Journal of Power Sources, 16 (1985) 205 - 232

REMOTE AREA POWER SUPPLY SYSTEMS: A CASE STUDY OF REQUIREMENTS AND OPTIONS*†

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(Received September 16, 1985, accepted October 3, 1985)

Summary

Studies have been made of the needs, current practice and future prospects for power supply to off-grid areas in the State of New South Wales, Australia. These studies have included a consideration of both the technical and financial aspects of available equipment. At present, it has been found that costs of traditional stand-alone power generation are high and system reliability is low. This is partly due to the poor match between the load demand and the method of power generation. There are significant barriers to the wider implementation of new power supply technologies, these include high capital cost, lack of performance data and technical guidelines, and limited consumer education Ways being investigated to overcome these problems are described

1. Introduction

Many areas of the world (so-called "remote areas") do not have an electricity supply network and, therefore, the inhabitants of these regions

*The views expressed in this report are those of the authors and not necessarily those of the Energy Authority

†*Note from the Editors*

Stand-alone power systems, incorporating "renewable" solar and/or wind technologies, offer the prospect of a cost-effective alternative to grid connection in meeting the existing and future electricity-supply needs of communities living either in remote areas of developed countries or in countries with restricted mains electricity networks This paper describes the approach being taken in Australia to developing so-called remote-area power supply (RAPS) systems Since electrochemical storage is a key element in many of the proposed RAPS systems, and is a major problem area where technological improvements are necessary, the Editors of this Journal invite further contributions on the design, testing and performance of power sources in RAPS applications — an emerging potentially significant market for both batteries and fuel cells

0378-7753/85/$3 30

require some form of alternative electricity generation system [1]. Such systems are also needed in isolated pockets within an area that is serviced by a network but where further connection to the grid is costly.

Recent developments in the fields of electronics and renewable energy technologies are making independent power supply systems more reliable and less expensive [2, 3]. However, the choice of a power supply system is often dictated by lifestyle, finance and demand patterns. Almost without exception, people in remote areas have had to weigh up lifestyle versus financial outlay. Included under lifestyle is the range of power supply features such as peak load, average load, hours required per day, voltage and waveform required, and any special appliance demands. The ability to pay, or more generally the financial situation of the consumers, is a determinant in selecting appropriate alternative supply technology.

In most circumstances, 240 V a.c power supply is required by rural farms for at least some of their load. Power supply from the grid network in rural areas is subject to more frequent supply interruptions, voltage-drop problems and frequency fluctuations than in city areas. These problems result from the vulnerability, and limitations, of long supply lines. Rural consumers largely accept these problems as part of country life. Farms not connected to the grid also suffer similar disruptions from alternative power supply systems. Most appliances in use in these farms will tolerate fluctuations in voltage and frequency. However, with more use of sensitive equipment, such as home computers, the demand for standards comparable with those of city power supply is expected to increase Power supply systems that have a projected life of more than five years should, therefore, anticipate this demand and as far as possible provide a supply of equivalent standard to that provided by the city grid network.

The need for a continuous (24 h) 240 V a.c. power supply means that many farmers are pressing for connection to the grid network. In areas where connection costs may be reduced for a variety of reasons, such as pooling of costs by a group of farms or by favourable consideration by the local supply authority, it is apparent that some farms will connect to the grid network in preference to all alternatives. The pressure for connection in outlying areas is expected to increase. Once connected to the network, the maintenance of supply must be attended to at the supply authority's cost and this may exceed any profit from electricity sales.

This paper examines the technical and non-technical problems to be overcome in providing viable stand-alone household power systems, and considers the State of New South Wales, Australia, as a specific case in point. An examination is made of consumer groups, available power supply systems, and their relative cost effectiveness. Finally, a discussion is presented of the work being undertaken by the Energy Authority of New South Wales that is aimed at developing systems based on specific combinations of conventional and new technology. These systems include more efficiently used diesel plant, fuel-saving devices such as wind generators and solar panels, and rechargeable batteries for storage of the derived electricity

2. Electricity supply characteristics

The necessary or desired (as opposed to currently achieved) electricity requirements for household power supply may be summarised by specifying two basic parameters load profile and power supply quality.

2 1 Load profile

The load profile is a curve of instantaneous power demand against time of day. It includes peak load, hours per day of power availability, average load and the load-factor relationship (ratio of average power to peak demand). The load profile can be used to analyse patterns of usage but unfortunately, little work has been done on typical load profiles for consumers in remote areas. Therefore, typical demand patterns need to be analysed and the analysis extrapolated to consider the changes that take place when, for instance, a continuous power supply is made available.

Where power is supplied by diesel generator alone, the measured load profile can be confused by artificial load added to the system to ensure adequate engine loading. An additional confusion occurs because the consumer may have a lifestyle based on activities centred around times when the diesel is running. Such activities as washing and ironing are crammed into evening periods simply to take advantage of run time on the diesel set.

Let us consider the components of the load profile. The peak load is reached when a significant number of appliances are turned on together, and is particularly noticeable if a motor-starting load is included. The peak load, measured in kilowatts, is the sum of the expected simultaneous appliance loads. For outback properties in Australia, the main household loads may include a refrigerator, air conditioner, freezer, coolroom, washing machine, other normal household appliances and some workshop tools. As a general rule, a peak load of 10 kW might be expected. Clearly, this will vary somewhat with consumer, depending upon such specialist loads as welding or sheep shearing demand. A list of common appliances and their power demand is given in Table 1. It can be seen that peak load requirements are high if refrigeration, cool room and air conditioning loads are in use.

Peak load requirements will not necessarily fall with changing supply conditions. Power is required to be available continuously if an effective cooling load is to be maintained. It is chiefly the difficulty of providing continuous power supply that plagues remote area power systems. The total amount of power required each day is more easily described as the average over the 24 h period, a 10 kW h per day demand may therefore be represented by an average load of 417 W.

The relationship between peak and average power requirements must be recognised when considering adequate supply alternatives. An installation that requires a very high peak demand, but a low average demand, will require a different system to an installation with a more closely matched peak/average demand. The power demand relationship may be expressed as a ratio termed the daily "load factor"; this ratio is usually expressed as the

TABLE 1

Typical appliance loads

Appliance	Rating (W)	Typical peak demand (W)	Energy demand (kW h per day)
Refrigerator	500	2500	3.6
Freezer	300	1500	2 0
Fan	100	100	1 0
Lights (total)	500	200	1 0
Kitchen			
Blender	350	1000	0 5
Coffee Pot	600		
Exhaust Hood	60		
Toaster	1000		
Washing machine	300	1000	0 5
Pump (small)	450	1000	1 0
Iron	1000	1000	0 5
Drill	250	1000	0 1
Stereo	100		0 1
Television	100		0 5
Sewing machine	100		0 1
Vacuum cleaner	600		0 1
Total			11 0 (~ 4000 kW h per year)
Other loads			
Air conditioner	1600	2000	38 (summer usage)
Dishwasher (with heater)	2400	2400	1
Hot water (storage)	3600	3600	8
Stove	6000	6000	4

average divided by the peak. For example, a homestead with a peak of 10 kW and an average of 417 W would have a daily load factor of 0.04.

A distinction should be drawn between "load factor" and "capacity factor". As stated above, load factor is the ratio of average power demand to the required peak load. The capacity factor of a system is the ratio of the net amount of power delivered by the system to that potentially able to be supplied Thus, an installation that runs a diesel set for a few hours each day may have a low load factor but a high capacity factor, meaning that diesel set use is optimal, but if use were extended for continuous supply it would be under-utilised. Often a high capacity factor is achieved through adding artificial load This is called a "load dump" and is of no financial value. Assessment of a particular installation must identify and discount any load-dumping activities. Thus, only a realistic capacity factor is considered. This can be compared with the load factor to determine if energy storage is needed. If, for example, the capacity factor and load factor are both greater than 0.8, then the system would be quite adequately provided for by a single diesel generator and no great value would be gained by introducing a storage system. It is a general requirement for efficient diesel engine performance that the capacity factor be better than 0.8. Low values indicate that the installed capacity is not well utilised and could lead to high maintenance costs and even engine damage.

