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It is the policy of the Journal to publish, as far as possible, papers covering the technical, economic, political, environmental and social aspects of energy research and development carried out in or applicable to Southern Africa. Only previously unpublished work will be accepted. However, conference papers delivered but not published elsewhere are also welcomed. Short discussions, not exceeding 500 words, on articles published in the Journal are also invited. Items of general interest, news, technical notes, reviews and research results will also be included. Announcements of relevant publications, reviews, conferences, seminars and meetings will be included.

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Southern & East African Regional Energy Forum

The first *Southern & East African Regional Energy Forum* was held in Harare, Zimbabwe, in November 1990. The second one is due to be held at the Good Hope Centre, Cape Town, South Africa, on the 13-14 October 1994.

The *Southern & East African Regional Energy Forum* is held under the auspice of the World Energy Council (WEC) and is an attempt to bring together the energy experts in the region for discussions on energy matters which are best addressed at the regional level. The first Forum showed that many of the problems facing countries in the region are common, and that many of the problems are not applicable to the more developed countries of the world. The regional discussions are thus an ideal manner of bringing together those working in the various sectors of the energy market with a view to them finding out what is being done in the region and to possibly start more collaborative ventures.

The Cape Town Forum has attracted notable interest. There will be a number of energy ministers and deputy ministers from a number of countries in the Southern African region, and in fact, from beyond the region itself. A number of European companies will be exhibiting at the Exhibition which will be held concurrently with the Forum.

Over 80 papers have been offered for presentation at the Forum. As a result, the organisers have decided that the Forum would be run on a rapporteur system. Two rapporteurs have been appointed for each session, whose task it will be to summarise the papers in each session and to expand the summary to include comments on any area of the topic of the session which is not adequately covered.

The proceedings of the Forum have been divided into 8 sessions:

Session 1	WEC Commission and Regional reports
Session 2	Demand for energy
Session 3	Supply of energy
Session 4	Energy for development
Session 5	Energy and the environment
Session 6	Financial and institutional structures
Session 7	Regional cooperation
Session 8	Conclusion and recommendations

Following the Forum a number of tours have been arranged to various parts of South Africa. These tours have been selected to combine visits to places of technical interest together with visits to the scenic areas of South Africa. The technical components cover oil refining in Durban, gas-to-oil conversion at Mossgas, coal-to-oil conversion at Sasol, power plants (coal-fired, nuclear, pumped storage), open-cast coal mining, nuclear research and uranium enrichment. These will be associated with visits to a game farm or the Drakensberg or the Garden Route, etc.

For further information on the Forum, contact

Ms Wendy Izgorsek
SANCWEC
c/o Eskom
P O Box 1091
JOHANNESBURG
2000
South Africa

Tel.: +27 (11) 800 5319
Fax.: +27 (11) 800 4228

Profile: Paul Kruger

Managing Director, Sasol

Paul Kruger has been involved in the oil-from-coal business for nearly 30 years. Since qualifying as a mining engineer in 1959 from the University of the Witwatersrand and with brief spells in gold and asbestos mining, he has devoted himself to a career with Sasol. In 1973 he obtained an MBL degree from Unisa's School of Business Leadership for which he received the Old Mutual merit award. In 1986, Paul Kruger attended the Stanford Executive Program at the Graduate School of Business in California. In April 1993 he was awarded the degree of Doctor Scientiae, Honoris Causa, by the University of Port Elizabeth.

Paul Kruger's career with Sasol began in 1964 when he started working at the Sigma Colliery, Sasolburg, where he later became mine manager. After the announcement of the development of Sasol Two in 1974, Paul Kruger was made responsible for the coal exploration and coal mining project phases. He was responsible for the commissioning of Sasol Two and the development of Secunda, and later for all three of Sasol's oil-from-coal operations.

In March 1986, Paul Kruger was appointed Managing Director of Sasol with executive responsibility for the group. He is also a Board member of the Rand Afrikaans University and Chairman of the Board of the CSIR. He serves on the Advisory Panel for Energy Affairs to the Minister of Mineral and Energy Affairs. He is a council member of the South African-Britain Trade Association and the S A Foundation. Paul Kruger also serves as a member of the Advisory Committee of the Technopark in Stellenbosch. He is a trustee of the Afrikaanse Handelsinstituut and a member of the S A Akademie vir Wetenskap en Kuns.

In order to keep fit, Paul Kruger jogs. He also has a keen interest in nature and whenever possible, spends time in the bush with his camera, enjoying the wild, particularly the bird life.

He is married to Gina (née Claassen) and they have two daughters, Greta and Ciska.

*Issues and options for interconnection in Southern Africa

**W P LEWIS

While there is no apparent shortage of aggregate energy resources, in Southern Africa their distribution and access is unequal. This especially applies to harnessing resources such as, hydro. It is suggested that the challenge can be met by the interconnection of power networks. This paper looks at the institutional and technical issues and options involved for regional interconnection. The aggregation of electricity markets through a power pool is examined as a practical means of resolving institutional concerns. The types and functions of power pools are discussed and in particular, transmission access and wheeling services. The problems of bulk power transfer are reviewed and solutions are likely to involve thyristor technology. It is suggested that it may now be possible to have multi-terminal DC transmission and real-time control of AC power systems. However, the real constraint for bulk power transfer over large distances may be cost. Thus this paper concludes with a discussion of marginal costs and how these may be reduced.

Keywords: power transmission; power pools; interconnection; wheeling; marginal costs; Sub-Saharan Africa; Southern Africa; energy trading

Introduction

While commercial energy, particularly electricity, is essential for economic development, in Sub-Saharan Africa its per capita consumption is declining. Over 80% of the population relies on traditional energy forms such as, wood and charcoal, and consumption almost parallels population growth which is expected to double to about 1 000 million within 20 years. The rate of fuelwood consumption is already causing chronic deforestation and urgent action is thus required to change the balance of energy supply and demand in favour of commercial energy.

Commercial energy resources abound in Sub-Saharan Africa, and include coal, oil, natural gas, hydro and geothermal energy. Most have yet to be fully developed, with possibly the largest resource being hydro, concentrated mainly on the Central African rivers of the Zambezi and Zaire respectively. The annual exploitable hydro capability of the Zaire alone is estimated at 530 000 million kWh[1]. Tapping this resource alone would provide much of the commercial energy needs of Sub-Saharan Africa well into the next century. However, hydro on this scale can only be developed economically with interconnected electricity grids and a sufficiently large and resilient energy market. This article discusses the issues and options in developing electricity grid interconnections and trading to enable wider market access to commercial energy resources.

