Photovoltaic water pumping and its potential for application in community water supply in South Africa

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Abstract

Photovoltaic pumping (PVP) is an established international technology with over a decade of operational use in the developing world. It can be an attractive technology due to its high reliability, low recurrent costs and utilisation of renewable energy. To date, application of PVP in South Africa has been minimal, with most systems operating on privately owned farms and game reserves. Reasons for this are: relatively high initial capital costs coupled with inadequate financing arrangements, general suspicion of a new technology which lacks a comprehensive support network and the high risk of theft and damage.

However, in the range where PVP has been shown to be economically competitive, there are an estimated 8 500 South African unserviced communities where this technology could be applied. To facilitate sustainable application of PVP for community water supply, it is necessary that a programme of pilot projects be initialised; a set of standards be established within the industry; more detailed research on economic viability be undertaken; and a comprehensive support network be developed.

Introduction

The utilisation of solar energy to power water pumps is a relatively new technology in South Africa. Investigation into the use of solar power for water supply was initiated by the United Nations Development Programme in 1978 (Kenna and Gillet, 1985). This study included literature reviews, field trials and laboratory tests. It was concluded that "there are some conditions under which solar pumps already can provide the best solution to local water needs". Several different solar technologies were investigated, including solar thermal devices. However, the most technically reliable and utilised solar technology today is photovoltaics (PV).

Photovoltaic pumping (PVP) involves the conversion of solar irradiance into electrical energy within an array of PV cells, usually constructed of monocrystalline silicon. This DC electricity is then used to drive an electrical motor and pump.

PVP for rural water supply has been utilised with varying degrees of technical and institutional success in Southern Africa. This is particularly the case in Namibia, Botswana, Lesotho and Zimbabwe. PVP projects have also been undertaken extensively in Francophone West Africa, South East Asia and South America. Furthermore, a comprehensive field testing PVP programme has been undertaken by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) in seven developing countries. However, application in South Africa has been mostly limited to privately owned farms and game reserves with a few rural water supply applications in KwaZulu-Natal and the former Transkei.

Technical description of PVP systems

PVP systems are available in various forms and can be utilised in a range of applications. Most systems are designed for use in boreholes, but there are a few systems designed to pump water from surface sources.

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The typical PVP system consists of four components: the PV array which is the power source, the controller or power conditioner which matches the power source to the load, the electrical motor and the pump (Fig. 1).

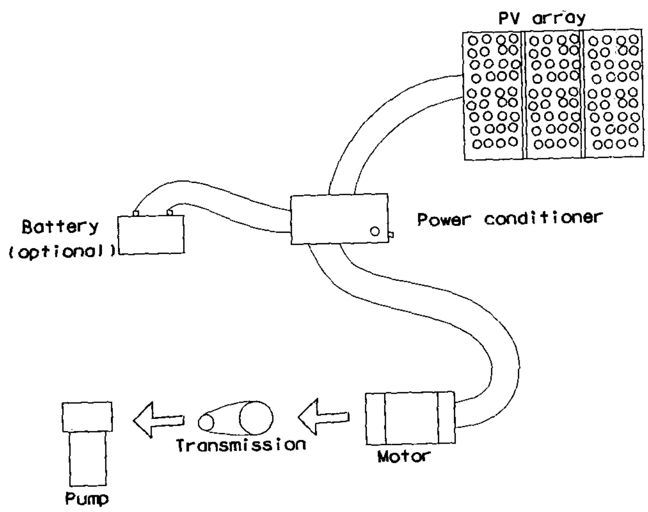

Figure 1
A typical PVP system (from Davis, 1993)

PVP systems can be categorised into DC and AC motor systems. DC motor systems run directly on the DC energy generated by the PV modules. They are more applicable in high-head low-flow situations. DC systems are the most commonly utilised in Southern Africa. AC motor systems include an inverter, which converts the DC energy to AC. This powers an AC motor and these systems are more applicable for higher flow requirements.

