RENEWABLE ENERGY OPTIONS FOR REMOTE AREA POWER SUPPLY

W W S Charters, Reader in Mechanical Engineering
University of Melbourne, Victoria, Australia
and Chairman
Victorian Solar Energy Council, Victoria, Australia

ABSTRACT

Stand alone systems based on photovoltaic modules with battery storage or wind power generation with battery storage, in a range of system sizes from a few watts to several hundred kilowatts; and grid connected systems based on the same technologies and on solar thermal electric technologies, are available in demonstration form up to 1-10 MW of electrical output with plans for 100 MW schemes in the conceptual design stage. These solar and wind technologies may prove most cost effective in the small scale when combined with a hybrid plant using petrol or diesel engine generators. Specific examples are cited to show the relative economics of the various systems using up-to-date Australian data, where remote area applications are possibly more similar to those in developing countries than those in the developed nations of the world.

INTRODUCTION

The technology associated with remote area grid extension is well known and significant improvements are not likely. Connection to the main state grids in Australia is now only economically viable for those homesteads located within a few kilometres of existing network systems (Figure 1). The cost of the connection depends heavily on the type of terrain traversed, the connection length, and the particular system employed. In Australia, the cheapest system used is the single wire earth return using a single steel wire which is operated at 10-20kV with a step down transformer providing up to 20kW at 240V AC (Figure 2). These lines are often limited in length by safety requirements to about 20km total length. If longer connections are envisaged more sophisticated and hence more expensive systems must be used.

Typical costs of electricity to the customer are given in Table 1 for Victoria, a heavily industrialised state in SE Australia, and for a selection of countries in SE Asia and the Pacific. The large variations in charges are due to many socio-economic and political factors as well as the power generation technology and cost of fuel used. The process of tariff setting for electricity and other fuel prices is really beyond the scope of this paper but the availability of remote area energy subsidies in many countries tends to mask the real costs to the community of providing power to remote locations. It should be noted that a connection cost of A$40,000 equates to an electricity supply cost of 65¢/kwh. Typical costs for electricity generation from diesel engines in Australia lie in the range of A$0.14-A$3/kwh.

As the discussion will be limited to the available options for electrical or mechanical power supply in areas not serviced by main electrical grid systems, the following renewable energy options are available for consideration:

1. Wind generations systems
2. Solar thermal systems

3. Photovoltaic systems
4. Mini and micro hydro plant
5. Biogas or biomass engine plant
6. Hybrid systems involving two or more of the previous options (Figure 3).

In many remote areas the power is generated at present using small scale petrol or diesel generators with or without battery storage depending on the expected power usage pattern. Recent developments in load management control involving the use of large scale battery storage can substantially reduce the costs associated with conventional diesel generation and are appropriate for consideration with connection to renewable energy technologies. Virtually all hybrid plants based on windpower, photovoltaics, other renewable energy options and a conventional engine generator include the facility to charge a battery bank.

ESTIMATION OF TOTAL LOAD

Before an electrical supply system can be designed, it is essential to have a realistic appraisal of the likely peak and average loads associated with particular appliances and the usage patterns to calculate the expected daily energy demand. A listing of typical appliances is given in Table 2 and the energy demand on a daily basis is shown on the same table. This type of preliminary analysis is vital because of the high capital cost of the renewable energy plant particularly the photovoltaic systems. Careful note should be made of the fact that the peak demand of some of the appliances is of the order of 2-5 times the appliance rating and that the installed system has to cope with this instantaneous requirement.

BASIS FOR COSTING OF RENEWABLE ENERGY SYSTEMS

The cost of electricity generation from all renewable energy sources has to be costed over the total life of the installation if a fair comparison is to be made with conventional electrical generating plant. As the systems will be installed away from main grid systems no credit can generally be given, in an economic sense, to power generated above the amount considered necessary for operation of the connected plant. This life cycle costing method can lead to two forms of comparison one based on least present worth and one based on annualised cost of electricity. Assumptions which need to be made include the actual plant life, rates of inflation and discount, fuel costs and fuel usage rates, battery bank conversion efficiencies, and costs for operation and maintenance of the plant. The assumed capital costs of the various system components have been taken from current retail prices within Australia with no allowance being made for subsidies, taxation, or other economic factors. The estimation of plant life is based on manufacturers data and current commercial guarantees.