* This paper is based on a previous report: Paper 4.1.04 "Opportunities in Africa for energy cooperation: The case for transmission interconnection", presented at the 15th Congress of the World Energy Council, held in Madrid in September 1992.

** Engineering & Power Development Consultants Limited, Marlowe House, Sidcup, Kent DA15 7AU, England

Demographic and economic overview

Sub-Saharan Africa comprises 47 countries, widely different in language and culture, but all with largely low income, rural, agrarian communities. The region has 9% of the world's population and the highest population growth rate, with urban growth almost double that of the population. Recent (1990) statistics[2] give a total population of 510 million, which is expected to double by the year 2009. Of this total about 40% are to be found south of the equator. The region has a young population, with two-thirds aged under 25 years. This is compounded by a low life expectancy (43-58 years), and death rates almost double those of developed countries.

Over the last two decades the economies of the region have declined significantly and there are serious foreign exchange shortages. For most countries the real GDP growth rate in local currency has not been able to keep up with the population growth rate, and this decrease in per capita income has generally been exacerbated by falls in local currency values against the US dollar (US$). Other economic problems are excessive debt burdens, instability and high inflation rates. The over-valuation of official currency rates is reflected in higher parallel black market rates and the formation of "dual" economies.

The regional economy is essentially dualistic, comprising a formal sector representing organised factors of agriculture, industry and commerce, and a large informal sector based on subsistence, in which governments have no role. This intensifies an already critical situation with respect to energy as, excluding South Africa, the region relies on fuelwood for 81% of all energy needs. This situation cannot be sustained, and action to reduce reliance on fuelwood is now an urgent issue for economic development and the protection of the environment.

Key factors in interconnection

While there is no shortage of aggregate energy resources on the continent, their distribution and access is unequal, and this especially applies to the harnessing of renewable resources, such as hydro. The challenge can be met by an ARPIS[3] (interconnection) programme, given the co-operation of countries in resolving dependency problems regarding the sharing of costs and benefits in the trading of electrical energy. The goal is to gain an increase in market size through regional co-operation, enabling economies-of-scale to reduce overall costs in electricity supply.

As noted in a World Energy Council (WEC) paper[4], "...a self-evident caveat for successful interconnection is that the benefits and costs must be distributed so that all participants gain over the alternative of independent power development". This caveat has a major influence on the way developing countries on the continent choose to meet their needs for electricity, as investments in power supply are very capital-intensive, particularly for low income countries.

Sharing the investment burden is the main advantage of interconnection, as it makes possible the aggregation of power markets and infrastructure between participating countries. However, firm energy sales (energy brokering) between utilities is often the motivating force promoting interconnection and the sizing of plants larger than for local needs. Other benefits from interconnection such as, reserve capacity sharing, may follow if a power pool is formed and development is integrated.

The fundamental economics of interconnection are usually predicated on firm energy exchanges on a bilateral basis or to a power pool at a competitive price. However, there are two key requirements: (1) a sufficiently large surplus of power to make transmission to more distant markets worthwhile, (2) the ability to deliver that surplus at a price below the "avoided" cost of power in the more distant market. Avoided cost is defined as the cost a "buying" utility would otherwise incur if it were not for power purchases from a "seller".

The avoided cost can often be regarded as the cost of self-sufficiency, and particularly so in assessing options for the purchase of firm power. Avoided cost is therefore a useful mechanism in assessing the benefits of an interconnection agreement. The theoretical basis for avoided costs derives from marginal cost determination of changes in the use of electricity. In this respect, the cost of new facilities are considered as marginal costs for changes in electricity use in the longer term. Benefits or avoided costs for a change that is expected to last for several years are determined by calculating the cumulative net present value of the annual avoided cost in terms of capital investment and operations to a total systems base over the horizon of the plan.

This approach was applied to investment studies for five core countries (Botswana, Malawi, Mozambique, Zambia and Zimbabwe) in a recent SADC*** Energy Project[5], and it was demonstrated that savings of up to 20%, or US$1,6 billion, in power development costs could be achieved by co-operation and interconnection. The intent of the project was to equitably distribute the benefits of interconnection and the integrated power development of generation and transmission capacities between the participants in a tight pool system.

The above-mentioned savings could then be basically realised by making more effective use of existing generation resources, by means of a strategy of extending and reinforcing the existing interconnected transmission system, including links to Zaire and South Africa as appropriate to offset the effects of drought and provide system support. The countries involved would be those with close access to the Zambia-Zimbabwe 330 kV transmission system and therefore able to participate directly in co-ordinated development. These countries are Botswana, Malawi, Mozambique, Zambia and Zimbabwe.

"Commercial energy resources abound in Sub-Saharan Africa, and include coal, oil, natural gas, hydro and geothermal energy. Most have yet to be fully developed, with possibly the largest resource being hydro, concentrated mainly on the Central African rivers of the Zambezi and Zaire respectively . . . Tapping this resource alone would provide much of the commercial energy needs of Sub-Saharan Africa well into the next century. However, hydro on this scale can only be developed economically with interconnected electricity grids and a sufficiently large and resilient energy market."

There is now a move to form a Southern African Power Pool (SAPP) as a priority for the next decade. The objectives are to move large blocks of power to areas experiencing shortages, and to extend interconnection to all the SADC countries. This can only be achieved by institutional reform and the liberalisation of electricity supply.

Institutional and dependency issues

The WEC Commission Report[6], in reviewing the primary energy resource base in Sub-Saharan Africa, observed that "...there is much scope for the exploitation of these (energy) resources within the framework of regional interchange of energy". While this is accepted as a valid conclusion in principle, it is well recognised that there are physical and institutional barriers to overcome. For example, the energy markets in many of the individual countries are small and dispersed. Thus, economically exploitable natural energy resources, such as hydro, are largely reliant on regional rather than local markets, and on the potential for trading in electricity.

It is self-evident that for successful regional interconnection, perhaps involving several countries, the net gain by all participants should be larger than independent development. However, there are many issues to be resolved before interconnection becomes a practical reality. Most of these are institutional and predicated on dependency problems with associated political risks. There are often problems related to conflicts of interest and operational matters, and planning for regional interconnection is also an important issue. In the latter case, this is because long lead times can often affect the economic viability and political attractiveness of the interconnection option.

