah	3.4.10.2	
10 h charge rate for battery Bank	I_{10}	$\frac{\text{BC2}}{10}$	BC3		A	3.4.10.2	
Recommended max. charging current		From manufacturer's specifications	BC4		A		
Selected battery charger		Brand and model	BC5			3.4.10.1	For parallel systems, the inverter also performs battery charging.
Selected charger capacity	I_{bc}	From manufacturer's specifications	BC6		A		For parallel systems, these cells are determined by the inverter's charging capacity, or that portion of the charging capacity that is used.
Selected charger nominal efficiency	η_{bc}	From manufacturer's specifications	BC7				
Selected charger nominal power factor	pf_{bc}	From manufacturer's specifications	BC8				
Max. charge voltage at typical max. output current	V_{bc}	Typically 2.4 V per cell × B13[1]	BC9		V	3.4.7.4 3.4.10.3	
Battery charger max. apparent power	S_{bc}	$\frac{\text{BC6} \times \text{BC9}}{(\text{BC7} \times \text{BC8} \times 1000)}$	BC10		kVA	3.4.10.3	

1 Values for B12 and B13 are from Table B7.

TABLE B10

GENERATING SET SIZING AND SELECTION (SEE CLAUSE 3.4.11)

Item	Symbol	Source[1]	Ref.	Value	Units	Refer Clause	Notes
Alternator surge ratio		Typically 2.5	G1			3.4.11.3 3.4.11.4	
Generating set oversize factor	f_{go}	Minimum and typical 10%	G2			3.4.11.2 3.4.11.4	
Maximum ambient temperature during operation		See note	G3		°C	3.4.11.5	Maximum ambient temperature should account for temperature rise within the generating set enclosure (if any), as well as climate.
Derating factor for temperature		From manufacturer's specifications	G4		per °C above reference	3.4.11.5	
Reference temperature		From manufacturer's specifications	G5		°C	3.4.11.5	
Derating for temperature		If G3>G5, then 1-(G3-G5) × G4, otherwise 1	G6			3.4.11.5	
Max. humidity		From manufacturer's specifications	G7			3.4.11.5	
Derating factor for humidity		From manufacturer's specifications	G8		per 10% above reference	3.4.11.5	
Reference humidity		From manufacturer's specifications	G9			3.4.11.5	
Derating for humidity		If G7>G9, then $\{1-\frac{(G7-G9)\times G8}{0.1}\}$, otherwise 1	G10			3.4.11.5	For consistency, humidity should be treated as a fraction (see Clause A2.2)
Altitude		Depends on location	G11		m	3.4.11.5	
Derating factor for altitude		From manufacturer's specifications	G12		per 100 m above reference	3.4.11.5	
Reference altitude		From manufacturer's specifications	G13		m	3.4.11.5	

(*continued*)

TABLE B10 (*continued*)

Item	Symbol	Source[1]	Ref.	Value	Units	Refer Clause	Notes
Derating for altitude		If G11>G13, $1-\frac{(G11-G13)\times G12}{100}$	G14			3.4.11.5	
Total derating factor for temperature, humidity and altitude		G6 × G10 × G14	G15			3.4.11.5	
Series system:							
Suggested minimum generating set rating	S_{gen}	$\frac{\text{BC10}\times\text{G2}}{\text{G15}}$	G16		kVA	3.4.11.2	
OR							
Switched system:							
Apparent power to run loads while charging			G17		kVA	3.4.11.3	
Load surge while charging			G18		kVA	3.4.11.3	
Required generating set rating (based on maximum demand calculations)		$\frac{(\text{BC10}+\text{G17})\times\text{G2}}{\text{G15}}$	G19		kVA	3.4.11.3	
Required generating set rating (based on surge calculations)		$\frac{(\text{BC10}+\text{G18})\times\text{G2}}{\text{G1}\times\text{G15}}$	G20		kVA	3.4.11.3	
Suggested min generating set rating	S_{gen}	The larger of G19 and G20	G21		kVA	3.4.11.3	
OR							
Parallel system:							
Minimum generating set rating (based on maximum demand calculations)		$\frac{(\text{AC11}-\text{IN9})\times\text{G2}}{\text{G15}\times 1000}$	G22		kVA	3.4.11.4	
Minimum generating set rating (based on surge calculations)		$\frac{(\text{AC12}-\text{IN11})\times\text{G2}}{\text{G1}\times\text{G15}\times 1000}$	G23		kVA	3.4.11.4	
Minimum generating set rating (based on battery charging requirements)		$\frac{\text{BC10}\times\text{G2}}{\text{G15}}$ + allowance for load	G24		kVA	3.4.11.4	
Suggested min generating set rating	S_{gen}	The largest of G22, G23 and G24	G25		kVA	3.4.11.4	

(*continued*)

TABLE B10 (*continued*)

Item	Symbol	Source[1]	Ref.	Value	Units	Refer Clause	Notes
Generating set selection							
Selected generating sets		Make and model	G26				There may be a minimum size restriction for generating set in parallel systems. See Clause 3.4.11.4, Note
Generating set rating		From manufacturer's specifications	G27		kVA		
Monthly generating set run time (see Clause 3.4.11.6)							
Generating set run time for equalizing charge		$\frac{B18 \times 30}{B17}$	G28		hours per month	3.4.11.6	
Worst month							
Generating set run time required for maintaining full SOC		If $PV17_{worst} < 100\%$, then $\frac{(1 - PV17_{worst}) \times PV11_{worst} \times 30}{BC6 \times PV2 \times M8}$, otherwise 0	G29		hours per month	3.4.11.6	
Nominal generating set run time	T_{gen}	G29+G28	G30		hours per month	3.4.11.6	
Best month							
Generating set run time required for maintaining full SOC		If $PV17_{best} < 100\%$, then, $\frac{(1 - PV17_{best}) \times PV11_{best} \times 30}{BC6 \times PV2 \times M8}$, otherwise 0	G31		hours per month	3.4.11.6	
Nominal generating set run time	T_{gen}	G31 + G28	G32		hours per month	3.4.11.6	

NOTES:

1 Use of cells G16 to G25 is dependent on system configuration (refer cell M10 in Table B4).

2 Values for AC11 and AC12 are from Table B3. Values for M8 is from Table B4. Values for IN9 and IN11 are from Table B6. Values for B17 and B18 are from Table B7.