2 2 Power supply quality

O'Flynn and Darveniza [4] have determined the electrical supply requirements of a rural consumer in the State of Queensland, Australia. This study considered consumption, voltage regulation, frequency stability, power factor, inrush current, and waveform. The consumption exceeded 5000 kW h per annum for the all-electric home. It was found that a peak capacity of 5 kV A was required with a voltage regulation of 6% and a frequency stability of 5%. The authors also concluded that most domestic appliances may be operated using a voltage source approaching a square wave

The quality of electricity supply includes voltage fluctuations, frequency stability, and waveform of a particular system In Australia, grid supply is 240 V a.c., 50 Hz. For appliance compatibility, it is desirable for remote power supplies also to be 240 V, 50 Hz. In view of this, it is remarkable that many remote area residents have only recently had access to 240 V power and that many still have not. Dwellings without grid connection operate with either 32 V d.c power exclusively, or have no electric power at all. In most instances, it is not a desire to do without 240 V power but rather a practical choice based on the cost of running a diesel set or installing a renewable energy system

The choice between alternating current or direct current is not difficult as it follows the choice of voltage. Direct current systems are, in general, low voltage systems Arcing during switching and lack of transformation severely limit use of d.c power in remote regions where normal appliance use is required Heavy loads such as large refrigerators and large motors cannot be effectively operated on d.c If a c. electricity is supplied, then 50 Hz power would be expected. Most control systems can maintain frequency stability within 5% and this would be quite satisfactory for a homestead power supply. Frequency-sensitive electronic equipment such as hi-fi turntables and computers may require an additional, small, well-regulated power supply

Modern diesel sets can usually maintain an accurate sinusoidal waveform. However, many alternative off-grid power systems use a waveform other than sinusoidal In most cases, the waveform is a modified square wave. A pure square wave may cause motor heating problems as well as producing unacceptable levels of radio frequency (r.f.) interference As radio reception is often central to the operation of the homestead and motors are a major load, the type of waveform produced by the power supply must be considered carefully. A modified square wave with adequate filtering is acceptable, although a pure sine wave is clearly preferred.

3. Off-grid electricity supply technology

Commercial, or near-commercial (say in the next three years), off-grid power supply technology includes fossil fuel (diesel and petrol) engine-driven generators, battery storage systems, wind-driven generators, photovoltaic panels, and mini-hydroelectric generators. Each technology consists of components that can be described under the general headings of either generation storage, control, or power conversion (or power conditioning) and needs to be considered in terms of usefulness for a particular application. Such consideration must take into account system performance, efficiency, reliability, maintenance, future prospects and cost.

Five technologies commercially available as sources of off-grid power supply for the various consumer groups in remote areas of the State of New South Wales are discussed below. These technologies are: (i) diesel- or petrol-driven generators; (ii) 32 V power systems with battery storage; (iii) diesel-plus-battery systems; (iv) wind-driven generator systems, and (v) photovoltaic panel systems.

3.1 Diesel- or petrol-driven generators

By far the most commonly used equipment is the diesel generator; it has provided power in remote areas for many years. Both the standard of generator set and its use have increased steadily over the years. In early times, simple engines were used and operated on petrol or kerosene. These units gave way to diesel engines, mainly because of increased reliability and better fuel economy. More recently, the advent of low-cost petrol engines has made available highly portable generators that augment the use of stationary diesel sets.

The power required to drive the electrical generator (usually a brushless or slip-ring alternator) is provided by an internal-combustion engine. In the case of the diesel set, this is a compression-ignition engine Such engines are inherently robust, reliable and fuel efficient if used appropriately. They are typically bulky and operate at low speed. The ability to produce power at low engine speed is one of the main reasons for the long service life of the engines (10 000 h can be expected). The compression-ignition feature also eliminates the need for potentially troublesome ignition systems. Accurate timing and precision in the original manufacture are critical to the engine's performance. Thus, initial care must be taken during operation by ensuring regular oil-, air- and fuel-filter changes, as well as routine service and operation to manufacturers' specifications. To ensure a correct operational temperature the engine must be run with a minimum load of 30%, and ideally with a load of 70% - 80%. Running of the engine at low load for long periods will result in carbonisation, cylinder-bore glazing and poor fuel economy.

Engine life will be severely shortened. Well loaded, the engine may achieve 20% - 30% conversion of fuel to shaft power, the remainder being lost as engine heat, exhaust heat, unburnt fuel and noise. Engine protection circuits are included in most diesel generator systems to ensure that the unit will not run in a faulty condition.

Petrol engines are the antithesis of the diesel engine. The light weight resulting from the high revving, less robust, spark-ignition system is an advantage for portable power supplies. However, the system is inherently unsuitable for continuous stationary power supply. The engines have an expected service life of some 1000 h. The engine limitations mean that the generator sets are usually small (0.5 - 8 kV A).

In early years, the conversion of shaft power to electricity was achieved by using a d c. generator Such generators require a commutator and brush system. The maintenance problems associated with brush systems and the limitation of d.c. power supply soon led to the use of alternators. The term "generator" remains in use to cover all devices that convert mechanical power to electricity. An alternator is a generator that produces a.c. power. A wide range of alternator types has developed. Most are self-exciting and, to an extent, self-regulating devices of remarkable reliability. The rotating-field brushless alternator is the most commonly used 240 V a.c. type, although slip-ring alternators are also used. The slip-ring alternator is a rotating-armature compound-wound device, older in design than the brushless type, and uses a transformer regulator rather than an electronic regulator. It is generally better able to handle overloads. This feature combined with the simpler field serviceable regulator, makes it a more robust unit for remote area use. It does, however, have a brush and slip-ring power take-off system and this requires maintenance from time to time. User preference has, as a result, tended towards the brushless alternator. Nevertheless, both types of alternator are suitable for use in remote area power supply and, in general, they perform well for many years with minimal maintenance.

Power supply from a modern diesel set is usually high quality 240 V a.c. and would not normally require further conversion or conditioning. Most rural installations are single-phase (one source of voltage and current), however, a significant number do use three phase supply. This is usually split into three single-phase circuits, but occasionally a large motor, used for say a cool room, may be of a three-phase type. From the point of view of the manufacture of the generators, the number of phases is usually linked to the size of the generator. Three-phase is used for large (usually greater than 15 kV A) sets where the three single-phase supply circuits can be evenly loaded For simplicity, three-phase supply should be avoided where possible.

In systems where the power demand is well matched to the diesel generator set, such as a roadhouse load, the only form of storage required is a fuel tank. Most installations, including single homesteads, have 200 - 400 litre storage tanks, sufficient for a few days' or weeks' supply. Refilling is rarely done by tankers. Usually, fuel is pumped from 200 l drums. Fuel cartage is a significant cost in the operation of the system. In some areas, large underground fuel storage systems are being installed to overcome interruptions to supply. Concern has been expressed, by at least one oil company, of the risk of long-term storage of distillate since the fuel changes with age and seasonal supply (oil companies change the fuel characteristics with season) and may become unusable.

Two forms of control need to be considered, these are power supply regulation and system operation control. Power supply regulation is usually achieved through a small solid state electronic or transformer regulator. Voltage regulation may be held within 2% - 3% and frequency within 4% of 50 Hz System operation control may vary in complexity from a simple remote start/stop switch to complete automatic operation. Time switches are also used for unattended installations.

3 2 32 V power systems

At present, 32 V d.c. systems form an important back-up to diesel generator sets. They used to be the only form of power supply for many remote graziers and, in some homesteads, this is still the case. However, the availability of modern diesels and the growing demand for 240 V a.c. supply has meant that they are gradually being replaced as the main source of power. This is being hurried along by the difficulty in obtaining 32 V appliances. Nevertheless, 32 V systems represent an excellent mix between renewable energy sources, diesel performance and load demand for the typical remote homestead.

Two methods of generation are employed: diesel- or petrol-driven and wind-driven The generators used in these d.c. plants are renowned for their reliability, often needing no more than a new set of brushes after years of service Although available for direct power supply, the d.c. generators usually charge batteries Generation is usually an *ad hoc* affair depending on manual engine starting and wind availability.

The diesel or petrol sets are usually single-cylinder engines, often water cooled, that are quite fuel inefficient. They are used to run a small (0.75 - 1 kW) 32 V d.c generator via a belt drive. The wind-driven generators are usually four-bladed (0.75 - 1 kW) compound-wound d.c. units or three-bladed (0.75 - 1.5 kW) shunt-wound d.c. units. The blades in the former generator are fixed-pitch folded metal airfoils that give an extremely reliable method of control. Three-bladed generators are variable-pitch fixed-tail units fitted with manual brakes.