As noted by Gata[7], "The electric power utility in most developing countries is almost entirely driven and managed through the political system in contrast to the practice in the largely market-led economies of the developed nations". Power utilities in most of Sub-Saharan Africa are usually parastatal (government-owned or -controlled), and thus are highly centralised and politically regulated.

Although there is no shortage of resources for economic power generation and supply, parastatals have performed poorly through the 1980s and are heavily in debt. It is now accepted that this is mostly because of institutional weaknesses that often result from being required to implement government social policies. It should be possible to resolve these problems with a strictly commercial mandate and private sector participation.

*** Southern African Development Community

An important concern is the widely divergent conceptions of "dependence" and "interdependence". The "dependence" issue is perceived as a major obstacle to gaining the full benefits of interconnection, because of a reluctance to give up some autonomy. This applies particularly, to energy *import dependency*, as the energy-deficient country usually has self-sufficiency concerns.

Interconnection of power systems involves some technical and supply dependencies, and a degree of financial dependence. There are potential conflicts on regulatory and organisational matters, and operation of the participating systems will require close co-ordination. Lack of such co-ordination will precipitate the risk of large system failure as almost invariably, there will be increased transmission requirements in terms of inherent capability and control sophistication.

A primary motivation for interconnection is the purchase of firm energy for a contract period, in order to enable demand to be met within a leastcost investment strategy for generation expansion. However, a problem arises if dependence is for an extended period or the purchase of firm energy is a significant portion of total demand in the supplied country. Some autonomy is lost by each participant and the energy-deficient country in particular, may have self-sufficiency concerns.

Nevertheless, imported energy is always a valid option in achieving least-cost investment, and political risk also applies if economic costs are high because this option is then denied. A practical compromise is to plan to preserve a reasonable power balance in each country over time by setting limits on the dependency of any one country relative to the region. A good rule of thumb is for each country to be responsible for up to 80% of power and energy coverage, and for load dispatching in its own network.

Financial dependence applies when the power export revenues accruing to a supplier country are necessary for the financial viability of its power subsector. This may represent substantial risks for the supplier country, particularly so if revenues must be in a stronger and scarce third currency. Where financial dependence is perceived as a problem, effective means of resolution may be special lending for the importer country or possibilities for counter-trade. In any event, financial dependence is a deterrent to the exercising of supply restrictions, provided agreements are equitable and covered through appropriate contract arrangements.

The operation of interconnected power systems usually requires much closer co-ordination than when systems operate independently. This can be a problem depending on the degree of technical compatibility and the integration of the participating systems. In essence, short of a system collapse, load is always followed by the frequency response mechanism of the entire interconnected system. The importance and degree of load following is therefore not an individual choice.

> "... firm energy sales (energy brokering) between utilities is often the motivating force promoting interconnection and the sizing of plants larger than for local needs. Other benefits from interconnection such as, reserve capacity sharing, may follow if a power pool is formed and development is integrated."

Uniformity throughout the interconnected systems must be maintained to avoid chaotic unbalances and ultimate system collapse. Each control area (utility or pool) must provide suitable automatic generation control (AGC) equipment and maintain responsive generation in reserve under the control of this equipment at all times in order to meet obligations to system balance and interchange requirements. This is the fundamental dependency for firm power exchange and power pool operation.

Finally, planning for interconnection can be a problem, particularly with regard to the complexity of the studies and the conflicts of interest that may be involved. Planning of interconnections for integrated regional development involves the optimal allocation of generation resources according to strategies which will enable the demand to be met at least-cost. This can only be achieved within a tight pool regime, in which autonomy in planning and operations is ceded to pool management.

Participants who become net importers of electrical energy under these strategies can claim that they support the development of their neighbours' energy resources to the exclusion of their own, with associated political risks. While such concerns must be recognised in evaluating alternatives, decision-makers must also recognise the political risk of inefficient investments and extra economic costs of electricity supplied under options other than the least-cost solution.

Provided these dependency issues can be resolved, there should be no impediment to developing a framework of law and regulation to enable access to markets and the free movement of finance, public and private, to sustain the provision of energy supplies. Engineers and economists can create and evaluate the options but finally it is a matter of political will, complemented by a spirit of trust and openness, especially in negotiating contracts.

It is encouraging that, under the auspices of SADC, studies have been undertaken to establish development plans, and that recent interconnection proposals have all resulted from joint studies by the main participants. Furthermore, an Integrated Operations and Planning Committee (IOPC) has been in existence since 1992 to manage the existing interconnections between Botswana, Zambia and Zimbabwe. This IOPC was reconstituted at the beginning of 1994 to include involvement in future planning studies and, in particular, with the forecasting of avoided costs, to determine how costs and benefits should be shared in a pool system. After the August 1993 SADC Seminar (in Malawi) on Inter-Utility Power Exchange and Pricing Policies, there is the hope that a greater spirit of trust and openness will prevail, and progress made towards forming a Southern African Power Pool.

Pooling arrangements and functions

The strategic importance of transmission is much greater than is indicated by its share in the overall cost of electricity supply. Specific benefits that accrue from network interconnections are:

- lowering of generation capacity reserve requirements;
- ability to achieve economies-of-scale;
- opportunity to interchange economy-energy;
- increased load and fuel diversity;
- opportunities for sale of surplus firm energy;
- emergency support on major breakdowns.

These benefits can be regarded as system-wide insofar as they are germane to the objectives that load demand be reliably served at minimum *total* system cost. However, these benefits can only be effectively obtained within the framework of a power pool that co-ordinates planning and operations so that economies-of-scale, increases in reliability, and other system benefits are achieved to the extent practicable.

At present, there are some fifty formal pool-type agreements or directives linking utilities in the world. The scope of pooling extends to informal agreements which can also realise significant benefits. Pooling has traditionally been used only in co-ordinated or central-style planning as the mechanism for ensuring economic efficiency. However, there is now an alternative via the competitive wholesale market, given third-party access to the transmission system and power resource bidding to determine the system marginal price for power dispatch, as in the U.K. model.

In a power pool some autonomy is inevitably lost by participants in meeting joint needs, as authority must be delegated to the pool. Stronger utilities therefore often see little to be gained from pooling and so resist giving the pool much authority, whereas weaker utilities tend to see the benefits and yield authority. The result is loose pools that are satisfied with few benefits, and tight pools which attempt to maximise pooling gains.

