Journal of Power Sources, 48 (1994) 247–254

Portable power stations

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Abstract

A description is given of a novel portable power system that is suitable for isolated users of electricity. The unit comprises: (i) a bi-directional, self-paralleling, microprocessor-controlled inverter; (ii) a set of gelled–electrolyte, valve-regulated lead/acid batteries; (iii) a fuel tank and diesel-generator set; (iv) a weatherproof enclosure; (v) renewable energy component(s). The key component is the 'smart' inverter that starts and stops the generator automatically and performs float- and boost-charging functions. The system strategy is to store the energy in fuel or in a renewable resource. With this approach, the battery is used only as a source of short-term peaking power and for the low-energy demands of the load curve. This allows maximum utilization of the battery component.

The demand for stand-alone power supplies

Since the invention of electricity, there has always been the requirement for stand-alone power supplies. In fact, the first electricity power stations were small stand-alone systems that were designed for particular applications. The concept of an electrical grid, as it is known today, was not implemented until the first quarter of this century. The work of expanding the grid still continues. Electrification is a key factor that affects the standard of living and the general quality of life.

Obviously, the grid cannot be brought to every person in the world. The present estimate of people without grid power is approximately 2 billion. It is doubtful whether all these people will ever be able to be connected to conventional power. They live in remote areas, on islands, or in areas of very low population density. Furthermore, with the world's population set to double by the year 2030, and with most of this increase occurring in the areas where there is a minimal electrical grid, there appears no possibility of ever supplying grid power to many future inhabitants of the planet. Finally, with the growth of communications and inter-cultural awareness through the mass media, there is an increasing and insistent demand for services from those who are not currently connected to the networks that many take for granted.

Small stand-alone power stations

In areas where there is no likelihood of grid connection, there is a need for small, through to large, stand-alone power stations. Diesel and gas plants of 0.5 to 10 MW are readily available as standard products from a number of reputable manufacturers. Below 100 kW, the provision of stand-alone power has been more difficult and more costly per unit of electricity delivered. The reasons for this are:

SSDI 0378-7753(93)01871-E

- load diversity is often poor (large peak-to-average power ratios)
- cost of civil works for small systems can be a high proportion of the cost
- cost of automatic control systems is proportionally higher on small systems
- areas that require such systems are usually very remote and the cost of fuel is high
- there is often a lack of trained staff to operate and maintain such systems
- spare parts and assistance may be days or weeks away

The packaged, modular hybrid power station (PMHPS) can solve all these problems associated with the provision of uninterrupted power at remote sites, as follows:

(i) *Load diversity*. Loads that drop to zero or very low levels force the Genset to run at very low power levels, this means that the engine efficiency will fall off rapidly. The PMHPS has an integrated smart inverter/battery that always ensures proper loading for the Genset.

(ii) *Civil works*. The cost of buildings for, say, a 2 MW plant will not be very different from that for a 100 kW plant. The PMHPS is a packaged system that does not require elaborate housing.

(iii) *Automatic control*. In the PMHPS, the automatic control is built into the inverter. This means lower cost and higher reliability.

(iv) *High fuel costs*. The PMHPS is very efficient. It always runs the diesel at greater than half load and so maximizes fuel efficiency and minimizes maintenance costs. Also since it is a hybrid, renewable energy sources such as wind, solar and microhydro can be easily fed into the system.

(v) *Trained staff*. The PMHPS is designed to run fully automatically and completely unattended for months at a time. The only part that requires regular service is the diesel and this can usually be performed by trained local personnel.

(vi) *Spare parts*. The battery section of the unit should not require any attention for five to seven years. The inverter has a design lifetime of ten years minimum, and should require no maintenance. It is a modular unit and if an inverter fails, it can be replaced by personnel with minimum training.

The typical load curve for a single user (homestead) system is shown in Fig. 1(a). The averaged loads will peak to 4 kW, but motor starting peaks of 7 to 9 kVA may be expected. The curve assumes that energy is used for domestic purposes. The corresponding load curve for a small, multi-user (village) system is given in Fig. 2(a). Here, it is assumed that energy is used primarily for village industry and lighting at night. A communal refrigeration system has been incorporated.

Packaged modular hybrid power station

A block diagram of the Hybrilite 9000 version of a PMHPS is presented in Fig. 3(a). The ratings for a 'homestead'-sized unit are given in Table 1.