3 Values for PV2, $PV11_{best}$, $PV11_{worst}$, $PV17_{best}$ and $PV17_{worst}$ are from Table B8. Values for BC6 and BC10 are from Table B9.

TABLE B11

BATTERY VENTILATION (FROM AS 4086.2)

Item	Symbol	Source[1]	Ref.	Value	Units	Notes
Maximum charge rate of battery (from all sources)		BC6 + PV7 × PV16	V1		A	
Minimum exhaust ventilation rate		0.003 × V1 × M8	V2		L/s	
Minimum vent area for natural ventilation		100 × V2	V3		cm^2	

1 Value for M11 is from Table B4. Value for BC6 is from Table B9. Values for PV7 and PV16 are from Table B8.

APPENDIX C

CALCULATION OF CABLE SIZE REQUIRED

(Informative)

C1 CABLE CURRENT-CARRYING CAPACITY

Table C1 shows the current-carrying capacities and voltage drop of single core (25 mm^2 to 70 mm^2) and twin core copper conductors (assuming 100 % duty cycle).

TABLE C1.1

TYPICAL COPPER CABLE CHARACTERISTICS (AUSTRALIA ONLY)

Conductor size Copper mm^2	Current-carrying capacity LV or ELV single phase a.c. or d.c.with C MCB or 'gG' HRC fuse protection							Single phase voltage drop mV/Am
	Unenclosed			Partly surrounded by thermal insulation unenclosed	Completely surrounded by thermal insulation unenclosed	Direct buried under-ground	In enclosure under-ground	
	Space from surface	Touching surface	Exposed to sun					
Stranded twin cables CU (data from AS/NZS 3008.1.1; Table 10 for current and Table 42 for voltage drop in mV/Am corrected to single phase values)								
1	15	14	11	11	7	17	17	51.63
1.5	19	18	14	14	9	21	21	33.03
2.5	27	26	20	20	13	30	30	18.94
4	37	34	27	27	17	39	39	11.78
6	46	44	34	35	22	50	50	7.5
10	64	60	464	48	30	66	66	4.46
16	85	80	60	64	40	114	86	2.81
Two stranded single cores CU (data from AS/NZS 3008.1.1; Table 4 for current and Table 42 for voltage drop in mV/Am corrected to single phase values)								
25	110	97	50	75	48	158	116	1.78
35	145	119	61	90	59	190	139	1.26
50	177	146	72	110	—	225	168	0.96
70	223	184	89	136	—	277	206	0.67

NOTES:

1 Single cables touching for whole length of cable route.

2 Ambient temperature 40°C, soil temperature 25°C.

3 For cable sizes not shown see AS/NZS 3008.1.1.

4 Maximum conductor temperature 75°C.

TABLE C1.2

TYPICAL COPPER CABLE CHARACTERISTICS (NEW ZEALAND ONLY)

Conductor size Copper mm²	Current-carrying capacity LV or ELV single phase a.c. or d.c. with C MCB or 'gG' HRC fuse protection							Single phase voltage drop mV/Am
	Unenclosed			Partly surrounded by thermal insulation unenclosed	Completely surrounded by thermal insulation unenclosed	Direct buried under-ground	In enclosure under-ground	
	Space from surface	Touching surface	Exposed to sun					
Stranded twin cables C_U (data from AS/NZS 3008.1.2; Table 10 for current and Table 42 for voltage drop in mV/Am corrected to single phase values)								
1	17	16	13	13	8	19	19	51.63
1.5	22	21	16	16	10	23	23	33.03
2.5	31	30	23	23	15	33	33	18.02
4	42	39	31	31	19	43	43	11.22
6	52	50	39	40	25	55	55	7.5
10	73	68	52	55	34	73	73	4.46
16	97	91	68	73	46	125	95	2.81
Two stranded single cores C_U (data from AS/NZS 3008.1.1; Table 4 for current and Table 42 for voltage drop in mV/Am corrected to single phase values)								
25	136	111	57	86	55	174	128	1.78
35	165	136	70	103	67	209	153	1.26
50	202	166	82	125	—	248	185	0.96
70	254	210	101	155	—	305	227	0.67

NOTES:

1 Single cables touching for whole length of cable route.

2 Ambient temperature 30°C,Soil temperature 15°C.

3 For cable sizes not shown see AS/NZS 3008.1.2.

4 Maximum conductor temperature 75°C.

C2 CALCULATION OF VOLTAGE DROP

Voltage drops in cables can be calculated as follows:

(a) Define mains and sub-circuits and measure/estimate the route length of each circuit (including vertical and switch runs).

(b) Determine the maximum current requirements for each circuit (maximum demand).

(c) Allocate the maximum permissible voltage drop to each circuit section.

(d) Apply information from (a), (b) and (c) in the following voltage drop equation:

$$V_c = \frac{1000 \times V_d}{I_{max} \times L} \qquad \text{. . . C2(1)}$$

or

$$V_c = \frac{1000 \times V_{nom} \times V_{\%}}{I_{max} \times L} \qquad \text{. . . C2(2)}$$

where

V_c = cable voltage drop, in mV/Am

V_d = allowed voltage drop, in volts (V)

L = route length, in metres (one way) (m)

I_{max} = maximum current loading, in amperes (A)

V_{nom} = nominal system voltage, in volts (V)

$V_{\%}$ = percentage voltage drop

(e) Look in Table C1 to find the cable that meets the calculated mV/Am requirement. Check that maximum demand is less than the current-carrying capacity of the selected cable, in its particular environment.

(f) Repeat (d) and (e) for all mains and sub-circuit sections.

WARNING—AUTO TYPE CABLE IS OFTEN RATED AT 32 V d.c.

Where the nominal system voltage is greater than 24 V, use cable with a suitable voltage rating.