The units used to measure PVP systems are daily duty (m^4/d) and peak watt (Wp). The unit of daily duty is the daily water demand (m^3/d) multiplied by the total head (m). Wp is the peak power output at full solar irradiation of a PV array at noon.

Status of PVP in South Africa

At present, there are approximately 2 500 to 3 000 PVP systems operating in South Africa. The majority of these are on game reserves and private farms. Most of these systems are very small and the daily duties range between 25 and 300 m^4/d (Morris, 1995). To date, there has been very little application of these systems for rural community water supply.

PV industry today

Dissemination of PVP systems in South Africa is presently characterised by a large number of small private commercial firms (Davis et al., 1994). These firms are usually based in urban centres and operate on a localised regional basis. There are also a small number of larger organisations which supply equipment to the dealers. The industry is relatively new with most firms being in operation from between three to five years.

Many of the subsystem components of PVP systems are designed and manufactured in South Africa. These components are for relatively small systems and are generally not suited to the larger applications required for community water supply. There are presently only a few local assemblers of PV modules, with most modules being fully imported. Several of the larger international manufacturers are considering large-scale importation to South Africa in anticipation of a growing market.

Institutional and financial arrangements for PVP

Present institutional arrangements for rural water supply are unclear. Clarification of these arrangements is considered of paramount importance in order to facilitate the implementation of PVP systems where they are considered feasible.

The Department of Water Affairs and Forestry (DWAF) has the national responsibility for water resource management. Possible involvement could include policy formulation for implementation and assistance in developing an institutional network. Other organisations that will be involved are:

- Department of Mineral and Energy Affairs - development of industry standards.
- Energy and Development Group - research and implementation.
- Energy for Development Research Centre - research.
- CSIR - research and implementation.
- Eskom - extension and financing.
- Non-Government Organisations (NGOs) - implementation, financing and research.

Financing arrangements that have been operating in South Africa include programmes undertaken by Eskom and an NGO called the Rural Technology Unit (RTU). Eskom are presently implementing a policy and associated tariff programmes for remote area power supply (RAPS) in regions not to be serviced by the grid in the near future. This involves design, installation and back-up services. RAPS also provides loans for the initial capital cost which can be repaid over a period of 20 to 25 years. However, the practical utilisation of this service for remote community water supply requires more investigation.

The RTU, located in Lower Mpako of the former Transkei, has been operating as a rural development service organisation since 1989 (Davis et al., 1994). Several PVP systems were installed by the RTU in the area. The PVP installation service provided by the RTU includes technical advice, credit facilities, an installation service and maintenance backup. The financing consists of a combination of development grants, government subsidies and community cash contributions. However, the RTU is only a very small organisation operating in a specific locality. The adoption of the RTU model by similar NGOs around the country should be investigated.

Level of acceptance of PVP technology in South Africa

Although PVP systems have been used on a wide scale internationally for rural water supply, there has been a fairly low level of acceptance of this technology in South Africa. Reasons for this include:

- High initial cost with no adequate financing arrangements available.
- High risk of damage or theft of PV array, which is the most expensive component.
- Inexperience of local manufacturers and installers.
- Lack of a comprehensive support network.
- Lack of general awareness of PVP as a technical option.

PVP system viability in South Africa

Technological viability

The pumping capabilities of a range of PV modules for a typical system are shown in Fig. 2. PVP systems are optimal for low daily flow and medium head applications. This characteristic is generally desirable for application in rural community water supply. However, there are other technical factors to consider when applying any technology to rural water supply.