OUTLINE OF RENEWABLE ENERGY TECHNOLOGIES FOR POWER GENERATION

Wind generation systems

Recent developments in wind generators have led to the increased availability of well designed units with the horizontal axis machine still the most preferred design. Modern machines offer considerable improvements in performance through the use of low speed, permanent magnet, brushless alternators which are available up to 15kw rated output and have a long service life in excess of 20 years. They are available with full wave rectification to produce low ripple DC for charging battery storage and with overcharge control using simple voltage limiter shut down.

The installed cost of small machines in the order of 1 to 5 kW is approximately A$2000-3000 whereas the cost of medium to large machines 15-150kW capacity may be as low as A$1000. Most studies indicate economic viability for wind systems when there is wind availability at a site corresponding to an average wind speed of 5m/s. In practice special attention must be paid to the particular design characteristics of the chosen machine, and the characterisation of wind at the site including wind turbulence effects.

A modern wind turbine rated at 4.5 kW may be expected to produce more than 4500 kWh/yr at a site with an annual average wind speed of 4-5m/s, at a machine cost including tower of about A$1600 per rated kilowatt. The full system cost, including all the power conditioning, would be about A$17,500 giving an electricity cost of about A60¢/kWh.

Solar thermal systems

The central receiver or power tower systems so far installed have nearly all been in excess of 1MW rated output and it appears unlikely that these solar systems would be cost effective in small module sizes. Studies carried out in Australia for the Northern Territory indicate that such systems could produce electricity at a cost in excess of A$1.33/kWh and at an installed cost of about A$8,500 per installed kilowatt.

In the smaller power ranges the preferred options would appear to lie with fixed concentrators, with low temperature systems using flat plate collectors, and with solar ponds. Although it is difficult to extract much hard data on costs for these solar thermal systems, a tentative costing of the price of electricity produced can be obtained using a discounted cash flow analysis. Under the assumptions given a comparison is made in Figure 4. Lower costs of electricity are achieved using flat plate systems or fixed concentrator systems. Central receiver systems are vastly more expensive. From this preliminary analysis, vacuum tube collectors and salt gradient solar ponds lie somewhere in the mid range but hold out the promise of substantial reduction with further development.

Photovoltaic systems

From the operational and maintenance point of view, these systems appear to offer the simplest method of power generation (Figure 5). The panels are usually designed to charge a 12V battery but may be connected to charge 24, 32, 48 or even 110V battery banks. A typical polycrystalline silicon panel, encapsulated with a clear low reflective cover, may be purchased off the shelf at about A$400 for 37 watts peak output. Such a panel will supply an open circuit voltage of 20V with a short circuit current of 2.5A. It is reasonable to assume that the balance of a system component cost will be of the same order as the cost of the panels in most installations requiring storage. Some recent work from the USA indicates the advantages to be gained from tracking PV systems but the output gain must be weighed always against the increased system complexity and requirement for maintenance.

Micro and mini hydro plant

In the correct locations, as for wind systems, small scale hydro is both technically and economically viable. Design and installation of such systems tends to be straightforward but there is a minimum requirement of 20m head and about 40L/s flow to ensure a continuous rated turbine output of 4kW. The total installed cost of such plant tends to lie in the range of A$1000-2000/installed kW.

Biomass or biogas engine power plant

In some areas it may be feasible to consider the production of wood as a renewable resource. Wood production rates vary substantially with soil types, tree species, rainfall and soil conditions. Cappicing systems generally provide faster production after harvesting and minimise the need for replanting. Indications are that a farmer in the 350-400 mm rainfall areas could be energy self-sufficient using fuelwood from a plantation of 2-4 hectares. Considerable work has been undertaken recently to improve wood stove efficiencies so that direct combustion in a wood boiler can be considered for steam production (Table 3).