C3 BATTERY CABLE SIZING

For more information see AS 4086.2.

Battery cabling should be kept as short as possible to reduce voltage drop at high currents.

The cable should be sized in accordance with Paragraph C2, but the limiting factor of the cable size will normally be the current carrying capacity rather than the voltage drop. The current loading for the battery cabling is the sum of the maximum d.c. demand plus the inverter continuous d.c. demand.

The current carrying capacity of the selected cable should not be less than—

(a) the rating of the main battery protection selected; and

(b) the sum of the inverter main and d.c. main protection, where these are separate circuits.

The cable should withstand, for at least 1 s, the prospective short-circuit current that the battery is capable of delivering. Where information regarding the short-circuit protection of a battery is not available from the manufacturer, the prospective fault current at the battery terminals should be considered numerically equal to 6 times the C_{120} capacity.

C4 WORKED EXAMPLE OF CABLE SIZING

C4.1 Cable loss

Allowable loss has been arbitrarily set for each circuit section. Total is not greater than 5%. (See Figure C1).

In this case the d.c. power outlets are rated at 10 A, i.e. 24 V × 10 A = 240 W giving a maximum demand for sub-circuit P1 of 20 A (480 W).

NOTE: Outlets should be labelled with rated voltage and power (or current), e.g. '24 V 240 W max'.

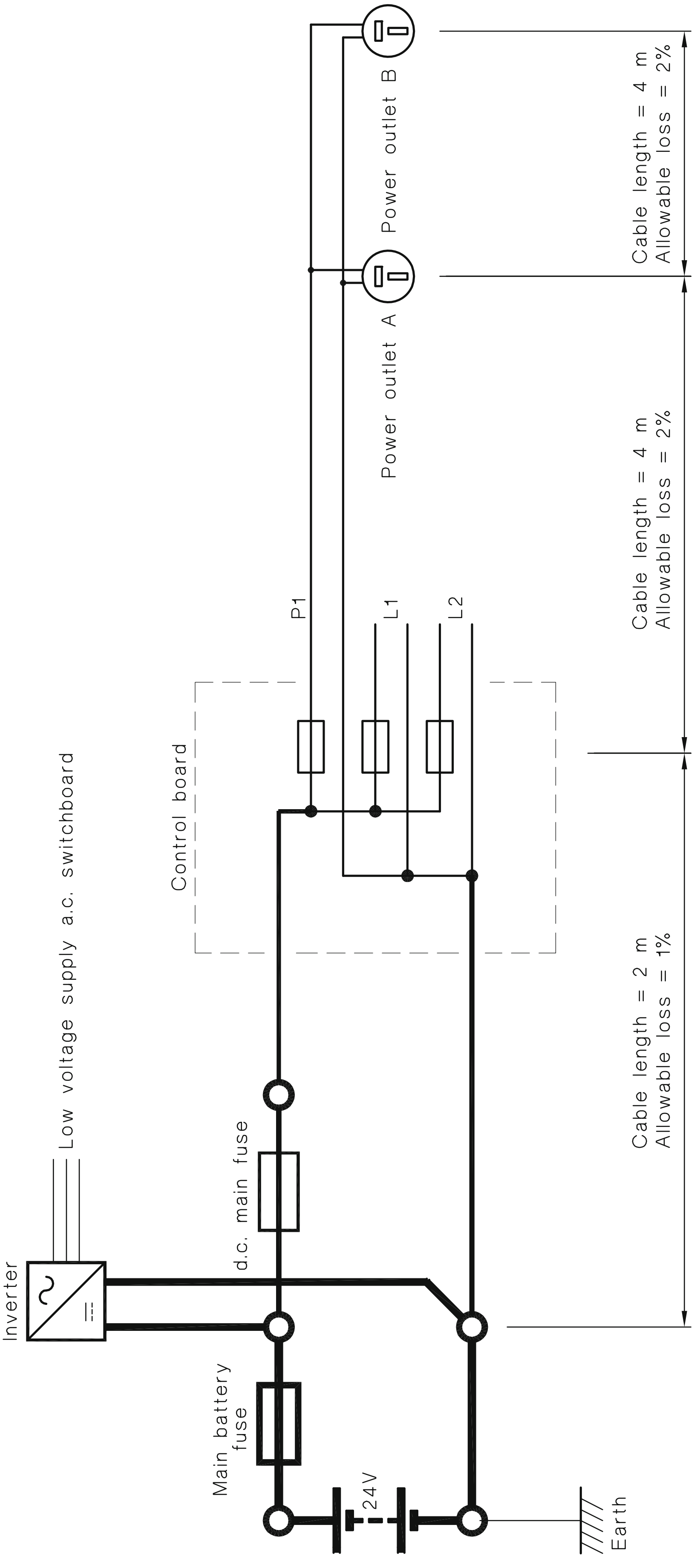


FIGURE C1 ELV CABLE SIZING EXAMPLE

C4.2 Cable size

The cable size can be calculated as follows:

(a) Control board to power outlet A:

Voltage drop (mV/Am) $= \dfrac{1000 \times V_{\text{nom}} \times V_{\%}}{I_{\max} \times L}$ (from C2(2))

$= \dfrac{1000 \times 24\text{ V} \times 2}{20\text{ A} \times 4\text{ m} \times 100}$

$= \dfrac{480}{80}$

$= 6.0$ mV/Am

Using Table C1.1 the smallest suitable cable size is 10 mm^2 at 4.6 mV/Am giving a loss (control board to power outlet A) of 0.36 V (1.5%).

(b) Power outlet A to power outlet B

Voltage drop (mV/Am) $= \dfrac{1000 \times V_{\text{nom}} \times V_{\%}}{I_{\max} \times L}$ (from C2(2))

$= \dfrac{1000 \times 24\text{ V} \times 2}{10\text{ A} \times 4\text{ m} \times 100}$

$= \dfrac{480}{40}$

$= 12.0$ mV/Am

Using Table C1 the smallest suitable cable size is 4 mm^2 at 11.78 mV/Am giving a loss (power outlet A to power outlet B) of 0.47 V (1.96%).