Isolated rural communities generally have little access to organised infrastructure. This can result in logistical problems in

Volume-Head for Different Array Sizes

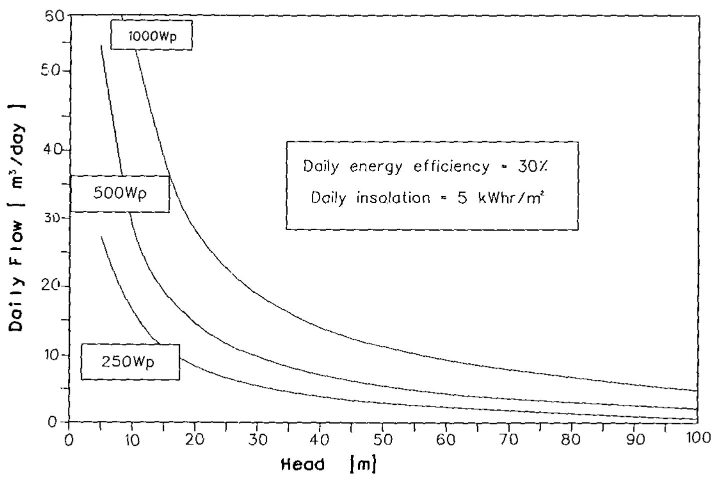

Figure 2
The pumping capabilities of a range of PV modules for a typical system (from Davis, 1993)

technology application. However, the components of PVP systems are light and easily transportable facilitating relatively easy installation in remote areas. More importantly, PVP systems require no fuel, are self-starting, require little maintenance and are reliable if installed properly.

The maintenance of PVP systems depends on the particular system. DC systems require replacement of brushes in the motor on a 2- to 3-year interval. Total maintenance on these systems, including pump maintenance, is estimated to cost R250 per event. AC systems require replacement of inverters on a statistical frequency of 5 to 10 years. Although this is a more costly exercise, it is easily undertaken by after-sales service of the supplier. PV modules are highly reliable with a design life of 20 years. They usually include a 10-year guarantee provided by the supplier.

International field testing conducted by GTZ supports the high reliability of PVP systems. In the operation of 90 systems over an average of two years, there were only 23 failure events resulting in downtime. The mean technical downtime resulting from these failures was 1.5% (Posorski, 1995).

PVP is well suited to the general groundwater environment in South Africa. More than 80% of groundwater in South Africa exists as secondary aquifers (DWAF, 1986). These aquifers are relatively shallow, yet their capacity and permeabilities are characteristically low. This effectively precludes the use of these aquifers for extensive exploitation. However, experience has shown that rural water supply requirements on a community level are relatively low. Therefore, the pumping characteristics of PVP systems shown in Fig. 2 correspond well with the typical aquifer capacity and rural water supply requirements.

PVP can also be utilised in the development of springs for water supply. This is particularly relevant for springs which are relatively remote from the target community. A PVP system can pump water to the community by day from a collection tank at the spring, which refills from the spring during the night. This application has been undertaken to some degree in Lesotho (Village Water Supply Section, 1994) and in the former Transkei (Fourie, 1995).

The large-scale exploitation of South Africa's surface water resources has already reached its maximum practical limit (DWAF, 1986). However, small-scale exploitation of surface water resources for community level water supply still has potential. This would require the construction of many small dams and weirs in close proximity to the target communities. In this application the utilisation of PVP could be technically viable.

Technical feasibility of PVP systems depends on an adequate supply- and support- institutional network. If this is not available, installation can be substandard and the repair and maintenance support may be lacking. This situation would be exacerbated by the remote nature of rural water supply application. At present, the institutional network in South Africa is less than optimal and it will require development to ensure sustainable application of PVP technology.

Economic viability

The biggest disadvantage to the utilisation of PVP systems is their high initial capital cost. The initial cost of a PVP system can be expected to be up to 4 times higher than a diesel installation alternative. This high cost can be attributed to PV panels, which are approximately 50% of the total initial system cost. However, the unit cost of PV panels is steadily decreasing with improving technology. The cost per Wp has dropped from US$10 in 1979 (Gosnell, 1981) to the present cost of US$3.5 (Morris, 1995).

Approximate initial capital costs for PVP systems for a borehole application in South Africa presently range from R25 000 for a 200 m^4/d system to R150 000 for a 2 500 m^4/d system (including PV array, subsystem and drilling of borehole). Unit cost *per capita*, assuming supply to a minimum standard of 25 ℓ/capita, is shown in Fig. 3.