Storage batteries are essential in wind-driven generating systems. The only commercial battery available at present for this application is the lead/acid system. The 32 V storage facility is made up of either individual 2 V cells, or 6 V or 12 V batteries. The general requirements for batteries installed in wind/electric systems are the same as those for any deep-discharge storage battery Preferably, the cells should have translucent cases or indicators to enable easy observation of plate and electrolyte condition. The case should have a deep space below the plates to accommodate the build-up of sediment and hence reduce the possibility of internal shorting of cells.

These larger cases also allow greater depth of electrolyte over the plates, thus extending the time between electrolyte top-ups and reducing maintenance tasks. Maintenance-free batteries have recently been developed that include a catalyst to recombine the hydrogen and oxygen produced by electrolysis of the electrolyte during the gassing phase. Physical retention of active materials can be assisted by supporting battery plates with plastic or glass-fibre envelopes. Self-discharge should also be kept to a minimum by using grid alloys of appropriate composition

Originally, batteries with a large capacity (~ 12 kW h) were employed for 32 V systems. As battery costs have risen, the option of smaller batteries has been taken up. A minimum of 200 - 250 A h (7 - 8 kW h) of storage is required in a typical system that uses both a wind generator and a diesel set. Battery life is the chief concern of most operators. Only 2 - 3 years is achieved from deep discharge batteries, and much less from automotive-type batteries. This short life is mainly due to poor installation, charge/discharge control and maintenance Charge control is critical to overall system performance. Charging must be initiated at the correct time and maintained at the correct rate. Overcharging must be prevented. In addition, the control system must ensure discharge is within defined limits and prevent discharge beyond a safe level for the batteries. Lack of easy state-of-charge indicators means that recharge is usually initiated when the terminal voltage drops markedly During charging, a simple cut-out regulator disconnects the current when the terminal voltage reaches a preset level. The relationship between this and the true state of the charge in the battery is vague when the batteries have been installed for a short while. Poor control, based on outdated devices, is one of the main reasons for battery deterioration.

Power is supplied from the battery bank directly to d.c. lighting and appliances. In most cases, there is no control to limit the energy withdrawn from the batteries and they may be discharged to a level well below the minimum recommended by the manufacturers. A simple cut-out operated by low battery voltage would minimise this problem.

Conversion of 32 V d.c. to 240 V a.c. is achieved by several different types of inverters. Low-cost rotary inverters are often used. They provide a good source of 240 V a.c. power for motor applications as they can overcome starting loads. Unfortunately, they are very inefficient and cannot be used for long-term power supply. Static (electronic) inverters have become available over the last few years. Most high quality inverters have a standby mode that uses little power. The operational mode is automatically switched in when a load is sensed. Such inverters can achieve 80% - 90% efficiency over most of the load range. Efficiency, no-load power usage, and cost are all expected to improve with new electronic devices becoming available. The waveform produced by the static inverters is rarely sinusoidal. Square wave, modified square wave or simulated sine wave using pulse-width modulation are available

Typically, 1 - 2 kW h per day will be provided by the system. Of this, only a small fraction is required at 240 V a.c. Large 240 V a.c. loads are usually powered by a standby diesel set. This demand may only be for a short time but if it is to power some motor load, such as a kitchen appliance, then the inverter will need to have a peak capacity of at least 0.8 - 1 kW. If a washing machine is occasionally required, then a 1.5 kW inverter would be needed. A unit of this capacity may cost more than the owner of a 32 V system is prepared to pay.

3.3 Diesel-plus-battery systems

A few diesel-plus-battery systems have been developed in an attempt to improve the utilisation of diesel generator sets and extend the time power is available. Typically, storage batteries are charged from the diesel generator during run times and batteries supply power requirements during low-load periods. Most of these systems have been built by the owner in an *ad hoc* manner. Voltages of the systems vary from 12 to 110 V d.c. These systems are an improvement on simply running the generator for periods of low load. However, the concept may be taken much further by dedicating the diesel set to battery charging alone. If this is done, the diesel efficiency can be improved further by reducing its size and running it fully loaded at all times

In low-voltage systems, the batteries are similar to those in 32 V systems. Banks are made up from 2, 6 or 12 V units. The performance of such storage systems depends on the charge/discharge characteristics, depth and frequency of cycling, and general maintenance. Strict limits must be adhered to in regard to the charging of batteries. If these are not used to determine the type of battery to be installed, then they may be mismatched to the generator. Poor performance and short life are the result.

Owner-built systems are usually d.c. and are used to power lighting and some light appliance needs. A simple 24 V battery bank with 4 - 5 kW h storage would be sufficient for several days of lighting. As with 32 V systems, some small commercial d.c. to 240 V a.c. inverters are used. The increased availability of 12 V d.c appliances, aimed mainly at the leisure market, may result in 12 V rather than 32 V systems being used in future.

Until recently the limit of diesel-plus-battery systems was determined by the capacity and poor efficiency of available inverters One recent development is the availability of an efficient, lower cost, high-power inverter made specifically for this application. The inverter is available at 10 or 20 kW capacity and claims better than 90% efficiency over the full load range. Power supply from the system is entirely 240 V a.c Such a breakthrough was needed for the diesel-plus-battery systems to be able to offer significant fuel savings and realistic power availability.

From a system efficiency point of view, the concept of dedicating the diesel set to serve as a battery charger has a great deal of merit, even though the batteries may only be 70% - 75% efficient. This is only true, however, for installations with low load factor and a variable load pattern. System efficiency stems chiefly from better loading of the diesel. The diesel is smaller, and is run at full load and for fewer hours.

In installations where the load is more constant, such as a roadhouse, diesel/battery systems offer very few advantages other than convenience The systems that are now commercially available may gradually replace the single diesel set in homesteads and small farms.

3 4 Wind-driven generator systems

For more than 35 years, wind generators have been used in New South Wales to charge storage batteries for small low-voltage lighting systems. A wind generator consists of a rotor that is driven by the wind to produce shaft power. This rotor is limited in rotational speed by some form of governor. The rotating shaft connects either directly or through a gearbox to drive a generator. Horizontal-axis wind generators are turned into the wind by means of yaw control systems, usually a tail vane.

Early Australian d.c. generators were effectively limited to 1.5 kW peak output and were either compound-wound or fully regulator-controlled. Although they were effective battery chargers, even in relatively low-wind areas, poor voltage regulation frequently led to overcharging. In 1965, a brushless alternator unit rated at 2 kW was introduced. The design consisted of a series-wound generator incorporating a fixed tail and automatic blade-feathering control. Over the past 5 years, many new types of wind generators have been developed in Australia and overseas. Many of these are still in the development stage but an increased interest in wind energy, particularly in the U.S.A., has led to a rapid increase in the availability of well-designed units. The horizontal-axis propellor type is still the most popular design.

The blades of propeller-type wind-generator rotors may be made from wood, folded metal sheet, aluminium or fibreglass. All materials are required to maintain strength and stiffness under extremes of temperature and wind pressure. The blades undergo countless repeated bending stresses and failure due to fatigue is an important design constraint. Exposure to the environment may lead to surface deterioration. Thus, regardless of the material used, it is important that the blades are well maintained. Aerodynamic design differences between rotors are relatively unimportant on small rotors (up to 8 m in diameter). If a standard airfoil is used, and the pitch angle is set between 12° and 14°, the rotor should be capable of efficient performance

Rotors of wind generators differ from the "wind wheels" of water-pumping mills. The latter generally use fan-type blades that achieve virtually no aerodynamic lift on the blade surface They are not designed to maximise energy conversion but to achieve high torque for mechanical pumping in light winds. In contrast, the rotor of a wind generator is designed to perform well in high winds by making use of aerodynamic lift on the blades. Such rotors only require two, three or four blades. A well-designed wind generator should achieve a tip-speed ratio (ratio of rotational speed of the tip of the rotor to the wind speed) of up to 8. This compares with a tip-speed ratio of less than 1 on most wind wheels and is a measure of the higher rotor efficiency.