Sub-circuit P1 loss = control board to outlet A loss + outlet A to outlet B loss

= 0.36 V + 0.47 V

= 0.83 V (3.46%)

Cable sizes are calculated for all other sub-circuits in a similar manner.

(c) D.C. main fusing to control board:

The total maximum demand is the sum of maximum demand of all sub-circuits.

If, for example, the maximum demand for sub-circuit L1 and L2 is 10 A and 5 A respectively:

Voltage drop (mV/Am) $= \dfrac{1000 \times V_{\text{nom}} \times V_{\%}}{I_{\max} \times L}$ (from C2(2))

$= \dfrac{1000 \times 24\text{ V} \times 1}{(20 + 10 + 5\text{ A}) \times 2\text{ m} \times 100}$

$= \dfrac{240}{70}$

$= 3.43$ mV/Am

Using Table C1 the smallest suitable cable size is 16 mm^2 at 2.81 mV/Am giving a loss (d.c. main fusing to control board) of 0.197 V (0.82%).

C5 CABLE SIZE OPTIMIZATION

C5.1 General

After the initial cable sizing calculations are performed it may become obvious that a reorganization of the sub-circuits or additional sub-circuits will optimize the cost and/or rationalize the cable sizes used. This will require re-calculation of cable sizing for the wiring system.

C5.2 Rationalization of cable size

If, for example, the allowable loss from the control board to power outlet A is increased to 2.5% and power outlet A to power outlet B is reduced to 1.5% leaving the total sub-circuit loss estimate unchanged at 4%.

Cable size control board to power outlet A .... 6 mm^2 at 0.60 V 2.50%

power outlet A to power outlet B .... 6 mm^2 at 0.30 V 1.25%

This rationalizes and reduces the cable size to 6 mm^2, but results in the total sub-circuit loss increasing from 3.46% to 3.75%.

C5.3 Minimization of cable losses

If, in the above example, 10 mm^2 cable is used in both runs, then the losses in the above example become—

control board to power outlet A................ 10 mm^2 at 0.36 V 1.50%

power outlet A to power outlet B .... 10 mm^2 at 0.18 V 0.75%

This rationalizes the cable size to 10 mm^2, and results in the total sub-circuit loss decreasing from 3.46% to 2.25%.

With experience, an optimal estimate of sub-circuit allocation and allowable loss estimate for each sub-circuit section will normally be achieved in the first pass.

APPENDIX D
CIRCUIT PROTECTION SIZING
(Informative)

D1 MAIN BATTERY PROTECTION

The main battery protection is generally sized to cope with the requirements of a connected inverter. The inverter specifications should be obtained from the manufacturer. The ratings required are as follows:

(a) Continuous power rating.

(b) Maximum power rating over a short period, e.g. for 30 minutes.

(c) Maximum surge power rating, e.g. for 10 s.

(d) Inverter efficiency at full load.

The required battery current (I_b) is then calculated for each of Items (a) to (d), as follows:

$$I_b = \frac{\text{inverter power rating}\,(W)}{\text{inverter efficiency} \times \text{nominal battery voltage}} \qquad \text{. . . D1}$$

Where inverter power ratings are given in volt amperes for the worst case situation consider this numerically the same as watts.

The appropriate time/current characteristic graph is then used to determine the rating of the main battery protection (see Paragraph D4).

NOTES:

1 Where an inverter is not used, the main battery protection is sized for the d.c. maximum demand. In this case, separate d.c. mains protection is not required.

2 Where the d.c. maximum demand is a significant percentage of the inverter continuous power, then the rating of the main battery protection should be increased.

3 AS/NZS 3000 requires that the protection size is never to exceed the current carrying capacity of the battery cabling or inverter cabling.

D2 D.C. MAIN PROTECTION

The d.c. main protection is normally sized for the d.c. maximum demand current, but must never exceed the current carrying capacity of the d.c. main cabling (see Paragraph D4).

D3 D.C. SUB-CIRCUIT PROTECTION

The d.c. sub-circuit protection is normally sized for the maximum demand current of the connected sub-circuit, but must never exceed the current carrying capacity of any section of the sub-circuit cabling (see Paragraph D4).

In most cases, the maximum demand will not be equal to the standard range of fuses or circuit-breakers. The next largest size in the range should be selected while ensuring that the size selected does not exceed the current carrying capacity of the smallest cable used in the sub-circuit.

D4 CIRCUIT PROTECTION SIZING EXAMPLE

An example of circuit protection sizing is shown in Figure D1.

An example of circuit protection sizing calculation is given below.

Example:

(a) Sub-circuit protection:

Sub-circuit P1 maximum demand is 20 A. The protection rating is 20 A.

Sub-circuit L1 maximum demand is 10 A. The protection rating is 10 A.

Sub-circuit L2 maximum demand is 5 A. The protection rating is 6 A.

(b) d.c. main protection:

The total maximum demand is 35 A. The protection rating is 35 A.

(c) Main battery protection:

The inverter ratings are as follows:

(i) Continuous power rating .... 1500 W

(ii) 30 min power rating .... 2500 W

(iii) 10 s surge power rating .... 5000 W

(iv) Inverter efficiency at full load 0.85

Equation D1 gives protection requirements for the following battery currents—

(A) 73.5 A continuous;

(B) 122.5 A for 30 minutes; and

(C) 245.1 A for 10 s

An examination of the time-current characteristics of a typical HRC fuse could show an 80 A fuse will satisfy the continuous rating but not the 30 minutes or 10 s ratings, so a 100 A rated fuse should be selected.

As the d.c. maximum demand is 35 A, the likelihood of the occurrence of a large d.c. load requirement at the same time as a large inverter requirement should be considered. In this case, as the main fuse rating has been increased to cater for inverter surge loads, giving a margin of 26.5 A (continuous rating), a 30 minutes rating of greater than 150 A and a 10 s surge rating of approximately 350 A. The main fuse size should not need to be increased further.