Methane production for use in relatively conventional internal combustion engines is yet another option through the biogas route. The digestion process proceeds well provided the temperature control is maintained either at 32-37°C or at 50-55°C depending on the type of bacteria chosen. Animal wastes tend to require about 10-15 days residence time and about 20% of the gas produced may have to be used for maintaining digester temperatures. After removal of the CO_2 contained the gas may be compressed and used in internal combustion engines at a conversion cost of about A$1000.

Hybrid systems

Each of the methods so far discussed of producing electricity has inherent advantages and disadvantages. With hybrid systems the aim is to combine two or more of the technologies to provide an improved overall efficiency. The penalty is that a hybrid system will require more sophisticated and expensive control equipment for regulation of the plant and for matching the plant output to the required load. Various hybrid options are open including diesel/wind and diesel/PV with or without battery bank storage. Some typical examples are appended to this paper in the Australian case studies quoted.

STORAGE AND POWER CONDITIONING

For virtually all renewable energy options it is critical to provide adequate storage for lull periods in order to satisfy the load requirements, and power conditioning of the output to successfully match the appliance characteristics. Recent developments have included the production of efficient high power inverters at relatively low cost. Typical efficiencies are in the order of 90% over the full load range and the inverters are available at 10kW or 20kW capacity, with power supply of 240V AC. The life of battery banks is highly dependent on the rate of discharge required, the boost facility provided, and the type of battery used. Boost charging is necessary at least once per month to ensure complete conversion of the plates which is not a problem with wind or diesel systems but may be difficult in minimal design PV arrays. Batteries must be of the deep discharge pure lead type which are now commercially available for lighting systems from several companies world wide. A figure of 3-5 days demand is often used when sizing the battery storage for wind or PV systems.

TECHNICAL AND ECONOMIC ANALYSES OF POWER GENERATION OPTIONS

Table 5 summarises several analyses extracted from the reference literature. The results depend to a large extent on the underlying assumptions which include capital cost of the plant, expected life for various components, maintenance and overhead charges, and other economic parameters involved with inflation and discount analyses. A typical case of water pumping, of particular reference to developing countries, is illustrated in Figure 6.

ACKNOWLEDGEMENTS

Most of the data used in this paper has been extracted from work published in Australia over the last two to three years as a result of a series of studies on remote area power supplies. These studies have been commissioned by state and federal governments in an attempt to evaluate directions for further work and to select existing options for demonstration plants in various locations within Australia.

REFERENCES

Requirements and options for remote area power supply systems in New South Wales, Energy Authority of NSW, Australia, July 1984.

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Saving energy in agriculture, National Energy Conservation Programme, Advisory Booklet No. 18, Australian Government Publishing Service, Canberra, Australia, 1984.

Renewable energy resources in Australia, National Energy Advisory Committee, Report Number 17, Australian Government Publishing Service, Canberra, July 1983.

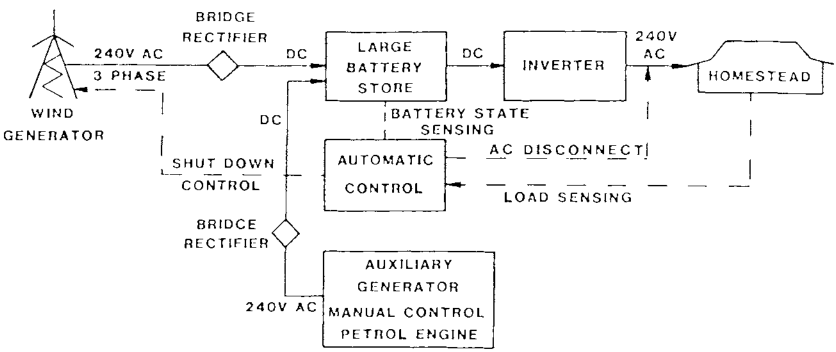
Remote area power supply workshop proceedings, Department of Resources and Energy, Canberra, Australia, May 1983.

Commercial applicability of solar ponds in Australia, Department of Resources and Energy, NERDDP Report, December 1984.