The rotors on early generators were fixed pitch, but most current battery-charging wind generators have some form of pitch control mechanism. Alternatives to this design include air brakes and swivel rotor systems. All methods aim to prevent the rotor from overspeeding in high winds. Stall regulation is a preferred method of speed control, but is only practical on large rotors (greater than say 6 - 8 m in diameter). Air-brake control has proven successful on many units, notably the early Jacobs range of wind generators from the U.S. The swivel rotor is used in the North Wind units from another U.S. manufacturer. Elektro GmbH of Switzerland and Dunlite of Australia are two manufacturers that use a pitch-control system in their range of modern wind generators. All methods work successfully. Air brakes may suffer from noise and swivel rotors tend to be expensive, but both are currently in use. Pitch control is the most widely used system and has been in use for more than 35 years.

Direct-drive generators are available up to 4 5 kW capacity. Although modern gearboxes are usually reliable devices, they are best avoided if possible as they represent an extra source of failure and another item for maintenance. They are usually a pinion and gear assembly with a 4 - 5:1 ratio.

Yaw on battery-charging wind generators is usually achieved by using a tail vane. Some units are tail-less, using a down-wind rotor that is pushed around in changing wind directions, but these are not common. A few vertical-axis wind generators have been built for battery charging but none are in commercial production. Similarly, electric yaw control is not commercially available. The tail is not only used for yaw control but may be pulled parallel to the rotor to turn it out of the wind as a method of shutdown. All wind generators require protection from high winds. Wind speeds may be monitored by means of a wind vane or anemometer. The control function activated when the wind exceeds a preset level may be designed to turn the rotor out of the wind, operate a brake pad or air-brake system. Whichever way the unit is designed to shut down, it is important that the system be fail-safe, as machine damage will usually result from continued operation in high winds. A manual over-ride should also be available.

A battery storage system capable of meeting demand of 3 - 5 days is normally installed if power is to be supplied continually Such installations may require substantial peak capacity and the preferred storage voltage is 110 V. For a given power demand, the current drawn is dependent upon the system voltage. Typically, a lead/acid battery may have a safe discharge current level numerically equal to about 10% of the battery's storage capacity For example, a 225 A h battery may sustain a discharge of 22.5 A, and the maximum power which may be drawn from a typical 110 V battery bank, capable of a 3 - 5 day storage, would therefore be 2.7 kW. In practice, higher surge currents may be drawn without damage to the battery. Unfortunately very little experience has been documented with regard to the performance of high-voltage battery banks operated in the manner necessary for power supply to a homestead. The Energy Authority of New South Wales is installing three homestead power systems, with battery voltages of 48, 110 and 240 V. These systems will be monitored for two years of operation and are expected to provide valuable field data. They are described in more detail below.

The need to store power in batteries means that some form of d.c. to a.c conversion must be employed. As mentioned above, the small commercial static inverters used in the past for 32 V lighting plants have often been inefficient. In larger systems, where the voltage is 110 or 240 V d.c., the efficiency of conversion may be increased. State-of-the-art inverters offer better than 90% efficiency over the full load range and operators can now achieve 24 h a c. power supply at 1 - 20 kW peak capacity.

From the foregoing discussion, it can be seen that battery life and the reliability of unproven technology (such as inverters) are two areas of concern for potential installers of wind/electric systems. Also hampering the wider implementation of the technology can be the lack of wind-speed data. A modern domestic-sized (4.5 kW) wind generator may be expected to produce in excess of 4000 kW h per annum in a 4 - 5 m s^{-1} annual average wind speed This is sufficient for all normal appliance needs, even allowing for system losses. This type of generator can also be used as a fuel-saving device in conjunction with a diesel generator. The performance of any particular unit is dependent upon site-specific features such as load profile, wind speed distribution and individual system design. However, in windy areas, wind generators can provide a viable source of power supply, or fuel saving, for people living in remote areas.

3 5 Photovoltaic systems

Of all renewable energy systems, photovoltaic systems offer the simplest method of generation from an operational point of view. The unit of electrical current generation in most commercial photovoltaic panels is the silicon cell. The cells are connected together and mounted (or "encapsulated") in a panel The panel consists of a clear, low reflective cover and backing material. The technology of cell manufacture is complex but, when encapsulated, the resulting panel is a remarkably simple low-maintenance and reliable source of power generation. The panel is usually designed to charge a 12 V battery, but may be connected with other panels in series to charge 24, 32, 48 or 110 V battery banks. The use of photovoltaic systems has increased quite dramatically in recent years. This expansion in activity has followed a progressive decrease in the cost of silicon cells. At the outset, the technology was only cost effective in very remote, low power demand installations such as navigational aids and communication links. As the cost of cells dropped, small home lighting systems became economic. Today, many homes with low demand (up to 1.5 kW peak) are using solar electric systems while higher demands are being met by solar hybrids, *i e* combinations of solar and wind, diesel, petrol, etc [5]

Peak output currents from photovoltaics are usually far less than the upper limit for charging a typical lead/acid battery Thus, no design limits are usually encountered in this area. Generation follows a daily cycle and the regular charging of the storage battery is an attractive feature of the technology. Although single-crystal silicon is still the most commonly used, progressive cost and efficiency improvements are leading to the introduction of polycrystalline cells into the market. Typical single-crystal or polycrystalline panels currently available have peak power ratings of 35 - 40 W, an open-circuit voltage of approximately 20 V, and a short-circuit current of 2 5 A. Amorphous silicon panels are now becoming available, but are currently high cost and have lower lifetimes and efficiencies.

The chief requirement of a battery in photovoltaic power systems is to provide power supply at night and in times of cloudy weather. The size of the battery store will vary depending upon the site. In some areas, 8 - 10 day storage may be required but usually 3 - 4 days is sufficient. Assuming a typical daily demand of 1 kW h, the storage requirement would probably be 3 - 4 kW h or 125 - 170 A h batteries at 24 V. Where ancillary power sources, such as petrol, diesel or wind generators are also used, storage can be reduced to 1 or 2 days.

Two further battery aspects are important, the rate of discharge required and the boost charging facility. As with all battery systems, the rate of discharge will influence the battery life. Boost charging of the battery is necessary at least once per month to ensure cell equalisation. In photovoltaic systems, this is a relatively simple matter, since the cells are self-regulating. In wind or diesel systems, however, boost charging must be arranged through the charge control system.

Small photovoltaic systems, suitable for a load such as lights, radio/television and a few appliances, have been successfully installed at many sites in New South Wales over the past 7 - 8 years. Larger systems for household loads are relatively few in number. With the advent of more efficient inverters, there are no technical reasons why photovoltaic systems cannot provide the entire power supply for a normal home or homestead. With present photovoltaic prices, however, hybrid systems using a diesel, for example, may provide more cost-effective power for large loads. Comparison with other technologies suggests that photovoltaic systems are cost competitive for certain loads. However, the very high initial costs of solar panels means that few customers could currently afford to install a large photovoltaic system. Since photovoltaic systems are modular, however, the system can be built up gradually with any increase in load being catered for by increasing the number of panels.

4. Off-grid consumers in New South Wales

The State of New South Wales can be divided geographically into three regions: eastern seaboard, central western and far western (Fig. 1). The physical features that define these three regions have influenced the present power supply situation Population density, economics and electricity demand patterns evident in the different regions have historically influenced

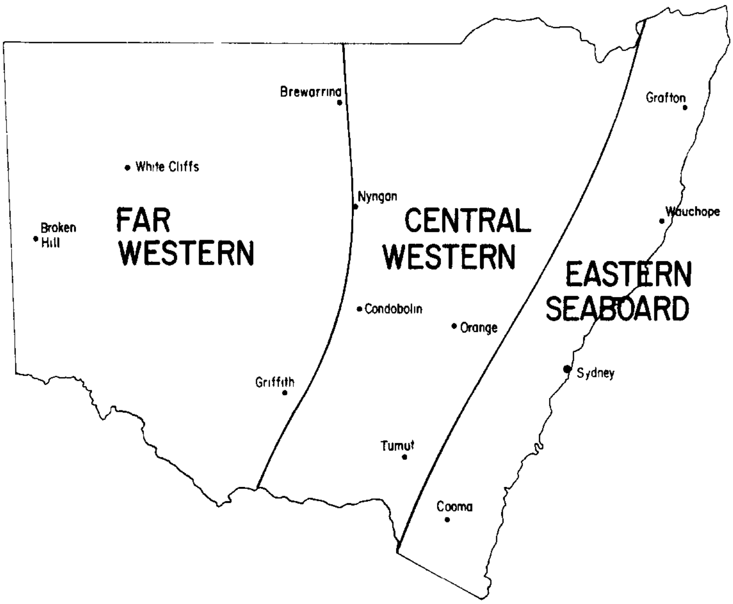

Fig. 1 Division of New South Wales into regions with different power supply characteristics

the extension of the grid network and still influence decisions regarding power supply

The people living in the far west of the State have managed without connection to the supply network for many years by operating a variety of diesel, petrol- and wind-driven generators, wood fueled, and LPG appliances. More recently, areas around Bourke Cobar and Hillston have been serviced with single-wire earth return (SWER) network connections Property owners in these areas are eager to connect to the new supply, but many find the connection fee (now averaging $40 000* per property) a burden. In addition, the supply is often disrupted by lightning and bushfires. Further away from these town centres, property owners are generally excluded from connection and remain with their mix of generators The problem of improving the power supply to these people, to a standard considered minimal in city areas, still remains.