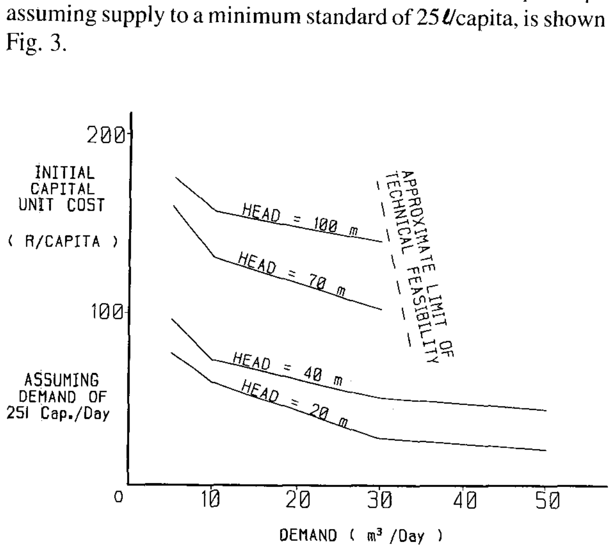

Figure 3
Unit cost of installation of PVP systems

In some cases, the minimal running costs required for PVP systems offset the high initial capital cost over time relative to diesel installations. Figure 4 shows a total cost (initial and running costs) comparison between PVP systems and diesel systems over a project life of 20 years (expected design life of PVP system).

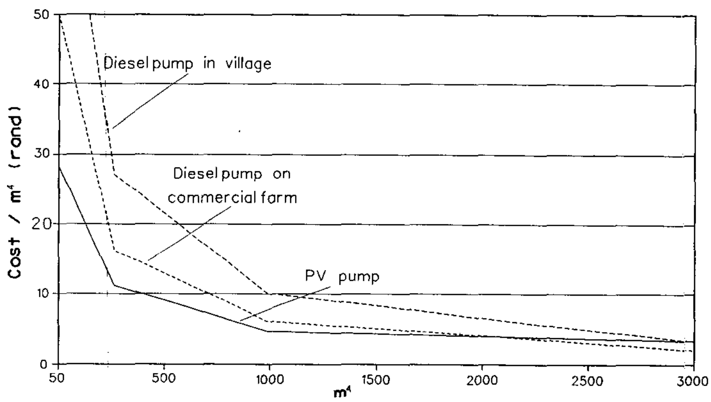

Figure 4
PVP vs. diesel pumping costs (from Davis, 1995)

The point at which PVP systems become economically viable is geographic and application specific. This is due to factors such as fuel availability and subsidisation, interest rates, import duties, infrastructure, institutional capacity etc. Estimates of this point range from a conservative 800 m^4/d for game farm application in South Africa (Davis, 1993) to 3 600 m^4/d for water supply to nomadic herdsman in Jordan (Krueger, 1995). Work undertaken by the Village Water Supply Section (1994) in Lesotho showed that for heads of up to 50 m PVP systems are economically viable when the daily duty is less than 1 300 m^4/d. For heads between 50 m and 120 m this reduces to 1 000 m^4/d. Experience of the GTZ international programme has derived a range of 1 000 m^4/d to 4 000 m^4/d (Posorski, 1995).

For applications of less than 200 m^4/d handpumps become a more economically viable option. In addition, for areas close to the established electricity grid, the use of electricity to power the motor is more economically feasible.

Windmills have been utilised for rural community water supply (Wiseman and Eberhard, 1987). The power output from windmills is proportional to the cube of the wind speed (Gosnell, 1991). Therefore, suitability of windmills is strongly site-dependant. The most significant problems with windmill application are reliability and maintenance (Wiseman and Eberhard, 1987). In 1986 there were 1 300 windmill installations in the former Transkei (at an average cost of R120 000 each) of which it was estimated that only 800 to 900 were still working (Wiseman and Eberhard, 1987).