The system shown schematically in Fig. 3(b) is designed to provide most of the power directly from the solar array during the day. Some energy is stored in the battery for night-time use. Such a system forms the basis for small-scale village industrialization.

Using modular interactive inverters, the systems can be supplied in various sizes:

- 3 kW inverter and 6 kW diesel (single phase)
- 5 kW inverter and 10 kW diesel (single phase)
- 10 kW inverter and 20 kW diesel (single phase)
- 15 kW inverter and 20 kW diesel (three phase)

Figure 2(b) shows a village load profile with a solar (PV) array added to reduce both fuel use and generator size. In this example, the required generator size is about

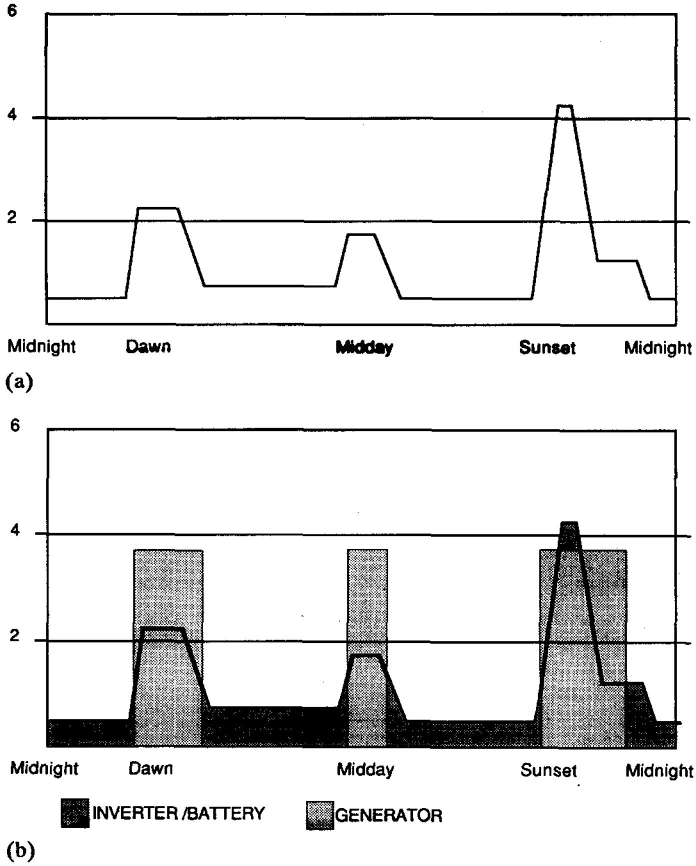

Fig. 1. Typical load curves for homestead system: (a) with and (b) without solar input.

one-third that which would be required for a stand-alone diesel set. No attempt is made to store the solar energy except for the supply of the small peaks at the top of the profile.

In the homestead counterpart (Fig. 1(b)), the controller in the inverter starts and stops the generator as shown. The periods in between are serviced by the inverter. Note that the inverter is also supplying peak loads.

Sunsine® modular sine wave inverter system

All sizes of PMHPS use a near-identical inverter module. All circuit boards, electrical connectors and the physical layout are also identical. The variations are only in the different sizes of transformers and, in the case of the three-phase versions, a single transformer is used for three modules. This modularity means that maintenance and spare parts are kept to a minimum.

Design of inverter module

The module measures approximately: 580 mm (width) × 460 mm (height) × 350 mm (depth). The module contains one each of the following components: power