CASE STUDIES

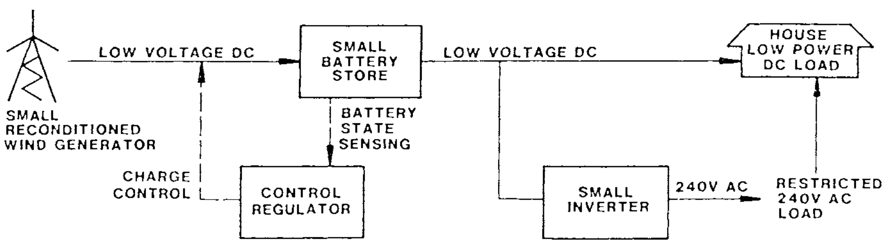
Economic Analysis 1 - Wind-driven generator system

Power System	Wind-driven generator system. Powered by a 4.5kW peak rated wind generator in an average wind speed of 5m/s. It is assumed that the wind generator is used in conjunction with a battery bank and a high efficiency inverter.
Typical User	Isolated farm within the grid services region or western district grazier, where the site is well exposed to the wind.
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of $17,500 for the complete system including battery bank, inverter, control and auxiliary generator. Residual value assumed is $2,000.
Peak Capacity	10kW, 240V AC.
Power Supply Available	24 hours per day.
Net Demand Assumed	Daily demand of 8kWh (2920 kWh pa) is considered typical and equates this system to others.
Fuel Used	Depends on wind speed distribution as to whether the auxiliary generator will be used. In this instance it is assumed the auxiliary generator does not contribute to the load.
Cost of Fuel Used	Negligible
Total Hours run	Diesel - period maintenance running only.
Payments Assumed	Batteries replaced every 7 years at $3000; operation and maintenance $100 p.a.
Discount Rate	5% over inflation.
Net Present Worth	$21,640
Annual Cost	$1730
Cost of Electricity Supplied	59 ¢/kWh



Economic Analysis 2 - Small wind generator system

Power System	A small wind driven generator power system for lighting and minor 240V AC demand. The wind generator considered is a lower cost reconditioned unit as typically used. New small wind generators are often too expensive for this type of installation. The system cost includes a small inverter (1.5kW, 240V AC) supply.
Typical User	Holiday home or small dwelling.
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of $5000 for the complete system with nil residual value.
Peak Capacity	1.5kW, 240V AC
Power Supply Available	24 hours per day DC, 1 hour per day 240V AC
Net Demand Assumed	1kWh (365 kWh p.a.)
Fuel Used	Nil
Cost of Fuel Used	Nil
Total Hours run	Nil
Payments Assumed	Batteries replaced every 7 years at $800; wind generator replaced every 7 years at $1000; operation and maintenance $50 p.a.
Discount Rate	55 over inflation.
Net Present Worth	$7800
Annual Cost	$630
Cost of Electricity Supplied	173 ¢/kWh

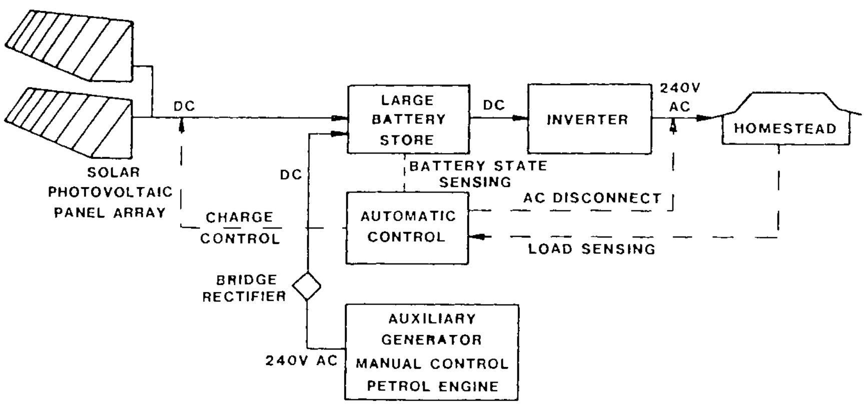


Economic Analysis 3 - Wind driven generator as a fuel saver on a large diesel generator set