It is worth noting that geography, history and circumstance usually dictate tight or loose pools, not elegant studies nor regulatory direction. Most tight pools were directly established rather than evolving slowly from loose pools. In a tight pool, systems are interconnected with several tie-lines having enough transfer capability for free-flow in each network and the equalising of marginal production cost/price, creating one super-system. This was the concept for the SADC core countries, by building upon the established Zambia-Zimbabwe 330 kV system and strongly interconnecting this integrated network with Botswana, Malawi and Mozambique, as shown in Figure 1.

Long distances between systems often preclude multiple strong ties and limit the potential gains from pooling. Such arrangements are loose by definition regardless of the size of individual networks, since production costs cannot be equalised because of limited interconnection. The West African grid from the Cote d'Ivoire to Ghana is an example of a loose pool arrangement insofar as several small networks are interconnected by a tie-line about 1 000 km in length along the West African coast. This interconnection provides the benefits of a hydro/thermal generation mix that mitigates drought conditions and encourages economy-energy exchanges. Since 1982 there have been proposals to extend

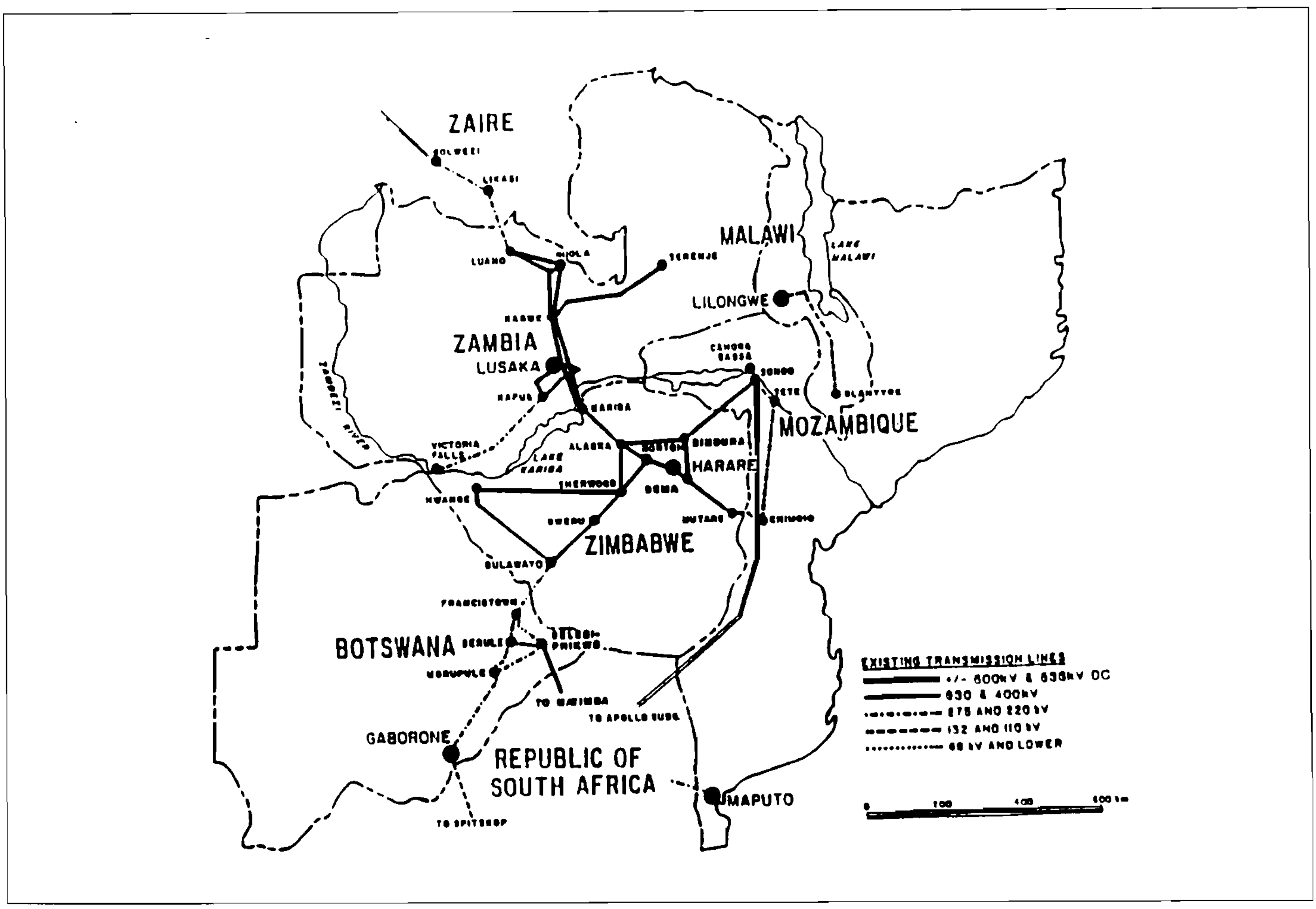

Figure 1: Sub-Saharan Africa interconnection network

(Source: SADC Energy Project AAA3.8: Phase II Technical Report, April 1993) the interconnection to Nigeria, but no decision has been made to date.

Most power pools do not fully represent the extremes of the "tight" and "loose" definitions, and classification depends on the extent to which pool functions are adopted and performed. Overall, at least ten functions are universal to good pool operation, and thus the full benefits of interconnection. These are:

- least-cost dispatch of energy;
- energy "futures" or contract market;
- capacity "futures" or contract market;
- operating reserve;
- reactive supply and transmission security;
- installed capacity reserves/standards;
- joint maintenance scheduling;
- expansion planning employing economies-of-scale;
- transmission access/services;
- membership/entry/self-policing.

Given that firm/economy-energy exchanges and capacity support are often the motives for interconnection, these are best achieved by least-cost dispatch within an energy/capacity contract market supported by agreements for maintaining operating reserves. Location of reserves and capacity balance across the pool system is important as transmission overloads/limitations may precipitate reserve constraints. Spinning or on-line reserves are needed to meet any instantaneous loss, and must be sized to cover the largest generator or tie-line, leaving enough capacity to match or regulate demand thereafter.

Reactive power (VAR) supply and transmission security is also an unavoidable task in reliable pool operation. In almost all cases, interconnection contracts between utilities require each party to supply the VARs needed for proper voltage support to keep tie-lines in service. If radial links interconnect networks then bilateral action may suffice. However, with multiple or parallel ties there can be unplanned "loop" flows and voltage fluctuations that need a collective, pool-wide, solution.