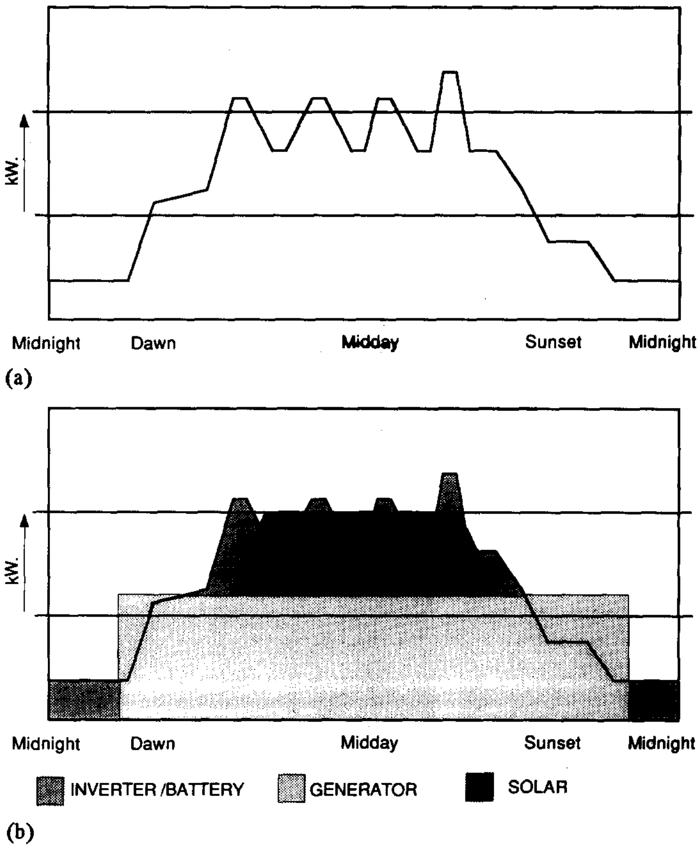

Fig. 2. Typical load curves for village system: (a) with and (b) without solar input.

board that uses power FETS; microprocessor control board; synchronizing board; communications board; transformer.

The power board implements a full 'H' bridge topology that is completely protected against short circuits, voltage transients, overtemperature, reverse polarity, low battery voltage and long- and short-term overload. Current in both arms of the 'H' bridge is measured on the power board and passed over to the microprocessor control board.

The microprocessor control board uses a microprocessor of the 8051 family that has on-board A to D conversion and pulse-width modulated outputs. The microprocessor has external RAM and ROM and a serial EPROM for parameter storage. The microprocessor may be accessed via a RS232 interface and has a resident monitor program and interface software. The circuitry performs all the sine-generation functions, i.e., intelligent current limiting, calculation of real power, reactive power, d.c. power. All the system energy relationships are available to the microprocessor and may be stored in RAM together with the voltage parameters for later retrieval. The microprocessor control board is fitted with a time-of-day clock.

The synchronising board contains CTs, VTs and relay/relay drivers for the on-board synchronizing relay or external synchronizing contactors. It acquires load and

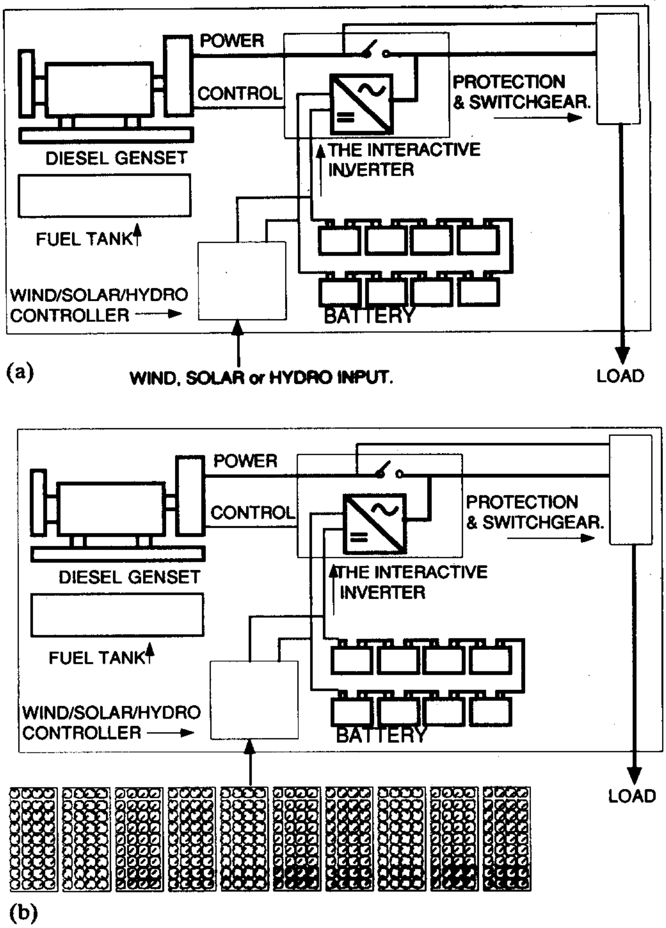

Fig. 3. Block diagram of: (a) homestead power station (Hybrilite 9000, manufactured by Dunlite Power Generation Pty. Ltd., South Australia); (b) power station with an optional solar array for fuel reduction, array rating 600 to 2400 W or 4 to 16 kWh/day.

system current and voltage so that the microprocessor may perform bumpless synchronization with external sources.