Power System	A large (8kW peak rated output) wind driven generator can provide fuel saving when run in conjunction with a diesel generator where the load is consistently high or a dummy load is used. Dummy load is of no economic value. In this analysis, the full output of the wind generator is assumed to be of economic value.
Typical User	Roadhouse, small town or hotel.
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of $11,254 with a residual value of $2000 plus $9000 for diesel replacement every 6.5 years.
Peak Capacity	20kW, 240V AC.
Power Supply Available	24 hours per day.
Net Demand Assumed	Total demand 70kWh/day (25,550 kWh p.a.). Contribution from wind generator would be 17,520 kWh p.a. (in an average wind speed of 6m/s).
Fuel Used	10,600 p.a. This assumed diesel is well loaded with running, ie no loss in performance compared with diesel-only system.
Cost of Fuel Used	$3922.
Total Hours run	Diesel run-time 6.6 hours/day (2,409 hrs p.a.)
Payments Assumed	Diesel replaced every 6.5 yrs at $9000. Fuel $3922 p.a. Operation and maintenance of diesel and wind generator $500 p.a. and $150 p.a. respectively.
Discount Rate	5% over inflation.
Net Present Worth	Total system $87,800. Wind generator only $12,370.
Annual Cost	Total system $7,040. Wind generator only $990.
Cost of Electricity Supplied	Total system 28 ¢/kWh. Wind generator only 6 ¢/kWh.

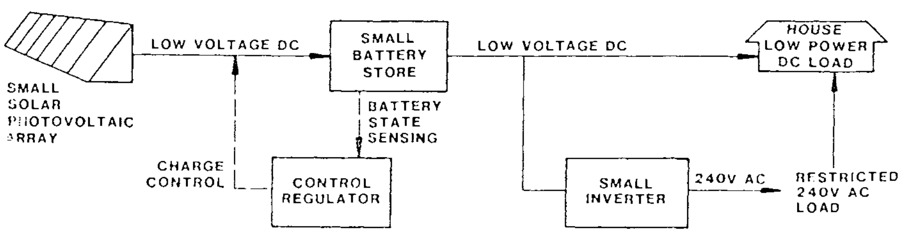
Economic Analysis 4 - Photovoltaic power system

Power System	It is assumed that a high efficiency inverter is used to achieve the required output to supply equivalent power to that of the diesel-only or diesel plus battery system. This prime source is, in this case, photovoltaic panels rather than diesel or weak generator.
Typical User	Isolated farm within the grid serviced region.
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of $34,000 for the complete system. 60 panels constitute the photovoltaic array with an expected peak output of 2.2kW. Residual value assumed is $2000.
Peak Capacity	10kW, 240V AC.
Power Supply Available	24 hours per day.
Net Demand Assumed	Daily demand of 8kWh (2,920 kWh p.a.). The array would just meet this load and expansion of the system to meet short term higher load would require an auxiliary generator to be costed in.
Fuel Used	Nil assumed if load strictly 8kWh per day or less.
Cost of Fuel Used	Nil
Total Hours run	Nil
Payments Assumed	Batteries replaced every 7 years at $3000; operation and maintenance $50 p.a.
Discount Rate	5% over inflation.
Net Present Worth	$37,250
Annual Cost	$3010
Cost of Electricity Supplied	103 ¢/kWh



Economic Analysis 5 - Small photovoltaic system

Power System	A small photovoltaic power system for lighting and minor 240V AC demand. Six 40W peak rated panels in the array. Includes a 1.5kW inverter for 240V AC supply.
Typical User	Holiday home or small dwelling.
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of $6000 for the complete system with a nil residual value.
Peak Capacity	1.5kW, 240V AC
Power Supply Available	24 hours per day DC, 1 hour per day 240V AC
Net Demand Assumed	1kWh (365 kWh p.a.)
Fuel Used	Nil
Cost of Fuel Used	Nil
Total Hours run	Nil
Payments Assumed	Batteries replaced every 7 years at $800; operation and maintenance $50 p.a.
Discount Rate	5% over inflation.
Net Present Worth	$7600
Annual Cost	$610
Cost of Electricity Supplied	167 ¢/kWh