The remaining pool functions clearly require co-ordination through an Integrated Operations and Planning Committee (IOPC), and the degree to which these functions are embraced defines the tightness of the pool. As already noted, in forming a Southern African Power Pool the role of the IOPC is beginning to be extended to include these functions. In this respect, one of the most important functions may be the provision of transmission access and services, since easy access to the transmission grid is essential to making transactions between distant utilities such as, SNEL (Zaire) and Eskom (South Africa). Both these utilities can provide essential support to the development of the Southern African grid, but access for power wheeling over a distance of 5 000 km so that SNEL and Eskom can directly trade firm energy may be a problem.

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The difficult question, and not just within Southern Africa or Africa, is what constitutes good and fair access to the grid? Access is meaningless unless energy can be traded, and in this respect the access capacity is important, since low levels often prevent movement of reasonably sized energy blocks in specific load periods. The question can thus be extended to include third-party access for independent (non-utility) generators competing in a wholesale power market. In any event, for access to be unconstrained an appropriate transmission capacity must be available. Furthermore, the cost of providing and maintaining that availability must be reflected in access costs, the rates for wheeling, and the terms and conditions applied for transmission use.

Options for bulk power transfer

Power flow on an AC transmission line is a function of phase angle, line-end voltages and line impedance, and it has always been understood that these parameters could not be controlled fast enough for dynamic stability. As a consequence, dynamic system problems have traditionally been solved by overdesign, in which generous margins have been allowed to ensure system recovery from operating contingencies without the benefit of real-time control. Thus for long distances, coupled with large power transfers, the high voltage direct current (HVDC) transmission has often held technical and economic advantages over AC options.

It has been postulated[8] that by using Flexible AC Transmission System (FACTS) technology, real-time transmission line control can be achieved. The integrated application of these devices is thus expected to remove the conservative, stability-induced, power-distance constraints presently applied in long-distance AC transmission. This should enable secure loadings of transmission lines to their full thermal capacity, and thus double the capacity of some power systems.

A fundamental notion behind FACTS is that it is possible to continuously vary the apparent impedance of specific transmission lines to force power flow along a "contract path". The "contract path" idea is an entirely new concept in system planning, relying on the use of thyristor-controlled series and shunt compensation to precisely control the impedance of transmission lines. By this means it is possible to maintain constant power flow along a desired path in the presence of continuous changes of load/generation levels in external networks. This has wide implications for the control of power pools, particularly for firm power wheeling.

FACTS offers a way to reduce transmission upgrade costs in improving the capability of existing networks. This is clearly important in the Southern African grid, assuming the network is used for wheeling through power between Zaire and South Africa, in addition to satisfying regional balances. Studies (for the SADC AAA3.8 Project[5]) showed that some 1 500 MW could be wheeled through the Southern African grid with only minor reinforcement to the main network and the addition of a 400 kV link between Serenje (Pensulo) in Zambia and Songo in Mozambique via Lilongwe in Malawi.

If an "export" scenario of 1 500 MW to South Africa is developed and operated as base load, it would result in energy sales to South Africa of about 10 000 GWh per annum valued at US$300 million, assuming a short-run avoided cost of US$30/MWh. As a point of reference, 10 000 GWh/a is about 7% of the current South African energy demand, which is about 140 000 GWh, and half the 1992 aggregate energy demand of the five SADC core countries. Demand growth in both systems is expected to increase at about 3,5% per annum, and therefore to double by 2010. The main market for energy trading south of the equator will therefore be South Africa, where the present demand is mostly satisfied by thermal generation.

The trade with South Africa is likely to be for firm power at a long-run avoided cost. Assuming this to be about US$1 500/kW, the ballpark cost of coal-fired generation with dry cooling towers and flue gas desulphurisation (FGD) gives some idea of the economic margins for making power available from a sending system, including generation and transmission. This is a key issue in the economics of interconnection which must be addressed along with the level of firm power to make trading to distant markets worthwhile.

Current HVDC costs are about US$400 million or US$300/kW for a bipole ±500 kV design delivering 1 500 MW over a distance of 1 000 km. This was a specific exercise, but a parametric analysis of different technologies in Brazil[9] suggests a delivered cost of US$600-700, for (N-1) transfers from 4 000-17 000 MW considering point-to-point transmission over a distance of 2 500 km.

With Zaire (Inga) generation in mind, and using US$700/kW for transmission, the marginal generation cost should not exceed US$800/kW for point-to-point delivery at the South African avoided cost. This may be practical (at Inga) but unlikely at many other hydro sites, thus killing the myth of cheap hydro. Other options must therefore be investigated for reducing marginal transmission costs as the practical alternative to matching an avoided cost of US$1 500/kW. In this respect, multi-terminal HVDC is now practical and may offer opportunities for reducing marginal costs by interconnecting networks and developing secondary markets *en route* to main load centres. The prospects for using this technology are exciting and are perhaps the best hope of bringing power to the continent, particularly countries deficient in energy resources.

Concluding remarks

An attempt has been made at a practical review of issues and options for interconnecting power networks and the trading of electrical energy. The review is based on recent ARPIS and SADC studies and is therefore pertinent to Sub-Saharan Africa, in which there is a particularly urgent need to greatly reduce dependence on traditional energy resources and improve economic performance.

While the case for interconnection cannot be denied, it is also clear that institutional and dependency issues must be addressed in a spirit of trust and openness to make interconnection effective. It is suggested that power pools are the practical means to realise the full benefits of interconnection and minimise costs. Various pooling arrangements and ten functions are identified. It is concluded that the character of a pool, loose or tight, depends on the functions adopted and performed, dictated mostly by geography, history and circumstances.

Distances across the continent between energy resources and markets are very large, particularly so in the case of hydro. An important function for any pool is thus likely to be transmission access and services for power wheeling without prejudice to other pool operations. In this respect, bulk power transfers could present special problems, particularly with system control and stability.

Solutions are very likely to involve the emerging FACTS thyristor technologies, which can double transmission capability. But for very large power transfers (>4 GW) over distances of 2 500 km or more, it is clear that the delivered cost of power could be a limiting factor, depending upon the marginal supply costs in the receiving power system. Much may depend on the marginal cost of generation additions at established hydro sites, or otherwise, on the development of *en route* secondary markets to reduce the marginal costs of remote transmission.

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Advantages of interconnections and the creation of a power pool in Southern Africa

*** P J E RUBBERS**

The purpose of this paper is to examine the role played in the past by cross-border interconnections in Southern Africa, and to evolve from these observations the possibility of creating a power pool in the region. The situation in Southern Africa is seen as similar to that prevailing in North America, where there are vast hydro resources to the North but relatively small loads, and a thermal system but large load centres in the South.