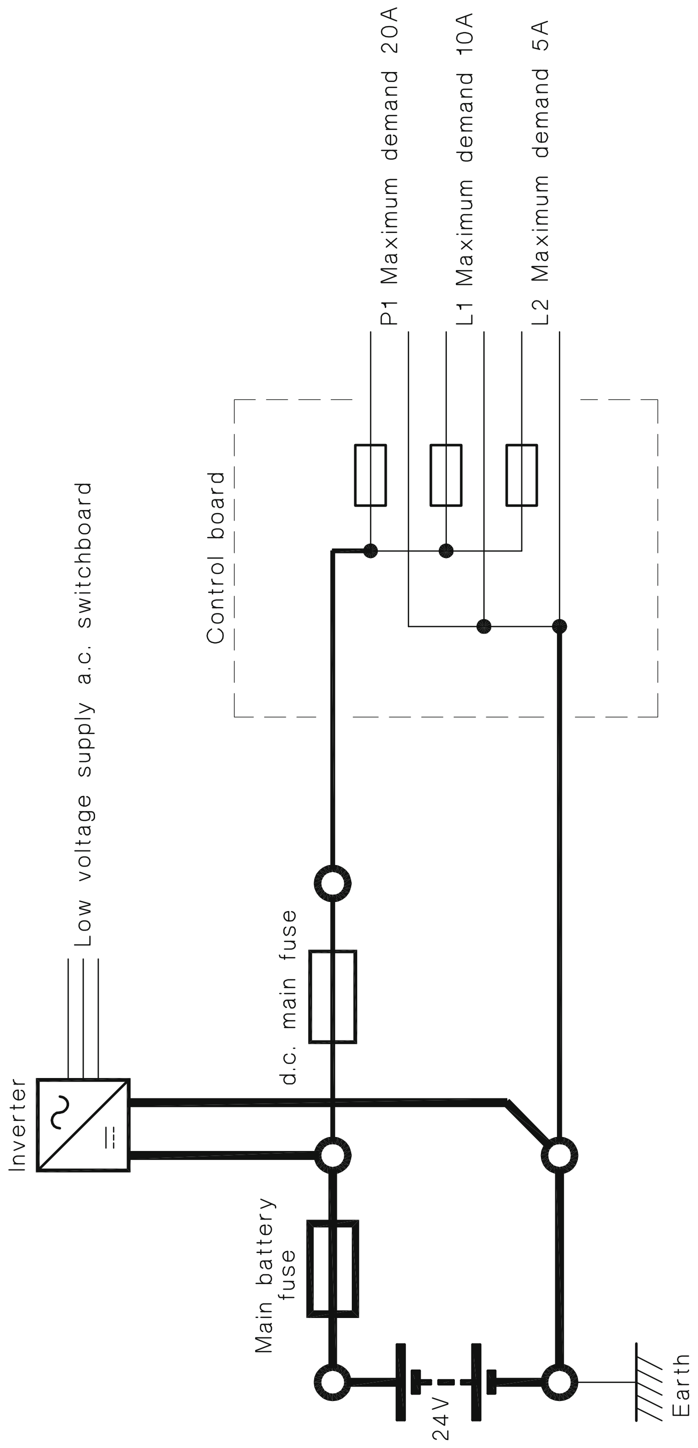


FIGURE D1 CIRCUIT PROTECTION SIZING EXAMPLE

APPENDIX E

LIGHTNING PROTECTION

(Informative)

E1 RISK ASSESSMENT

Where it is desired to minimize all avoidable risk, a lightning protection system should be installed. Given the value of equipment and potential for personal injury with stand-alone power systems, a lightning risk assessment should be made.

E2 RISK INDEX

The risk index, R, is obtained as follows:

$$R = A + B + C + D + E \qquad \text{. . . E2}$$

where

A = ‘type of structure’ index and, for the purposes of this Appendix, ‘A’ will normally have a value of 2

B = ‘construction’ index

C = ‘height’ index

D = ‘situation’ index

E = ‘lightning prevalence’ index

The index values A to E are obtained from Tables E1 to E5 and Figure E1.

After obtaining the risk index, the risk assessment and need for protection can be obtained from Table E6.

E3 PROTECTION REQUIRED

E3.1 General

For most stand-alone power systems, lightning risk is often low and protection is usually not needed. The exceptions are installations on high ground and in lightning prone areas, wind generator towers or masts, and aerial wiring where any part is exposed to a lightning risk.

Wind generator and tower protection is dependent on the design of the particular manufacturer, but should incorporate a minimum of a 35 mm^2 conductor or 5×6 mm^2 conductors connected to earth, either through the footings or separate earth conductor system. Power cable protection should incorporate some form of lightning protection, such as metal oxide varistors between the conductors and earth, at the tower.

E3.2 Cable entry to battery/equipment enclosure for high risk installations

Any connected regulator or controller should also be equipped with internal lightning and surge protection in the form of clamping circuits, comprising a combination of device types such as metal oxide varistors, transient absorption zener diodes, circuit-breakers or similar protection.

TABLE E1
TYPE OF STRUCTURE

Usage and contents	Value of index *A*
Protection not justified having regard to nature of building, occupancy and contents	−10
Structure and contents inert, occupation infrequent, e.g. domestic outbuilding, farm shed, roadside hoarding, metal chimney or mast	0
Structure containing ordinary equipment or a small number of people, e.g. domestic dwelling, store, shop, small factory, railway station, tent or marquee	1
Structure or contents of fair importance, e.g. water tower, store with valuable contents, office, factory or residential building, non-metallic chimney or mast	2
Cinema, church, school, boat, historical monument of medium importance, densely populated marquee	3
Museum, art gallery, stadium, entertainment complex, telephone exchange, computer centre, aircraft hanger, airport terminal, airport control tower, lighthouse, industrial plant, power station, historical monument or tree of major importance	4
Petrol and gas installation, hospital	5
Explosives building	15