The area not serviced by any part of the network is not the only region to require some form of stand-alone electricity generation system Within the network isolated consumers include weekend farms or cottages, hobby farms, small farms, and community groups. Some wish to be self-reliant, some only require a small amount of power and the cost of grid connection cannot be justified. Some seek the lowest cost option.

*All costs in this paper are given in terms of Australian currency

At present, production of stand-alone power by conventional diesel systems in use in the above areas is often expensive inefficient, unreliable and inconvenient. Extension of the SWER network to all consumers would be very expensive and of questionable reliability in the very isolated regions

Five off-grid consumer groups have been identified. (i) far western district graziers, (ii) isolated hotels, roadhouses, small towns, or mine sites, (iii) isolated farms (often small or hobby farms) within the grid-serviced region, (iv) weekend or part-time residences (*e.g.* holiday homes), and (v) alternative-lifestyle community groups. The following sections discuss the characteristics, current practice and trends in electricity generation for these consumers.

4.1 Far western district graziers

4.1.1 Electricity requirements

The graziers in the far west of the State, although numerically small, occupy a vast tract of land. The region covers approximately one-third of the State, extending west of a line drawn from Brewarrina, through Nyngan and Condobolin to Griffith. Grazing activities include both sheep and cattle The difference in land use between sheep and cattle may at times be important for power supply considerations because heavy short-term electrical loads such as shearing are significant

The far western region is very hot in summer but has cold winter periods. Air conditioning is a necessary, but not often available, feature. The generally dry climate makes evaporative cooling feasible. The hot summer period also makes cold storage of food a necessity. Both coolrooms and conventional refrigerators are required if satisfactory food storage is to be achieved. The cold winter nights demand some form of heating, but this is usually of such a minor nature that an auxiliary heater, often wood fired, is all that is required. Electric space heating would not generally be needed. Rain is sparse throughout the region and water pumping is necessary. The electric power supply would normally be expected to operate the domestic water-pumping needs, however, stock water is usually pumped by wind- or diesel-driven pumps, and more recently by photovoltaic powered pumps.

The remoteness of much of the region means that service, spare parts, and even simple repair information for on-farm machinery is often difficult to obtain. Graziers are rightfully wary of new technology because even a simple repair may take several days and possibly involve hundreds of kilometres of travelling. Grid extensions in such areas are also subject to the difficulties of remoteness. It is estimated that the average length of connection to the remaining customers in regions such as this is 12 km. However, the real cost incurred in such regions is maintenance of the grid lines, which averages $200 per km per year The remoteness also affects overall power supply reliability Repair teams, whether for grid lines or on-farm machinery, may take several days, if not longer, to restore power supply Many householders, therefore, retain their original power system for emergency use.

A homestead in the far western district is similar in many respects to a city home and would not be expected to use less power if it were available If anything, additional demands such as extra residents, workshop loads, cooling on a larger scale, both for food preservation and space cooling, and site-specific loads such as water pumping, mean that electrical loads may be expected to be higher than those for city counterparts. In fact, present homestead electricity demand is quite low Lack of reasonable power supply has meant that a variety of alternative energy sources are used (such as LPG, wood, direct diesel engine power, etc) Thus, power demand varies widely depending upon the solutions found by individual graziers Values of 5 - 48 kW h per day are encountered with 8 - 10 kW h being most common

4 1 2 Present electricity generating practice

Homesteads with small 32 V wind-driven plants and ancient single-cylinder back-up generators stand beside homesteads with modern 25 kV A diesel sets that are run for 16 h per day. Maintenance is also as variable. In the main, present generators are 32 V d.c systems that utilize wind and diesel plant or 240 V a c diesel or petrol-only plant The 32 V systems consist of outmoded d.c generators (500 - 1500 W), a small battery bank, a crude control panel, and possibly a small (300 - 500 W) static inverter. Wiring in these low-voltage systems is often poor The use of low voltage is an invitation to tolerate substandard insulation and connections. Wiring in a 32 V household is invariably substandard for 240 V connection. Conversion of base plant to 240 V standards therefore requires complete rewiring, which escalates the cost of conversion

Despite their limitations, 32 V systems are inherently low-cost and an efficient power supply for low electricity demands. A complete system might be installed for a few thousand dollars and, if a wind generator is used, can be run for a few dollars per day This is not to say that the cost per kW h is low because the systems are very limited in power output. Their suitability, however, is declining with the growing demand for power.

The range of type, size and quality of 240 V a c diesel installation is wide Some graziers claim satisfactory performance from 4 kV A plant, while some have installed 25 kV A units By far the most common is the 8 kV A two-cylinder plant, although most would agree that this is a compromise between meeting peak loads of 10 - 12 kV A and fuel usage.

Typically, the generators are run either 4 - 5 or 10 - 16 h per day. The choice is usually based on the method used for refrigeration. If LPG refrigerators are used, then the diesel running time may be reduced to a few hours at night. In either case, the demand is not necessarily well matched to the diesel capacity. The diesel size must be such as to allow for peak loads, and for much of the time it is run at very low loads or artificially loaded with unnecessary lighting or heating to avoid engine damage. Some control switching, together with water-heater load, means that a better match is reached, but this is not a common practice. LPG is expensive in remote areas and absorption-cycle gas refrigerators are less efficient than thermostat-controlled compression-cycle units. The high capital cost of the gas refrigerators compared with 240 V a c. electric refrigerators is also an inhibiting factor However, although the capital cost of the diesel set is relatively low, the high fuel cost can also result in very expensive electricity, particularly if the diesel capacity is not well matched to the load.

The wide variety of supply systems currently installed means that there is a wide range of load profiles and related features. The load profile for a 32 V system can be expected to show a low peak of only a few kW and a low average demand. The load factor may be low but, because storage is included in the system, this is of little consequence to the overall efficiency. The capacity factor is usually high, meaning that the systems are generally well utilized.

The chief limitation of the systems is their small peak capacity (usually limited to a maximum of a few kW). The systems are usually considered to be a low-cost lighting plant and as such provide reliable, cost-effective, 24 h power supply. The total usage from such systems may be 1 - 2 kW h per day or an average of 80 W. Appliances with 32 V ratings are still in use but are becoming more difficult to obtain Interestingly, 12 V appliances are becoming more common, a result of consumer appliance developments, particularly for camping and caravanning The 32 V d.c. lighting system is quite adequate for reading and is possibly easier on the eyes than poorly regulated a.c. lighting

Diesel-only systems that do not provide refrigeration load are typically run at night (4 - 5 h) to provide lighting and some appliance loads (such as a washing machine or a television set). The average load over 24 h for such systems may be 400 - 600 W. However, the load profile for such installations during the run time usually shows a continuous high load for the diesel set (2 - 4 kW) This only applies when the consumers are well organised and undertake those tasks requiring electricity in the few hours of run time. If the diesel set is small in capacity (say 4 - 6 kV A), then the capacity factor may be as high as 0.75 and the diesel set is efficiently utilised. If the diesel is of larger capacity, or the consumers are not well organised, then the capacity factor may be as low as 0 03

In diesel-only systems where refrigeration load is included, the average load might be 500 - 700 W. The load profile in this case may again show a high peak and low capacity factor, again with engine damage as a result. It is usual in these installations to have some dummy load connected to ensure adequate engine loading at all times. This false load leads to unnecessary fuel usage and poor economics but does maintain engine life

4 1 3 Current trends

Over the past 10 years there has been a steady move towards the installation of diesel generator sets. In parallel with this, the use of 32 V systems has declined. The use of gas or kerosene lighting has also faded out. For the next few years at least, this trend is expected to continue New technology is beginning to have an impact. Diesel-plus-battery, wind generator and solar systems are now available as alternatives to diesel-only systems. They could represent a marked improvement over the current practice of running a diesel generator alone Indications are that alternative technology, now in its infancy, will be the mainstay of power production within the next 5 - 8 years.