An important step towards the creation of a Southern African Power Pool will come with the commissioning of a 400 kV line between Matimba and Bulawayo which is planned for 1995. It will then be possible to exchange electricity on a large scale with countries to the north of South Africa. This will provide a substantial saving potential for the whole region, and as far as South Africa is concerned, it will enable Eskom to better fulfill its commitment to reduce the price of electricity in real terms.

Keywords: Southern Africa; power pools; wheeling; power generation; energy trading

Glossary

BPC = Botswana Power Corporation
EDM = Electricidade de Mozambique
HCB = Hidroelectrica de Cabora Bassa
SNEL = Societe Nationale d'Electricite
Swawek = South West African Electricity Commission
ZCCM = Zambia Consolidated Copper Mining
ZESA = Zimbabwe Electricity Supply Authority
ZESCO = Zambian Electricity Corporation

Introduction

In North America it is estimated that the savings resulting from inter-utility electricity trade are of the order of $20 billion per annum. Inter-utility trade, either directly or within power pools, has occurred on that continent for several decades and is still expanding. The latest development in U.S.A. legislation, making wheeling mandatory, will further facilitate this process.

European utilities have also devoted their attention to electricity trade and a number of pooling arrangements have been in existence for a long time. The creation of the Common Market is adding new impetus to their efforts.

The purpose of this paper is to examine how inter-utility trade and power pools could be introduced into Southern Africa. It also describes those aspects of the Southern African region which could result in the development of such a power pool, and the steps that should be taken to ensure its implementation.

Energy in Southern Africa

South Africa

Electricity consumption in South Africa has increased very rapidly during the 1950-1980 period - 8,0% per annum on the average. The ever-increasing demand necessitated massive generation expansion, which was implemented mainly with coal-fired stations and tied collieries in an area to the east and south of Johannesburg. This is where 90% of the power is generated today. The remaining 10% is generated by two peaking hydro stations (320 MW and 220 MW respectively) situated half-way between Johannesburg and Cape Town, two pumped storage stations (1 000 MW near Durban and 400 MW near Cape Town respectively) and one nuclear power station (1 800 MW) near Cape Town. This uneven spread of generation has led to an extensive transmission system linking all the major load centres in the country.

Between 1982 and 1983, after growth had considerably slowed down, South Africa's national utility (Eskom) had five 3 600 MW coal-fired stations either under construction or on order, resulting in the prospect of an excess of generating capacity that would rapidly increase in the years to come. The possibility of cancelling contracts was considered at the time but not exercised because the costs were judged to be too high (loss of forward exchange covers, etc.). In order to reduce fixed costs, it was decided instead to shut down five old coal-fired power stations (680 MW each) and to mothball another seven and a half (6 050 MW).

The years 1985-1993 were definitely years of consolidation. The peak load still grew from 17 850 MW to 23 126 MW, but the rate of growth dropped considerably. The emphasis also shifted from the supply side to the demand side in order to absorb, as fast as possible, the excess of generating capacity. A large number of new domestic consumers were connected (145 000 in 1992 and 208 000 in 1993) and customised tariffs were introduced to the process industries, linking electricity prices to international commodity prices. For example, a new aluminium smelter will start production in April 1995 and consume 800 MW at full load.

In spite of these actions, there was, at the end of 1993, a total of 31 434 MW of plant in service for a peak demand of 23 126 MW. If one adds the 6 099 MW of plant mothballed and a reserve margin of 25% is assumed, the excess capacity is of the order of 8 625 MW. With a load growth of the order of 2,5% per annum, it is anticipated that the excess of generating capacity will not come to an end before the year 2010.

Namibia

In 1993, Swawek, the national utility of Namibia, had a maximum demand of 255 MW, which is growing at 2% per annum. The generating capacity consists

* Power Systems, Eskom, P O Box 1091, Johannesburg 2000, South Africa

of a coal-fired station near Windhoek (120 MW), a hydro station (Ruacana) on the Cunene River (on the border with Angola) which can produce 240 MW, and diesel units at Walvis Bay which are rated at 25 MW.

Unfortunately, Ruacana must be operated as a run-of-river station because the Gove Dam, which is upstream from Ruacana in Angola, has been damaged. Namibia is interconnected with South Africa via a long double circuit 220 kV line of 860 km.

The Ruacana Power Station can normally meet all of Namibia's power needs during the first half of the year, plus some sporadic exports to South Africa. During the second half of the year most of the energy is imported from South Africa because this energy is slightly cheaper than that generated at the Windhoek coal-fired station.

The supply agreement between Namibia and South Africa is based on time-of-use. It provides an incentive to Swawek to operate Ruacana during peak hours (when energy in South Africa is comparatively expensive) and to import energy during off-peak hours when the price is low. Swawek is clearly suffering from the troubles which have plagued Angola since 1975. Until Ruacana can be run normally, Namibia will not be self-sufficient from an energy point of view.

Botswana

Botswana had a peak demand of 190,3 MW in 1993 and a generating capacity (exclusively coal-fired) of 152 MW (132 MW at Morupule and 20 MW at Selebi-Phikwe respectively). Botswana is in a favourable position, geographically, in that it can import from Zimbabwe/Zambia in the north and from South Africa in the south. The Botswana Power Corporation (BPC) can import cheap energy from the north when hydro power from the Zambezi is available, or the more expensive but more reliable coal-fired energy from South Africa during droughts. The 132 kV lines from Gaborone to South Africa and the 220 kV line to Zimbabwe are, however, too weak for any exchange of energy between South Africa and Zimbabwe. To rectify this, automatic generation control (AGC) devices must be installed in Zimbabwe and Zambia. Until then, the BPC must operate its "split" system, with the chop-over facility when an incident occurs.

Mozambique

In 1968, Mozambique entered into an agreement with Eskom for the export of 1 450 MW (plus 350 MW non-firm energy) from Cahora Bassa, a hydro station which was to be constructed on the Zambezi near Tete. In 1975 the scheme was commissioned, and until 1981, it supplied power to South Africa without too many problems. From 1982 however, the supply was discontinued because of repeated sabotage along the 1 500 km DC lines linking Cahora Bassa to Johannesburg. Since then the only load connected to Cahora Bassa has been that of the local network (approximately 20 MW) and, as a result, the power station has been grossly under-utilised.