TABLE E2
CONSTRUCTION

Construction	Value of index *B*
Fully metallic structure, electrically continuous	0
Reinforced concrete or steel frame with metallic roof	1
Reinforced concrete or steel frame with concrete or other non-metallic roof Cottage or small building of timber or masonry with metallic roof	2
Large area building of timber or masonry with metallic roof Small building of timber or masonry with non-metallic roof	3
Large area building of timber or masonry with non-metallic roof Large tent or marquee of flammable material Membrane structures with metallic frames	4

TABLE E3
HEIGHT

Height of structure m		Value of index *C*
Exceeding	**Not exceeding**	
0	6	0
6	12	2
12	17	3
17	25	4
25	35	5
35	50	6
50	70	7
70	100	8
100	140	9
140	200	10
200	—	11

TABLE E4
SITUATION

Situation	Value of index *D*
On the flat, at any elevation	0
Hillside up to three-quarters the way up, or mountainous country up to 1000 m	1
Mountain top above 1000 m	2

TABLE E5
LIGHTNING PREVALENCE

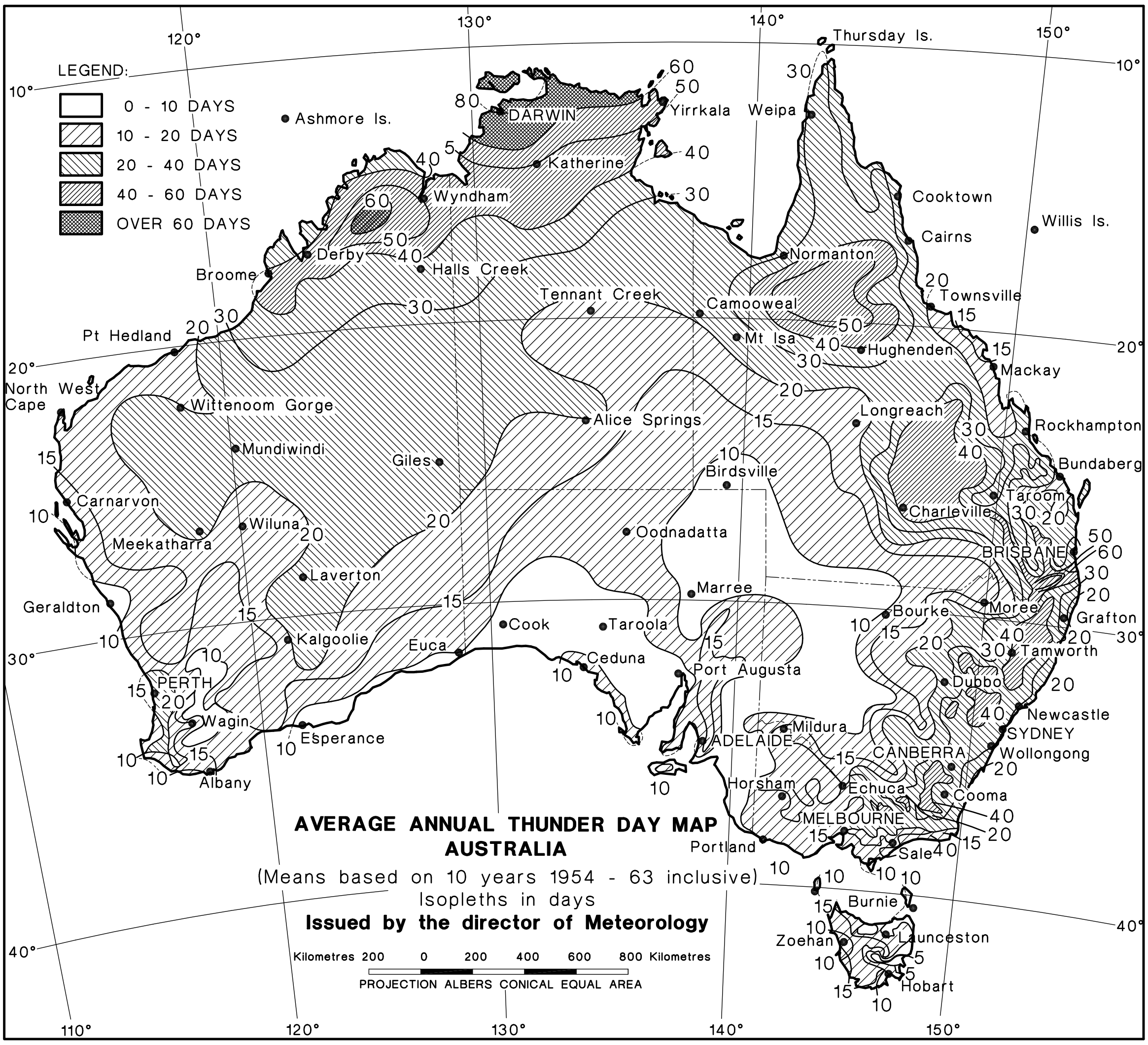
Average thunder-days per year (see Figure E1)		Value of index *E*
Exceeding	**Not exceeding**	
0	2	0
2	4	1
4	8	2
8	16	4
16	32	4
32	64	5
64	—	6

NOTE: If the information in Figure E2 is insufficient to distinguish between index values, the value immediately above should be used.

TABLE E6

ASSESSMENT OF RISK AND NEED FOR PROTECTION

Risk index *R* (*R* = A + *B* + *C* + *D* + *E*)	Assessment of risk	Need for protection
<11	Negligible	Not needed
11	Small	Not needed
12	Fair	Might be advisable
13	Medium	Advisable
14	Great	Strongly advisable
>14	Very great	Essential



NOTES:

1 Contours on the map join locations having the same number of thunder-days per year, a thunder-day being a day on which thunder is heard.