The communications board has analogue and digital inputs and digital outputs, a pulse-width modulated output, an RS232 interface, and provision for a liquid-crystal display.

The transformer provides full isolation and a guarantee of no d.c. component on the output. The integrating inductor for the 'H' bridge is incorporated in the transformer.

In general, the efficiency of the inverter is above 90% for most of its usable load range. The peak efficiency depends upon model and is around 93%. The total harmonic distortion is $<3\%$. It meets or exceeds most relevant standards for mains connection. Voltage regulation is ± 2 V over the entire load range. RF interference can be suppressed to any practical level. The sine-generation synthesis frequency is 3 kHz for 50 Hz operation and 3.6 Hz for 60 Hz operation, see Fig. 4.

TABLE 1

Ratings of a Hybrilite 9000 power station for homestead use

Inverter	3 kW, continuous 3.6 kW, 1 h 5 kW, 10 min
Generator rating	5 kW, continuous
System rating	10 kW, 10 min 8 kW, 1 h
Usable energy storage	3.8 kWh
Design energy output	5 to 40 kWh per day; depends on generator run time and renewable energy
Output frequency	50 or 60 Hz
Output voltage	220 or 240 V

Applications of inverter system

The inverter is able to perform almost all the control functions for a diesel solar or diesel/wind hybrid system in a weatherproof canopy that contains the diesel generator, the battery and the fuel tank.

In the case of the Hybrilite 9000 hybrid energy system, the inverter starts and stops the generator in response to a rather complex algorithm. The inverter measures the battery depth-to-discharge, the instantaneous load power and the energy consumed over the past 5 min and for the past 1 h. Battery voltage is also factored in, as is the battery temperature and the time of day. Renewable sources are also monitored. The inverter then starts and stops the generator so that the battery life is maximized and the fuel consumption is minimized.

As soon as the inverter has started the generator, it synchronizes itself with the generator and, in response to its own software commands, it will either add its power to that of the generator or charge the batteries by reversing the power flow through itself. In the battery charging mode, the inverter performs float/boost, constant-current/constant-voltage functions. Whilst charging batteries, it will immediately abandon charging and add its power to the generator if it senses that the generator is overloaded. The inverter will also supply VARS to assist the generator with voltage regulation.

When the inverter has finished charging the batteries and the load has dropped to a low level, it shuts down the generator. The transfer from generator to inverter and inverter to generator is break free.

The inverter starts and stops the generator automatically. As it is fully reversible, the inverter acts as a high-efficiency, temperature-compensated, unity power-factor, battery charger when required to charge batteries. The inverter performs float- and boost-charging as programmed, see Fig. 5.

An automatic voltage-controlled diesel charger is sometimes used as a 'backup' in marginal PV-based systems. The controller is set to start the diesel at a set point somewhere between 1.97 and 2 V/cell. Figure 5 shows that such a configuration is incapable of determining the depth-of-discharge with an acceptable degree of accuracy. The situation is made worse by inadequate PV input because the PV latter tends to shift the discharge towards the 100-h rate. Any attempt by the user to lessen the load will also make the situation worse, by again shifting the effective discharge towards the 100-h rate.

The irony of the above situation is that a larger battery size in comparison with the peak system load (a long autonomy period) guarantees that the battery voltage