> **"In spite of their low rating, the interconnections in the Southern African region have already served the utilities well in helping to overcome energy shortages. These interconnections have been most useful when linking countries with different characteristics, for example, a predominantly coal-fired system with a hydro system (Namibia-South Africa) or two hydro systems having different rainfall patterns (Zaire-Zambia)."**

The peak demand of Electricidade de Mozambique (EDM) in the Maputo area is 96 MW and nearly all of this is imported from South Africa. EDM has a small hydro station with limited power at Corumana (9 MW) and an old coal-fired station, rated at 30 MW, which was "mothballed" in 1993, after the Eskom tariff was reduced as an incentive for EDM to do this. Before the DC lines from Cahora Bassa to South Africa were sabotaged, Eskom was wheeling Cahora Bassa power to Maputo, so the cost of energy to EDM was very low and payable in local currency (there is no interconnection inside Mozambique territory between Maputo and Cahora Bassa). Since the DC lines were taken out of service in 1982, EDM has been paying Eskom in Rands, which is a considerable drain on Mozambique's financial reserves. It is thus to everyone's advantage to reinstate the DC lines to Cahora Bassa as soon as possible to again make Mozambique the massive exporter of cheap energy it once was with the 2 000 MW Cahora Bassa scheme.

Zimbabwe

In 1993, the maximum demand of the Zimbabwe Electricity Supply Authority (ZESA) was 1 460 MW compared to a generating capacity of 1 724 MW. The main power stations are Kariba South (hydro 624 MW) and Hwange (coal 836 MW). In the last few years, ZESA has imported energy from Zambia via the two 330 kV interconnectors at Kariba. These imports should progressively diminish as the load in Zambia continues to grow, but this will be compensated by imports either from Eskom (via a new 400 kV transmission line from South Africa) or from Cahora Bassa (via a new 400 kV transmission line from Harare to Cahora Bassa).

The Zambezi is subjected to long cycles of wet and dry years because it is situated entirely in the Southern Hemisphere. These cycles make the provision of hydro energy somewhat unpredictable although its cost is lower than coal-fired power. Over the past few years the water level at Kariba has been dropping progressively, and by the end of 1992 the situation became so alarming that rationing was introduced. Fortunately, good rains have fallen since then and these measures have been lifted. ZESA plans to add two additional generating units at Hwange Power Station (380 MW) and, in time, to build a new hydro station called Batoka, upstream of Kariba. Such a station would be a major project with an installed capacity of 1 200 MW or 1 600 MW.

Zambia

The maximum demand in Zambia is 950 MW as opposed to a generating capacity of 1 608 MW which is almost exclusively hydro: 600 MW at Kariba

North, 900 MW at Kafue and 108 MW at Victoria Falls.

Zambia is interconnected with Zimbabwe to the south by 330 kV (two lines) and with Zaire to the north by 220 kV (one line). The interconnection with Zaire has played an important role in the past two years because of the drought.

For future growth, the Zambian Electricity Corporation (ZESCO), is considering the development of the lower Kafue (450 MW) or alternatively, the construction of Batoka on the Zambezi in co-operation with Zimbabwe.

Zaire

With an installed capacity of 1 730 MW at Inga and 450 MW in the Shaba Province, Zaire could become a major exporter of energy, since the combined load in western and southern Zaire (which are interconnected by two 530 kV DC lines), does not exceed 700 MW. The generating system is entirely hydro but the Zaire River and its tributaries are not subject to the same climatic cycles as the Zambezi because they flow on both sides of the equator. As a result, the energy (at least from Inga) is more reliable than further south. At present, the export potential of the Société Nationale d'Electricité (SNEL) towards Zambia is limited by the need to rehabilitate several generating units at Inga and in the Shaba Province, and by the low transfer capacity of the 220 kV interconnection between the two countries.

Overall situation

From the information given above, it is possible to draw a capacity balance for each country in the region as shown in Table 1. Table 1 shows that there is a surplus of generating capacity in the region and that the surplus is substantial, namely, 12 000 MW or 36%.

UTILITY	1993 PEAK (MW)	REQUIRED CAPACITY (MW) (GPM=25%)	APPROX. INSTALLED CAPACITY (MW)	TYPE OF PLANT	ENERGY SHORT-AGES	APPROX. CAPACITY SURPLUS (MW)
SOUTHERN NETWORK						
Souith Africa (Eskom)	23 126	28 908	37 533	Coal	No	8 625
Namibia (Swawek)	255	319	360	Hydro Coal	Yes	41
Botswana (BPC)	190	237	152	Coal		-85
Mozambique - South (EDM)	96	120	39	Coal	Yes	-81
NORTHERN NETWORK						
Zambia (ZESCO)	1 050	1 313	1 608	Hydro	Yes	295
Zimbabwe (ZESA)	1 460	1 825	1 724	Hydro Coal	Yes	-101
Mozambique - Central (EDM)	20	25	2 000	Hydro Coal	No	1 975
Zaire (SNEL)	700	875	2 180	Hydro	No	1 305
TOTAL	26 862	33 622	45 596	-	-	11 974

Table 1: Capacity balances in Southern Africa

The role played by existing interconnections

Zaire-Zambia and Zambia-Zimbabwe interconnections

Interconnections already exist between Botswana, Zimbabwe, Zambia and Zaire, on the one hand, and between Botswana, South Africa, Mozambique and Namibia, on the other hand. These interconnections have played a major role in recent years when Zambia and Zimbabwe were suffering as result of the drought. During that time some 180 MW were imported from Zaire via the 220 kV Zaire-Zambia interconnection, of which 60 MW was wheeled through Zambia to Zimbabwe. This power replaced or supplemented that which normally flowed from Zambia to Zimbabwe. Also, Zambia stopped exports to Botswana via Zimbabwe, and Botswana started to import the shortfall from South Africa. In spite of these measures, the situation in Zambia and Zimbabwe became very critical at the end of 1992, to the point that Zambia declared *force majeure* and stopped all exports to Zimbabwe. The dam levels at Kariba and Kafue were then very close to the critical level when it would no longer be possible to generate power. Fortunately, the situation has since improved.

Interconnections with South Africa's neighbours

The generating system in South Africa is based on coal and is thus less vulnerable to water shortages. Nevertheless, the drought was so severe in 1983 that the load factor of several power stations had to be modified at high cost to avoid a situation where high-merit stations could no longer generate power because of a lack of cooling water. If strong interconnections with neighbouring countries had been in operation that year, the situation would have been much less critical. Some US$100 million which was spent on temporary weirs and on re-dispatching the load towards less efficient stations (where water was still available), could have been avoided.