4 2 Isolated hotels, roadhouses, small towns and mine sites

4 2 1 Electricity requirements

The electricity demands are similar for isolated hotels, roadhouses, small towns, and small mine sites The majority of these consumers, not connected to the grid network, are located in the same geographical area as the far western district graziers. Air conditioning is a necessary demand and refrigeration in summer is imperative for the commercial survival of these concerns. Water pumping is another essential load and, in installations that provide for accommodation, can represent a major system design factor. Water purification although not currently a common demand, could represent a major load if grid power were connected

The region is sparsely populated and centres such as hotels form a valuable focus for meeting as well as providing necessary accommodation. The very fact of the remoteness means that these centres are under pressure to maintain a reliable power supply As a result, the installed power supply system is placed under quite different pressures to those of the graziers

The installations in this grouping all serve a large number of people and require, in general, a reasonably constant supply of power for loads such as refrigeration, which must have power for at least 15 h per day, and all-night outside lighting. Well-stocked and insulated refrigerators may remain cold without power supply for up to 10 h, but beyond that time there is a severe risk of food spoilage as the refrigerator warms up. In addition to refrigeration, heavy loads such as electric cooking, large-volume water heating and space cooling are also usually required. The load profile that emerges from such installations is quite different to that of the single homestead The main difference, apart from quite a significant increase in the amount of electricity required, is the flatness of the load profile compared to the quite variable load pattern found in a single homestead. This is because the consumers are generally aware of the problem of too high a peak load and have sufficient appliances installed to enable organisation of the load, *i e* load management, to suit the installed generator. Time switches and controls that limit the simultaneous turning on of heavy appliances can smooth out the load curve and reduce the peak demand.

Peak-load requirements vary depending upon the size of the installation (*i e* number of people serviced). Most installations require several refrigerators, some space cooling, electric cooking and a significant lighting load. Given that the installation is well load managed, with automatically controlled switching to limit simultaneous cutting in of appliances, peak loads of 14 to 20 kW may be expected. However, this may range as high as 30 - 40 kW in larger hotels or a mine site that uses large electric motors Rarely would the peak load requirement be less than 10 kW. However, the average load for a typical roadhouse with several refrigerators and some cooking and water heating load, but little or no accommodation, would possibly be about 3 kW (70 - 80 kW h per day). Clearly, it is difficult to generalise because the demand depends upon the number of people serviced, the degree of energy conservation practised and the nature of the particular installation. With a peak load of 15 kW and an average of 3 kW, the load factor is 0.2. If a 15 kW diesel set is run 15 h per day, the capacity factor is 0.32. This is far better than the typical homestead but still short of achieving optimal performance from a diesel set. Larger installations may further improve the system configuration by installing diesel sets of different sizes to better match the load, *i e.* achieve a higher capacity factor. In most cases, however, the capacity factor is unlikely to improve much beyond 0.4 and dummy load is still required to ensure correct engine loading.

Voltage required by all installations is 240 V a.c. Frequency and waveform requirements may be less exacting than for industrial installations in the city. Most appliances used in these remote installations will tolerate voltage and frequency fluctuations that may occur from time to time with diesel sets. However, modern control equipment should be capable of quite accurate stability control. As with the homestead power supply, r f interference cannot be tolerated as it may disrupt radio communications.

4 2 2 Present electricity generating practice

Without exception the present generating system used in these installations is a medium-sized diesel set (15 - 35 kV A). The systems are almost always without back-up (from plant such as a 32 V generator) because the demand is consistently high. Emergency supply in the event of a breakdown is provided by a second diesel set. The diesel engine is usually a low-speed (1500 rev min^{-1}) type with a 10 000 h service life before major overhaul. With a power availability demand of 15 - 20 h per day, this life may be reached in less than 18 months. Typical installations claim a maximum trouble-free life for a new generator of 2 - 3 years. To maintain such a power supply is an increasing burden. Costs of fuel, labour and replacement parts are escalating. Supply is being maintained in many installations by the constant efforts of the proprietor. It is little wonder that local electricity supply authorities are continually pressured for grid extensions in such areas

4 2 3 Current trends

With the rising cost of running the diesel units, consumers are seeking alternative power supply options. Some interest is apparent in battery storage systems, either as a prime source in smaller installations or as a "piggy-back" system in larger installations The interest is in the better matching of load and engine performance. Current trends seem to be toward more rational use of the existing diesel set with a growing interest in fuel-saving add-on renewable energy systems

4.3 Isolated farms within the grid-serviced region

4.3.1 Electricity requirements

A small group of off-grid farm-based consumers (perhaps a few hundred) exists within the area serviced by the conventional power network. This area includes both the central western and eastern seaboard geographical regions (Fig. 1). The entire area is well populated and most farms would be connected to grid power or are within a few kilometres of a power line. However, there exist pockets of developing farmland in which farmers face costly connection fees. Such farms seek alternative power supply systems and, like the western district graziers, usually install a single diesel set. Where diesels are used, consumers tend to fit as much activity as possible into the periods of diesel running. As a result, the observed load curve is of short duration and with a high average for the run time

The farms are often isolated by rugged terrain and lend themselves to renewable energy system use. Wind and water generators may be used where individual sites permit. Solar cells are able to take advantage of sunny exposures in the coastal area or in the clear air of mountain regions. The climatic and other physical features of the farms vary widely: coastal regions have mild climates, thus little space heating or cooling is required; farms in mountain regions may require space heating. In general, the climate is more hospitable than the far western district and the farms smaller. This is reflected in lower electrical demand. Refrigerators need not be as large nor use as much power, the need for space cooling is reduced and the farm size (and therefore the electricity consuming workload) is less. However, the farmer needs to have periods of recreation and the usual list of low-power farm jobs have to be done Thus the demand-load curve reflects the need for power availability for long hours of low load as well as periodic peak loads Many installations operate on small diesel sets (4 - 5 kV A), thus providing a practical peak limit of 3 - 4 kW. In many cases, this would be considered adequate. However, with the prospect of conventional power supply availability, the peak could be expected to rise to 5 - 6 kW through the relaxation of load-management practices.

Many farmers express the frustration of being tied to the diesel runtime for farm repair work The inconvenience of diesel generator power supply is made more acute for these farmers by the fact that many of them have come from areas supplied by the grid network. Lack of a continuous power supply means that excursions away from the farm for even short periods become difficult if food is to be kept frozen, etc. Often neighbours are required to start the diesel plant each day the farm is unattended.

A farmer in this group may require 8 kW h per day or an average of 333 W Load factor values of 0.1 or less may be encountered. An improvement in load factor over that for the western district graziers may be expected in many installations, reflecting the lower peak load for similar average demands. Even with the improved load factor, it would not be a proposition to consider running a diesel set for long periods without dummy load provision. In practice, the diesel set is run for only short periods and the capacity factor may be as high as 0 6 - 0.7 in an installation where the load is well managed In the case of continuous supply, the low load factor indicates that a simple diesel-only system is not satisfactory.

4 3 2 Present electricity generating practice

As mentioned, most farms in this group use small (4 - 5 kV A) diesel generators to supply household power These are run for a few hours each day There are, however, a number of farms that use some form of renewable energy system, based either on photovoltaic panels or a wind generator. Some farms have a modern automatic diesel generator installed, but by far the most common installation consists of an old manual-start generator with remote stop Heavy specialist loads, such as welding and pumping, may be met by dedicated engines This system of providing power by separately matching load and supply results in a high capacity factor (*i e* 0.6 - 0 7) for the main diesel generator. This well-loaded diesel generator need only be run for 1 - 2 h in the morning and 3 - 4 h at night. The low run time and high capacity factor mean that the generator is well utilised. Refrigeration must be powered separately in these systems, usually by using LPG.