The specific range of applications for which PVP systems are economically viable in rural community water supply in South Africa has not yet been identified. It is imperative that this be determined. This can be accomplished by desk-top comparative benefit cost analyses. These would involve the calculation of the present value of initial capital costs, operation and maintenance costs, and economic and social benefits of the different options. This should be followed by field pilot projects in several regions for different applications to verify the previous study.

This information is important for organisations such as the DWAF and the Reconstruction and Development Programme (RDP) office which are committed to subsidising the initial capital costs of water supply projects to a basic minimum service. The initial capital cost of PVP systems is presently a perceived disincentive to public authorities. If these systems are shown to be economically viable over the long term for certain applications, the subsidisation of their installation will become more attractive.

PVP system demand for rural community water supply

Considering the economic viability data outlined above, the communities that can be potentially serviced by PVP systems can be estimated. Assuming that the range at which PVP systems become uneconomical compared to diesel systems is 1 000 m^4/d to 3 000 m^4/d, the size of communities which can be serviced to a minimum standard with respect to groundwater depth can be calculated. This is shown in Fig. 5.

At this stage, it can be assumed that communities with populations below 1 000 are viable for the application of PVP systems. Assuming this, the number of unserviced communities in each Province which suit this criterion can be derived, but databases which contain rural community data are only now being developed. However, rough estimates of the number of relevant communities are shown in Table 1.

TABLE 1
ROUGH ESTIMATES OF THE NUMBER OF RELEVANT COMMUNITIES

Province	Estimated number of unserviced * communities with population under 1 000	Total number of communities
Northern Province	1 000	2 000
Mpumalanga	200	300
KwaZulu-Natal	4 000	15 000
Eastern Cape	3 000	6 000
Northwest Province	300	1 200

* Unserviced communities are assumed to be communities where supply is less than 25 ℓ/capita·d.

Although these data must be treated with caution, there is obviously a significant number of communities where PVP system application is viable. This is dependant, however, on the validity of assumptions made, which should be verified by further study.

Sociological feasibility

As for all motorised installations for rural water supply, a high level of community involvement and education is necessary to ensure the long-term sustainability of PVP systems. This includes practical involvement of the communities in planning, implementation and maintenance of installations.

Primarily, it is important that a community prefers the PVP system alternative for its successful application. As awareness of PVP systems at the 'grassroots' level is fairly limited, extensive and comprehensive education in communities is necessary. Assuming that a PVP system is chosen by a community, a programme of capacity-building would be required to ensure that the community can effectively undertake or arrange operation and maintenance. The capacity of localised NGOs and CBOs (community based organisations), such as RTU (see under **Institutional and financial arrangements for PVP**), to undertake these education and capacity-building programmes should be investigated.

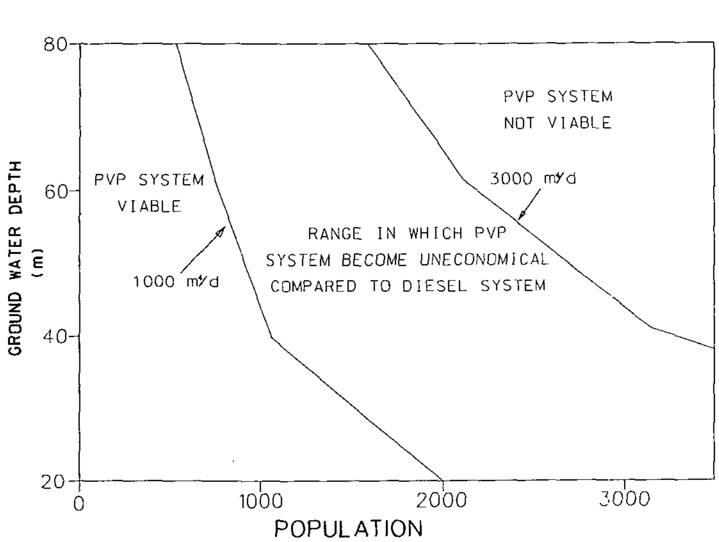

Figure 5
Community sizes for which PVP systems are viable (assuming basic needs supply of 25 ℓ/capita·d

Unlike diesel systems, PVP systems do not require high levels of operation and maintenance. However, the problem of theft and vandalism of PV modules is of particular concern due to their high cost. To reduce this risk, it is imperative for the community to be highly involved in any PVP installation project and to have complete ownership upon completion. This ownership should include the responsibility for maintenance, operation and replacement costs of damaged or stolen components.