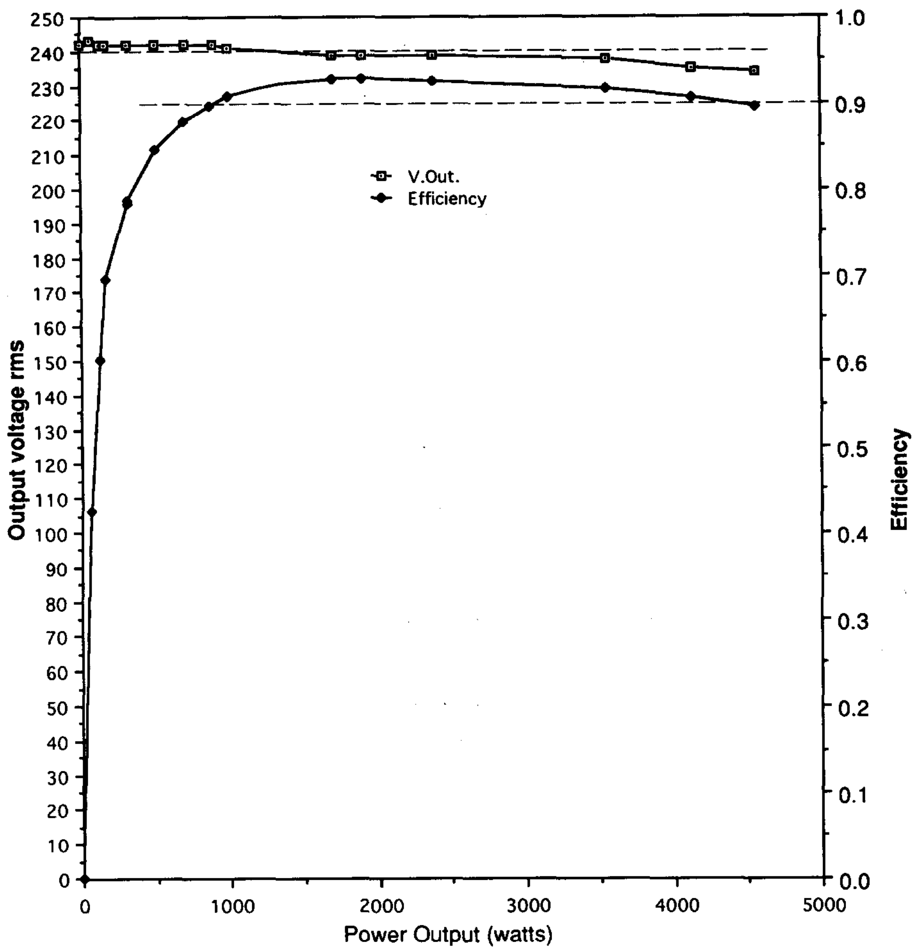

Fig. 4. Inverter-efficiency and voltage-regulation curves (Sunsine 3 kVa, 96 V, interactive inverter).

will not drop sufficiently to intersect the start set point until the battery depth-of-discharge has reached the >70% region.

Differences in the electrolyte specific gravity may cause one or more cells to reach the 100% depth-of-discharge region. After a few cycles these cells may fail.

Attempts to improve the situation by incorporating a measure of battery depth-to-discharge, using shunts or Hall effect modules, have been successful but the cost and complexity of the controller expands rapidly. An embedded controller in the inverter is ideally placed to have access to all the relevant data and to make an informed decision as to when to start and stop the generator.

Conclusions

A description has been given of both the philosophy of design and the hardware of a small portable power station. This power station is called the packaged hybrid

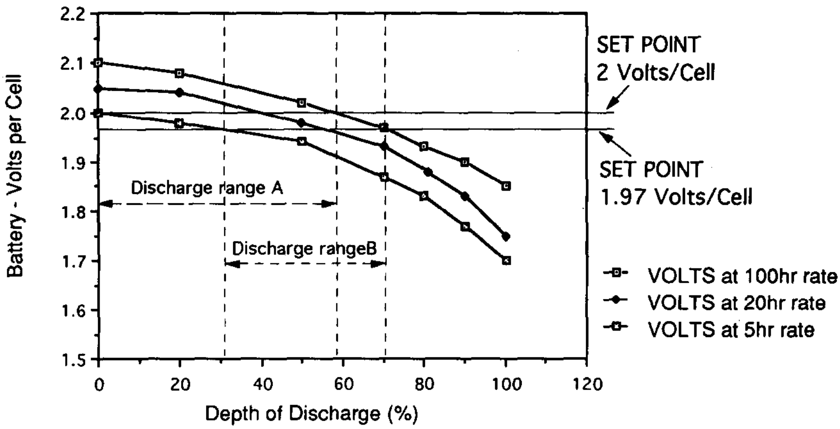

Fig. 5. Battery characteristic curves. If the controller 'start' set point is at 2 V per cell, the uncontrolled discharge range (A) is 0 to 58%. If the controller 'start' set point is at 1.97 V per cell, the uncontrolled discharge range (B) is 31 to 71%.

modular power station (PHMPS). The system makes use of the strategy of storing the energy in fuel or in the renewable resource itself. It uses the battery only as a source of short-term peaking power and for the low-energy cycle of the system. This means that battery utilization is maximized. The inverter always forces the diesel to run at the maximum loading possible. Thus, fuel is conserved, and both running costs and emissions are reduced. The systems are based on a 'smart' interactive inverter that has been developed by the author's company with the support of Siemens Ltd.