2 A colour copy of this map is available from the Bureau of Meteorology.

FIGURE E1 AVERAGE ANNUAL THUNDER-DAY MAP OF AUSTRALIA

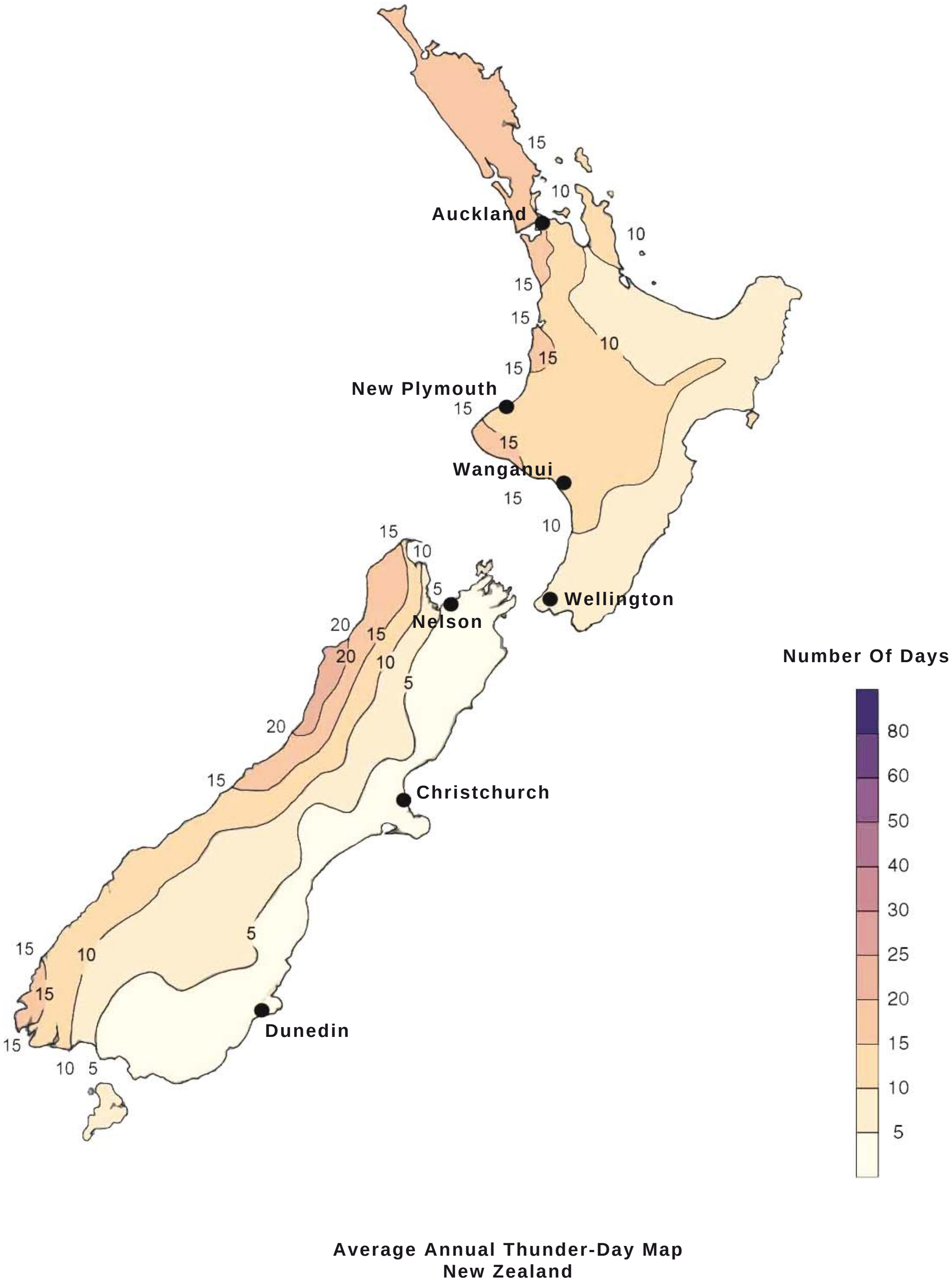


FIGURE E2 AVERAGE ANNUAL THUNDER-DAY MAP OF NEW ZEALAND

APPENDIX F

GLOSSARY OF SYMBOLS

(Normative)

Symbol	Definition	Unit	
A_s	ratio of instantaneous current to continuous current output of the alternator (the alternator surge ratio)	dimensionless	
C_{10}	10 h rate capacity of the battery	ampere hours	Ah
C_x	battery capacity, specified for an appropriate discharge rate x	ampere hours	Ah
DOD_d	daily depth of discharge of the battery	a percentage	%
DOD_{max}	design maximum depth of discharge of the battery	a percentage	%
E_{ac}	design daily a.c. load	watt hours	Wh
E_{dc}	design daily d.c. load	watt hours	Wh
E_{hyd}	design daily energy from hydro-electric sources	watt hours	Wh
E_{pv}	design daily energy from photovoltaic array	watt hours	Wh
E_{tot}	total design daily energy demand from the d.c. bus	watt hours	Wh
E_{wind}	design daily energy from wind turbines	watt hours	Wh
f_{dirt}	derating factor for dirt/soiling	dimensionless	
f_{go}	generating set over-size factor	dimensionless	
f_{hyd}	hydro fraction	a percentage	%
f_{man}	derating factor for manufacturing tolerance	dimensionless	
f_o	oversupply co-efficient	dimensionless	
f_{pv}	solar (PV) fraction	a percentage	%
f_{ren}	renewable energy fraction	a percentage	%
f_{temp}	temperature derating factor	dimensionless	
f_{wind}	wind fraction	a percentage	%
g	gravitational acceleration (9.8 metres per second squared)		9.8 m/s^2
h_{net}	net head	metres	m
H_{tilt}	daily irradiation on the tilted plane, i.e. on the plane of the array	peak sun hours (PSH)	h
I_b	battery current	amperes	A
I_{bc}	maximum charge rate of the battery charger	amperes	A
I_{max}	maximum current loading	amperes	A
I_{mod}	derated current output of a photovoltaic module	amperes	A