Irrespective of the degree of ownership that a community has of an installation, the risk of damage and theft will always be present to some degree. Conventional insurance is prohibitively expensive due to the perceived risk. However, some success has been experienced by locking the panels into the frame and fitting the system with a vibration activated alarm. A community member living close to the installation would then be tasked to respond to the alarm on the occasion of its activation. This, of course, assumes that the community is fully involved in the protection of their installation.

Environmental considerations

The nature of the energy source utilised by PVP systems determines that they are environmentally friendly. Solar energy is renewable with no noxious by-products. Local utilisation of solar power is therefore significant with respect to the sustainable energy consumption on a global scale.

A network of small-scale PVP systems also results in less impact to the hydrological systems and riparian ecosystems than one large-scale water supply project. This is particularly important in many rural areas in South Africa which are presently environmentally degraded. Soil erosion and degradation of water quality are characteristically problematic in these areas due to over-utilisation of marginal lands. In addition to this, there is no risk of degradation of groundwater quality due to fuel spills.

Compatibility of PVP application with DWAF policy

The DWAF has recently published a White Paper (DWAF, 1994) which outlines the Department's new policy with specific regard to water supply and sanitation services. This policy statement reflects the change of emphasis in the DWAF which corresponds to the RDP adopted by the Government of National Unity. Therefore, it is imperative that any technology implemented for water supply ties in with this policy.

One of the key principles of the RDP is that services be provided and paid for in a manner which does not require ongoing Government funds. Previously, this was a significant problem concerning rural water supply installations for many reasons. However, one of the major advantages of PVP systems is the low level of operation and maintenance required, resulting in minimal ongoing costs. Hence, the responsibility of PVP system operation and maintenance is very much within the capacity of an organised rural community.

The RDP stresses that women must be actively involved in all levels of project development. This is particularly important in rural water supply as it is the women and childrens' responsibility to collect the water for the household. With the involvement of women in the evaluation of systems alternatives; systems with higher reliability could be viewed as more attractive. The low levels of downtime experienced by PVP systems means that women would rarely be required to collect water from traditional, and also labour intensive, sources (such as springs, rivers and wells). This time-saving results in an implicit economic benefit to the whole community.

The environmental sustainability of PVP systems discussed above is compatible with the DWAF's policy of regarding water as an "indivisible" natural resource. The implementation of small-scale PVP systems minimises detrimental externalities and ensures the protection and conservation of the natural water resource base.

Further investigation required

Internationally, much research has been undertaken on the technical and economic viability of PVP systems for rural community water supply. These studies have shown that PVP systems are sustainably viable for small-scale and remote application. However, PVP systems remain largely ignored in South Africa, particularly in the area of rural community water supply. This is due, in part, to the lack of institutional arrangements necessary for their successful application and lack of precise data on the economic feasibility of PVP system application in South Africa. Therefore, to take advantage of the potential benefits of PVP systems, further work needs to be undertaken in the following areas:

- Establishment and regulation of standards within the industry.
- Formation of a national policy regarding subsidies for installations.
- Development of a network for implementation of financing.
- Marketing of PVP systems.
- Organisational network for system installation.
- Organisational network for operation and maintenance training and support.
- Desk-top economic viability study of PVP systems against other technologies taking into account the net present value of all economic and social costs and benefits.
- Programme of pilot projects for various applications in different regions.

Many of these areas of work are dependant on each other. For example, the formulation of a national policy on subsidisation of PVP systems is dependant on the economically viable range for application of these systems. In addition to this, the work would be a combination of efforts undertaken by various government and private organisations. Therefore, it is essential that effective and continuing co-ordination of this work be undertaken.

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