Economic Analysis 6 - Remote grid extension

Power System	It is assumed that the grid is to be extended 5-8km from the distribution line. A SWER line is to be constructed and a step-down transformer installed. To equate the real cost of electricity supply with other systems, the electricity charge per kWh is taken as the gate price paid by the local authority rather than the tariff paid by the consumer (which includes profit).
Typical User	Isolated farm or western districts grazier. (Roadhouse small town or hotel - note that any extension of the grid is likely to go through such centres and not require 8km connections).
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of $35,000 with nil residual value.
Peak Capacity	10kW, 240V AC (20 kW)
Power Supply Available	24 hours per day
Net Demand Assumed	8kWh, of 2920 kWh p.a. (70 kWh or 25,550 kWh p.a.)
Fuel Used	Nil
Cost of Fuel Used	Nil
Total Hours run	Nil
Payments Assumed	At 3 ¢/kWh supply charge totals $88 p.a. ($770). Operation and maintenance $200 per km, totalling $1600 p.a.
Discount Rate	5% over inflation.
Net Present Worth	$56,000 ($64,530)
Annual Cost	$4,490 ($5,175)
Cost of Electricity Supplied	154 ¢/kWh (20 ¢/kWh

TABLE 1: Comparison on indicative energy prices Australia and South East Asia & Pacific Region (as of December, 1984)

Country	Electricity c/kWh		Gas (LPG) c/kg	Distillate c/litre	Petrol c/litre
Aust, Vic.	8	(2.8 off peak)	21	44	45
Fiji	20		98	46	62
Malaysia	11		70	28	55
Philippines	6		60	47	54
Thailand	8.5		45	33	50
Tonga	23		53	50	58

* All figures quoted in Australian currency (1984 dollars)
A\$ = US\$ 0.75

TABLE 2: Typical appliance energy loads

Appliance	Rating watts	Typical Peak Demand watts	Energy Demand kWh/day
Refrigerator	300	1500	2.0
Freezer	300	1500	2.0
Fan	100	100	2.0*
Lights (total)	500	200	1.0
Kitchen:			
* Blender	350)		-
* Coffee Pot	600)		0.2
* Exhaust Hood	60)	1000	0.1
* Toaster	1000)		-
* Mixer	300)		0.1
Washing machine	300	1000	0.5
Pump (small)	450	1000	0.5
Iron	1000	1000	0.5
Drill	250)		0.1
Stereo	100)		0.3
Radio/TV	100)	1000	-
Sewing machine	100)		-
Vacuum cleaner	600)		-
Total	**NA**	**8300**	**9.8**
Other loads			
Air conditioner	1600	2000	38*
Dishwasher	2400	2400	1
Hot water (storage)	3600	3600	8
Stove	6000	6000	4

* Assumes 24 hr usage

TABLE 3: Typical efficiencies and wood requirements for running wood heaters

Type	Annual heating load 5GJ (Typical of warmer areas of Australia eg Queensland)	Annual heating load 10GJ** (Typical of many areas of Australia eg SA, NSW)	Annual heating load 30GJ (Typical of colder areas of Australia eg Tasmania)
	tonnes*	tonnes	tonnes
Open fire place 10 per cent efficient	3.1	6.3	18.8
Pot-bellied stove 30 per cent efficient	1.0	2.1	6.3
Slow combustion stove 60 per cent efficient	0.5	1.0	3.1

Source S A Department of Woods and Forests and Department of Mines and Energy

Notes

* Calculated on 16 GJ + 20% moisture content, air dried wood.

** 10 GJ is the heating load required to maintain the living room temperature of a typical brick veneer house in Australia (with insulated ceiling) at about 20°C during waking hours.