The cost of electricity, although still high, is considered reasonable by most farmers. Real cost of generation varies between installations, depending upon how well the farmer is organised. The cost is misleading, however, because it does not take into account the total cost of energy provision to the farm. The cost of LPG used for loads that could be electrified must therefore be included in any comparison with alternative systems.

Renewable energy systems currently installed are commonly low-power low-cost supplies. Peak power is limited to 1 - 2 kW. Photovoltaic systems usually consist of four to six 40 W panels, but some have as many as ten panels installed. Such systems provide 0.8 - 2 kW h per day. Wind generator systems are of similar capacity, although in areas of high wind the net energy generated may be higher.

The small diesel generators provide 240 V a.c power with reasonable reliability Voltage fluctuations are apparent near full load and frequency control depends upon the particular unit installed. The renewable energy systems mainly provide low-voltage (24 - 48 V) d.c. power for lighting and small appliance use. Limited use of inverters extends the power supply to 240 V a.c (1 - 2 kV A) in some installations

4 3 3 Current trends

Where grid connection costs remain high, the demand for 240 V continuous power supply has led to the development of new power systems The use of advanced stand-alone power systems is expected to increase in the future, *e g* diesel-plus-battery systems that can provide 24 h power at a competitive cost.

In summary, whether by grid connection or alternative systems, the current trend is towards provision of power at a standard equivalent to that provided by the city grid network. With the popularity of small-hectare farming, there will be increasing pressure for grid extensions

4 4 *Weekend or part-time residences (holiday homes)*

4 4 1 *Electricity requirements*

Consumers in this group are scattered throughout the eastern part of the State Many are located near the coast but the grouping also includes those consumers located in bushland settings along the Great Dividing Range With the popularity of hobby farms increasing, the number of sites where power is required in the next few years is also likely to increase. Currently, several hundred such sites exist. In general, the homes are situated in areas with mild climate and access to alternative sources of energy, such as wood for space heating, water heating, and cooking. The coastal locations are often well placed to take advantage of renewable energy systems. The access to wood and limited, or part-time, occupations results in very low electrical demand with power required for only short periods each week. Many homes operate without any electricity at all by using LPG for lighting and refrigeration Where electricity is required, it is for low-power domestic appliances only

The load profile of such installations varies widely. In many instances, however, a peak of only a few kW would be expected. Power may be required continuously if refrigeration is included The average power may be limited to a few tens of watts. As a result of this low demand, the load factor would also be expected to be low if occasional use is made of high peak a.c. demands such as an electric kettle or refrigerator-motor-starting load. However, the low demand also means that almost any type of power supply can be tolerated Direct current lighting and low-voltage d c. refrigeration allow a wide range of supply system alternatives. Voltage and frequency stability are not critical.

4 4 2 *Present electricity generating practice*

The generation of electricity for these installations varies widely Some homes use a small diesel generator but many rely on portable petrol-driven generators. Increasing use is being made of photovoltaic panels, charging a small battery bank. Some low-cost reconditioned wind generators are also used to charge batteries for lighting In some cases, lights are hooked up directly to an automotive battery Running costs of a small petrol generator are quite high and are compounded by the short engine life. However, since they are available in smaller sizes than diesels, they are better suited to low load demands and provide an adequate low-cost system.

4 4 3 *Current trends*

At present, consumers are interested in photovoltaic systems and this interest is expected to increase. Unless the capital cost of small wind generators decreases significantly, they are not expected to be able to meet the low budget set for most installations Second-hand wind generators will continue to be used

In summary this group of consumers is expected to continue to operate small engine-driven generators augmented by small solar or wind energy/

battery systems. Cost of electricity, per kW h, may be high, but is not the main concern for consumers in this group. Their principal interest is to achieve some form of power supply at the lowest capital cost.

4 5 Alternative-lifestyle community groups

4 5 1 Electricity requirements

A typical community in this group consists of several homes and some small workshops. It is difficult to gain a true estimate of the number of such small communities in New South Wales, however, there are probably many hundreds of remote community sites where some form of power is required Many of the groups are situated along the eastern seaboard region where they have the advantage of mild climate and ample alternative sources of energy such as wood. They are usually well placed to utilise renewable sources of energy because low electrical demand and generally low cash flow means that appropriate low-cost systems can be devised that utilise wind, solar or water power. Electrical demand is essentially limited to lighting and some small d.c appliances Most heating is based on wood, and refrigeration is not usually a necessity Power tools are minimal and very few electric motors are in use.

It is difficult to formulate a typical load profile for individual dwellings in such communities because the load is so small and is very user specific. However, peak demand for an individual home may be as low as 1 kW. Average demand is usually low for long periods (perhaps only for 2 - 3 lights) but power is required continuously. It is most common for power needs to be met by individual household systems. If the community has a central power supply system then a consistent load profile may be determined because user-specific variations tend to be evened out The profile would be generally flat with a low peak of some few kW. The average power requirements of the community are chiefly determined by the number of dwellings. 240 V a.c. is sometimes desired, although low-voltage d.c. power is most commonly used. Voltage and frequency fluctuations are not critical.

4 5 2 Present electricity generating practice

Although a great deal of variety is apparent, present systems aim to achieve consistent daily power supply. The advent of photovoltaic panels during the mid-1970s led to a general swing toward installation of low-voltage systems based on this technology. At present, many homes are powered by small (1 - 4 panel array) solar systems Supply is mostly d.c. but some small (0.5 - 1.5 kW) inverters are used to achieve 240 V a c. Rebuilt wind generators and home-made hydroelectric generators are also used These systems are able to deliver daily power at a far lower cost than, say, a petrol-driven generator.

4 5 3 Current trends

It is not expected that the financial status of the community-based consumers will change in the near future. The need for a low-power continuous supply is also expected to continue. This demand pattern suits systems such as those based on photovoltaic panels. The installation of such systems is expected to continue and replace any petrol-driven generators currently used

5. New South Wales Government projects

Economic analyses of alternative power supply systems for remote areas show that in many situations capital-intensive technologies can provide power at a competitive life-cycle cost. In reality, however, cash-flow restrictions often mean that the most economical solution in the long term cannot be financed. This situation is the chief reason for the current widespread use of diesel generators as they have the least impact on short-term cash flow. Renewable energy systems, on the other hand, have a high initial capital cost and often cannot be seriously considered by lower income farmers.

Although it is difficult to estimate what reductions in capital costs might occur with technical advances and increased sales, the Government of New South Wales is undertaking a demonstration programme aimed at evaluating a combination of technologies that may be cost effective for remote area residents in the State in the short term. At the same time investigations are being made into ways of financing such systems. Three stand-alone power systems using renewable energy technologies are currently being installed at remote homesteads that would otherwise use diesel generators. They will be field-tested for two years and monitored in detail The three systems are photovoltaic/diesel, wind/photovoltaic, and wind/diesel.

Photovoltaic/diesel This system is designed to provide 5000 kW h per year (13.5 kW h per day) from 2.5 kW of photovoltaic cells and a 5 kV A diesel generator. It incorporates a 5 kW inverter and 35 kW h of battery storage at 110 V.

Wind/photovoltaic This system is designed to provide 3000 kW h per year (8 kW h per day) from a 1 kW (swept area 7 m^2) wind generator and 1.2 kW of photovoltaic cells It incorporates a 5 kW inverter and 29 kW h of battery storage at 48 V.

Wind/diesel This system is designed to provide 5000 kW h per year (13.5 kW h per day) from a 4.5 kW (15 m^2) wind generator and a 4 kV A diesel generator It incorporates a 10 kW inverter and 26 kW h of battery storage at 240 V.