Symbol	Definition	Unit	
$I_{T,V}$	output current of a module at average daily equivalent cell temperature, daily average module operating voltage, and irradiance specified under standard test conditions	amperes	A
L	route length	metres	m
N	number of modules in the array (an integer)	dimensionless	
N_p	number of parallel strings of modules in the array (an integer)	dimensionless	
N_s	number of series connected modules per string (an integer)	dimensionless	
pf	power factor of the device when running	dimensionless	
pf_{bc}	power factor of the battery charger	dimensionless	
P_{hyd}	electrical output power of the hydro generator	watts	W
P_{mod}	derated power output of a module	watts	W
P_{stc}	rated output power of the module under standard test conditions	watts	W
PSH	Available solar energy numerically equivalent to the daily solar radiation in kWh/m^2. It is the equivalent number of hours per day at a location if the solar irradiance was a constant 1 kW/m^2.	hours	h
Q	flow rate through the turbine	kilograms per second	kg/s

Symbol	Definition	Unit	
Q_{array}	average daily charge output of the array	ampere hours	Ah
S_{bc}	maximum apparent power consumed by the battery charger under conditions of maximum output current and typical maximum charge voltage	volt amperes	VA
S_{gen}	apparent power rating of the generating sets	volt amperes	VA
$S_{inv,30min}$	30 min. apparent power rating of the inverter at the expected maximum ambient air temperature	volt amperes	VA
$S_{inv,sur}$	surge rating of the inverter at the expected maximum ambient temperature	volt amperes	VA
S_{max}	maximum a.c. load demand	volt amperes	VA
$S_{max,chg}$	maximum a.c. load demand during battery charging	volt amperes	VA
S_{sur}	a.c. surge load demand	volt amperes	VA
$S_{sur,chg}$	a.c. surge demand during battery charging	volt amperes	VA
$T_{a,day}$	daytime average ambient temperature for the month of interest	degrees Celsius	°C
T_{aut}	number of days of autonomy	dimensionless	
$T_{cell,\ eff}$	average daily effective cell temperature	degrees Celsius	°C
T_{eq}	design equalization period (i.e. time between equalizing charges)	days	d
$T_{eq,run}$	equalization run-on time	hours	h
T_{gen}	nominal generating set run time	hours per day/month/year	
T_{stc}	cell temperature at standard test conditions	degrees Celsius	°C
V_{bc}	typical maximum charge voltage of the battery charger at maximum output current	volts	V
V_c	cable voltage drop per unit current per unit length		mV/Am
V_d	allowed voltage drop	volts	V
V_{dc}	nominal voltage of the d.c. bus (i.e. battery voltage)	volts	V
V_{nom}	nominal system voltage	volts	V
$V_{\%}$	percentage voltage drop	a percentage	%
γ	power temperature co-efficient	per degree Celsius	
η_{batt}	the energy efficiency (i.e. watt hour efficiency) of the battery	dimensionless	
η_{bc}	energy conversion efficiency of the battery charger	dimensionless	
η_{coul}	coulombic (ampere hour) charge efficiency of the battery	dimensionless	

Symbol	Definition	Unit
η_{gen}	efficiency of the electrical generator (micro-hydro systems)	dimensionless
$\eta_{hyd\text{-}batt}$	energy transmission efficiency from the hydro generator to the battery	dimensionless
$\eta_{hyd\text{-}cable}$	energy transmission efficiency from the hydro generator to the battery, i.e. from the effect of a.c. and d.c. cable losses	dimensionless
η_{hydss}	efficiency of the micro-hydro subsystem	dimensionless
η_{inv}	average energy efficiency of the inverter when supplying the design a.c. load profile	dimensionless
$\eta_{inv(inv)}$	energy efficiency of the interactive battery inverter ininverter mode	dimensionless
$\eta_{inv(chg)}$	energy efficiency of the interactive battery inverter in charging mode	dimensionless
η_{invhyd}	the energy efficiency of the hydro generator inverter (a.c. coupled systems)	dimensionless
$\eta_{invwind}$	the energy efficiency of the wind turbine inverter (a.c. coupled systems)	dimensionless
η_{mech}	efficiency of the mechanical transmission between turbine and electrical generator	dimensionless
$\eta_{pv\text{-}batt}$	energy transmission efficiency from the photovoltaic array to the battery i.e. from the effect of cable losses	dimensionless
$\eta_{pv\text{-}batt\text{-}load}$	energy transmission efficiency of the cabling between the PV generator and the load via the main inverter and battery	dimensionless
$\eta_{pv\text{-}load}$	energy transmission efficiency of the cabling between the PV generator and the load	dimensionless
η_{pvinv}	energy efficiency of the reversible inverter	dimensionless
η_{pvss}	the efficiency of the PV subsystem	dimensionless
η_{pvss2}	sub-system efficiency from the PV energy generator to the load	dimensionless
η_{pvss3}	sub-system efficiency from the PV generator to the load	dimensionless
$\eta_{ren\text{-}batt}$	the energy transmission efficiency of the cabling between renewable energy generator and battery	dimensionless
$\eta_{renbatt\text{-}load}$	energy transmission efficiency of the cabling between the renewable generator and the load via main inverter and battery	dimensionless
$\eta_{ren\text{-}load}$	energy transmission efficiency of the cabling between the renewable generator and the load	dimensionless
η_{reninv}	energy efficiency of the renewable energy	dimensionless

inverter

Symbol	Definition	Unit
η_{renss}	the efficiency of the subsystem from a renewable energy generator to the d.c. bus	dimensionless
η_{renss2}	sub-system efficiency from the renewable energy generator to the load	dimensionless
η_{renss3}	subs-system efficiency from the renewable energy generator to the load	dimensionless
η_{turb}	efficiency of the turbine at the specified flow rate and head	dimensionless
$\eta_{wind\text{-}batt}$	energy transmission efficiency from the wind turbine to the battery	dimensionless
$\eta_{wind\text{-}cable}$	energy transmission efficiency from the wind turbine to the battery, i.e. from the effect of a.c. and d.c. cable losses	dimensionless
η_{windss}	efficiency of the wind subsystem	dimensionless

NOTE: Peak Sun Hours is the available solar energy measured in hours (h). It is numerically equal to the daily solar radiation in kWh/m^2. It is the equivalent number of hours per day at a location if the solar irradiance was a constant 1 kW/m^2.

APPENDIX G

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NOTES

NOTES

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