TABLE 4: Economic summary for comparison of system costs

System	Daily demand kWh	240V AC Power available daily, hr	Run time for engine, hr	Net present worth A$	Annual cost A$	Power cost A4/kWh
Wind 4.5kW peak & batteries	8	24	-	21,640	1730	0.59
Wind 750W peak & batteries	1	1 (24 hr DC)	-	7800	630	1.73
PV 2.2kW peak & batteries	8	24	-	37,250	3010	1.03
PV 240W peak & batteries	1	1 (24 hr DC)	-	7600	610	1.67
25kVA diesel & wind 8kW peak	70	24	6.6	87,800	7040	0.28
Grid extension	8 **(70)**	24 **(24)**	- **(-)**	56,000 **(64,530)**	4490 **(5175)**	1.54 **(0.20)**

Figure 1: Remote areas - cost effective options for electricity generation, 1983

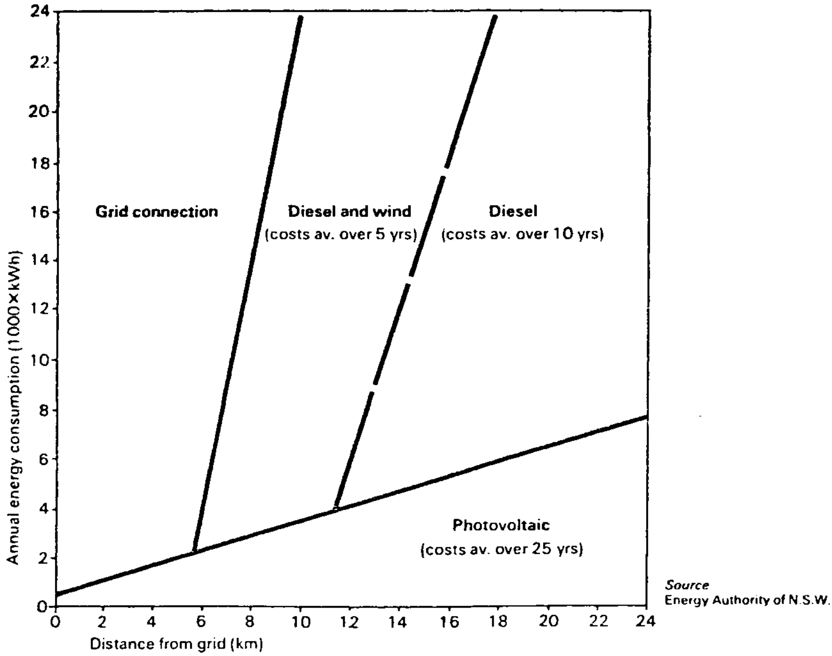


Figure 2: Remote Electricity Grid Extension

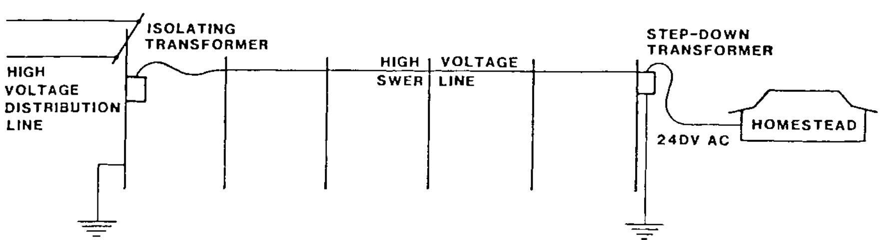


Figure 3: A hybrid power supply system layout

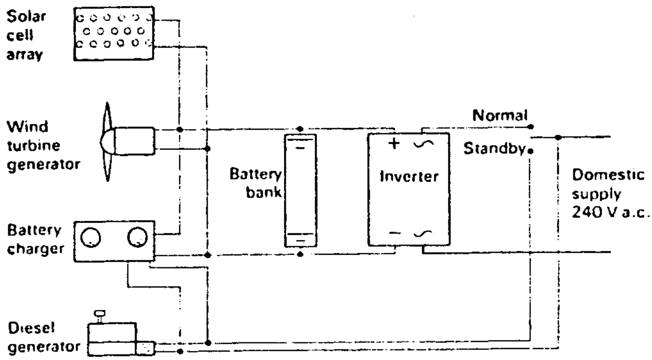


Figure 4: Solar collector cost comparison

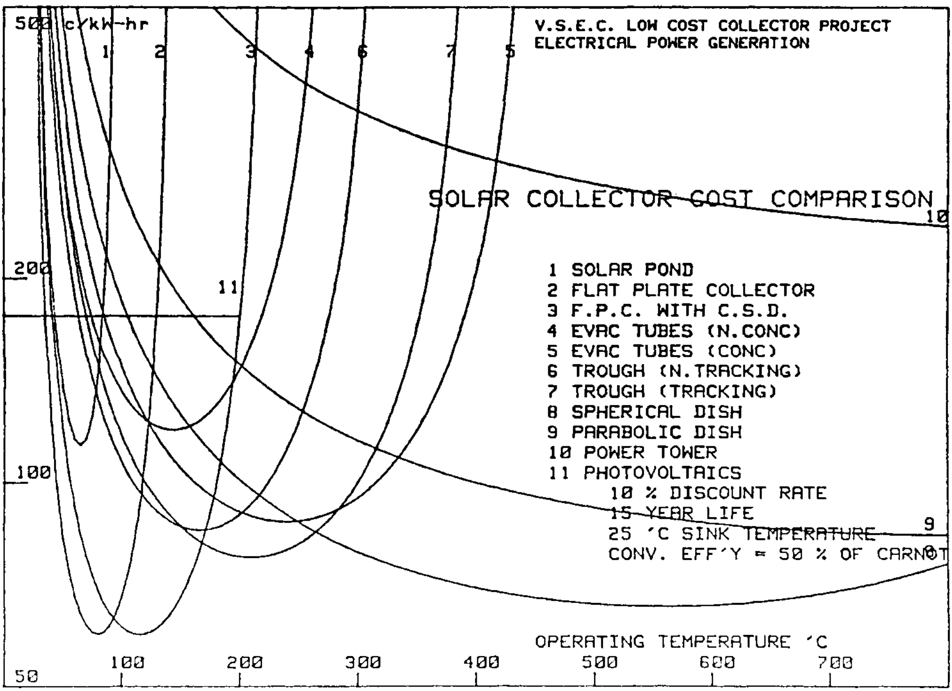


Figure 5: A typical photovoltaic system circuit

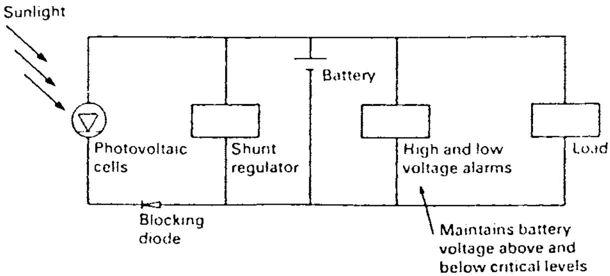
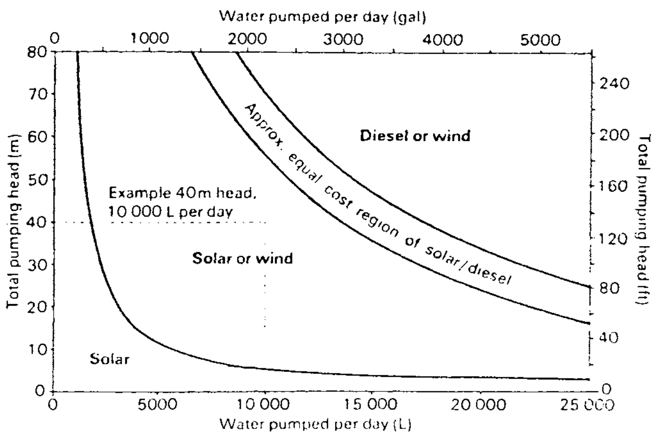


Figure 6: Bore pump sizes showing region where wind, diesel and solar (photovoltaic) systems are estimated to be most cost effective (1983 costs)



Source
Energy Authority of N S W