All three systems are automatically controlled to make best use of available renewable energy sources and supply 240 V a.c. power continuously. They are of modular construction and are self-contained. Battery banks and diesel generators are housed in insulated containers. Photo-

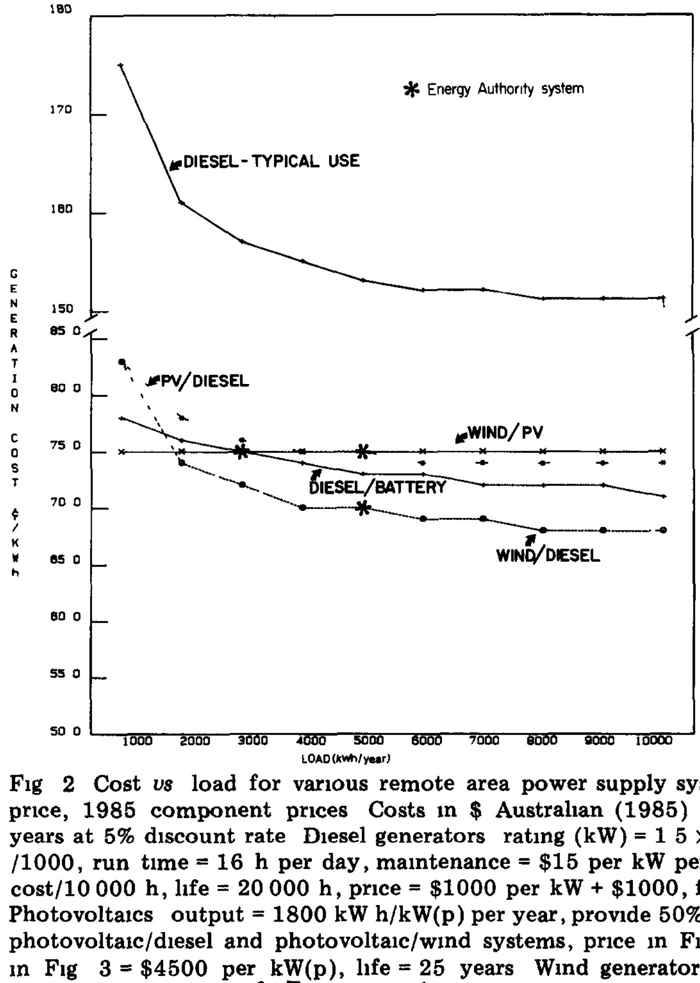

Fig 2 Cost *vs* load for various remote area power supply systems Constant real fuel price, 1985 component prices Costs in \$ Australian (1985) Systems costed over 25 years at 5% discount rate Diesel generators rating (kW) = 1 5 × av annual load in kW h /1000, run time = 16 h per day, maintenance = \$15 per kW per 1000 h and 50% initial cost/10 000 h, life = 20 000 h, price = \$1000 per kW + \$1000, fuel price = 52 ¢ per litre Photovoltaics output = 1800 kW h/kW(p) per year, provide 50% of annual load in hybrid photovoltaic/diesel and photovoltaic/wind systems, price in Fig 2 = \$9000 per kW(p), in Fig 3 = \$4500 per kW(p), life = 25 years Wind generators output = 0 25 $\rho \bar{V}^3$ A, where ρ = 1 225 kg m^{-3}, $\bar{V}$ = 4 5 m s^{-1}, provide 50% of annual load in hybrid wind/diesel and PV/wind systems, price = \$900 per m^2, maintenance = 2% of capital cost per annum, life = 20 years Batteries discharge level = 50%, life = 6 years, price = \$130 per kW h, storage provided = 1 day effective, efficiency output/input = 85% Inverters rating (kW continuous) = annual load in kW h/1000, price = \$1500 per kW, life = 20 years, efficiency output/input = 95%

voltaic arrays are mounted on the container and their inclination can be readily adjusted. Wind generators are adjacent to the containers, with one having a lattice tower and the other a spun concrete tower.

This project provides the opportunity to gain detailed performance data on components and systems that will assist in the further development of commercial systems. It will also increase public awareness of these technologies and hasten their acceptance and use. To illustrate the relative costs of electricity supply from these and other system options currently available, life-cycle costs, based on current component prices, have been

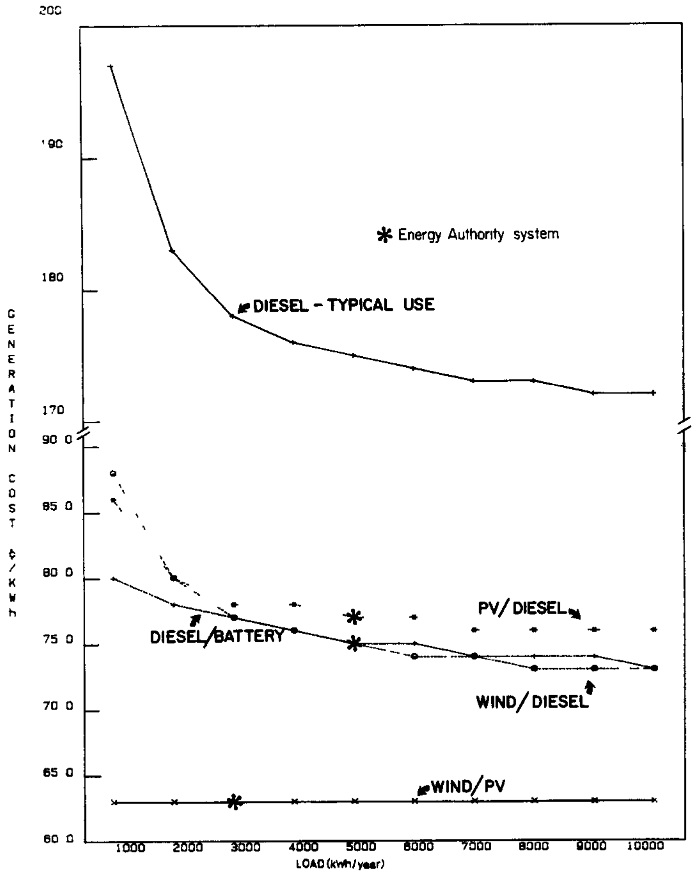

Fig 3 Cost *vs* load for various remote area power supply systems Fuel price increasing 2% per annum (real), photovoltaic prices 50% of 1985 prices (See legend to Fig 2 for data.)

calculated. These are shown in Fig. 2 for a range of possible household loads The expected costs of power supply over 25 years for the three systems being constructed for the Authority are indicated. They fall in the range 70 - 75 ¢ per kW h.

An ideal diesel-only system may be the most cost-effective option at current subsidised fuel prices, although it does not allow the convenience of 24 h power. However, diesel generators are typically not run at optimum load levels and this results in considerably higher electricity costs, as shown

The requirement for 24 h power supply in Australia is demonstrated by consumer willingness to pay premium prices (some over $50 000) for grid connection. However, the provision of a continuous supply from stand-alone power systems involves a cost penalty. The cost of power from diesel/battery and renewable energy based systems reflects this. Nevertheless, these systems are still more cost effective than either typical diesel-only systems or grid extension in many isolated areas of Australia.

As an example of possible future costs for power from the systems shown in Fig. 2, a photovoltaic price reduction of 50% (from $9000 per kW(p) to $4500 per kW(p)), which might be anticipated by 1990 and a fuel price escalation of 2% per annum, leads to an electricity price reduction of 15% - 20% in the photovoltaic/wind/battery system to 60 - 65 ¢ per kW h On the other hand, there is little change in electricity price for the photovoltaic/diesel/battery system, thus indicating that an increase in photovoltaic contribution would be cost effective. In fact, a photovoltaic/battery system may be the lowest cost option. The effect of these possible future price trends on electricity costs from stand-alone power systems is shown in Fig. 3.

The Energy Authority of New South Wales is also investigating the use of renewable energy technologies and battery/inverter systems for isolated community power supply as an alternative to diesel power stations.

6. Conclusion

Recent technical developments are increasing the options for stand-alone power supply Price trends indicate that systems based on these new technologies can already provide viable alternatives to grid extension or traditional diesel-only power systems in many areas

However, little data currently exist on system performance, component life, or consumer load profiles. The Energy Authority of New South Wales has undertaken a number of studies on remote area power supply and is currently evaluating renewable energy based systems that incorporate these promising new technologies.

Renewable energy technologies, in particular, have a high initial capital cost, even though their lifetime running costs may be low. The Energy Authority of New South Wales is examining ways of alleviating the capital cost problem where the consumer, and the community at large, would benefit from use of renewable energy based, stand-alone, power systems.

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