The interconnections from South Africa to Mozambique and Namibia have played a key role over many years. The 275 kV line supplying Maputo was commissioned in 1973 and, although the idea at the time was to wheel energy from Cahora Bassa, it has continued to supply the city with power, even after the lines from Cahora Bassa had been sabotaged.

The double circuit 860 km, 220 kV line from South Africa to Windhoek has provided Namibia with a reliable standby and has been used to compensate the cyclical inflows of water to Ruacana. This line carries most of Namibia's electricity for about six months of the year.

Interconnections versus self-sufficiency

In spite of their low rating, the interconnections in the Southern African region have already served the utilities well in helping to overcome energy shortages. These interconnections have been most useful when linking countries with different characteristics, for example, a predominantly coal-fired system with a hydro system (Namibia-South Africa) or two hydro systems having different rainfall patterns (Zaire-Zambia).

As can be seen in Table 1, two utilities which have sound financial reputations (BPC and Swawek) are also importing a large proportion of their electricity needs. Obviously, other factors are also at work (Mozambique and ZESA are also net importers), but if one appreciates the difficulties of operating complicated machinery in an environment where skilled manpower is scarce, it is clear that a lower risk is associated with importing energy. Also, it is more cost-effective to pay for what is actually received than producing the energy locally and paying high fixed costs even if the plant does not operate.

It can be concluded that the few interconnections in the region have already been very beneficial and that the utilities would be well advised to build additional interconnections and to improve the performance of existing power stations rather than to allocate their resources to the construction of new power stations.

The 400 kV Matimba-Bulawayo interconnection

Configuration of the regional network

There are in reality two large electricity networks in Southern Africa, (1) the Eskom-Swawek-EDM system, and (2) the SNEL-ZESCO-ZESA system. These two systems are linked by very weak 132 kV or 220 kV lines crossing Botswana. In the north, the system is predominantly based on hydro power with practically infinite reserves in Zaire, while in the south generation is predominantly thermal with very large and virtually untapped coal reserves. South Africa and Eskom in particular, cannot ignore that coal-fired electricity is more expensive, technically more complex, and more environmentally unfriendly than hydro energy. The other utilities must also recognise that reliability of supply with hydro sources is often more difficult to achieve than with coal-fired stations. Having noted these problems, ZESA and Eskom decided at the end of 1991 to start a joint feasibility study to evaluate the savings that could be achieved by building a 400 kV interconnection from Matimba (a 3 690 MW power station in the north-western Transvaal near the South African/Botswana border) to Bulawayo in Zimbabwe. The feasibility study is now complete and has been a combined effort by ZESA and Eskom personnel without the involvement of any consultant.

Initially, it was planned that the line would go around Botswana and cover a distance of 510 km. But the Botswana Power Corporation (BPC) indicated their preference for a line that crossed Botswanan territory, if they were allowed to establish a step-down station at Selebi-Phikwe in the future.

This proposal was accepted because the line length would be reduced by 100 km (a saving of US$16 million) and because the additional outlet in Botswana would make the scheme even more attractive from an economic point of view.

The two generating systems were simulated in detail with the actual costs of building and operating power stations in the two countries. Bearing in mind that Eskom will have an excess of generating capacity until 2010 and ZESA has seemingly a shortage of capacity, it was immediately obvious that large savings which were much higher than the cost of the interconnection itself could be achieved.

(1) Base Case

The overall capital, operating and fuel costs in the ZESA and Eskom systems were evaluated, first assuming no interconnection. Under this option (the Base Case) there was a sizeable portion of the load in Zimbabwe which could not be met because of a shortfall of generating capacity in the early years.

The expansion plan under this option includes the rehabilitation of old thermal (ex-municipal) stations, the addition of two new 200 MW coal-fired units at Hwange Power Station, the construction of five 200 MW coal-fired units at (Sengwa), and a new hydro station on the Zambezi called Batoka which would have a total capacity of 1 200 MW to 1 600 MW, half of which would be owned by Zimbabwe (Time horizon: 2010).

(2) Option 1

Under Option 1, ZESA would build two parallel lines between Harare and Cahora Bassa and import 500 MW from 1996 to 2003 (after 2003, all the energy from Cahora Bassa must return to Eskom). The rehabilitation programme of the old stations (thermal and municipal) would be curtailed and some of the plant would even be decommissioned. The rest of the generation expansion programme remains the same as that in the Base Case, apart from the first 3 units of the new coal-fired station which are now deferred by four years.

(3) Option 2

Under Option 2, there would be one line instead of two from Harare to Cahora Bassa in 1996, and one line is built from Bulawayo to Matimba in 1995. The expansion programme of ZESA would be the same as under Option 1, except that all five units at Sengwa would be deferred by four years (Table 2).

The three options were acceptable to Zimbabwe and satisfied their objectives of job creation and self-sufficiency. Operation, maintenance and fuel costs were evaluated with a probabilistic computer model and the imports from Eskom were costed at Eskom's marginal cost rates. The capital costs and the residual value of the assets in 2010 were also calculated. The present values are given in Table 3, where the capital costs of Options 1 and 2 include the relevant construction costs of ZESA's interconnections with Hidroelectrica de Cahora Bassa (HCB) or Eskom.

Analysis of the results

The Base Case, without any interconnections, has the lowest present value if one ignores unserved energy. The amount of unserved energy is, however, so high,

YEAR	BASE CASE	OPTION 1	OPTION 2
1995	Old Thermals I+II	Old Thermals I	Old Thermals I 1 line to Eskom
1996	–	2 lines to Cahora Bassa to 12/03	1 line to Cahora Bassa to 12/03
1997	–	–	–
1998 1999 2000	Hwange 7 Hwange 8 Sengwa 1	Hwange 7 Hwange 8 –	Hwange 7 Hwange 8 –
2001 2002 2003	Sengwa 2,3 Batoka 1,2 Batoka 3	 Batoka 1,2 Batoka 3	– Batoka 1,2 Batoka 3
2004 2005 2006	– – Sengwa 4	Sengwa 1,2 Sengwa 3 Sengwa 4	Sengwa 1 Sengwa 2 –
2007 2008 2009 2010	Sengwa 5 – – –	Sengwa 5 – – –	Sengwa 3 – – –
2011	–	–	Sengwa 4,5

(Note: All new units are rated at 200 MW)

Table 2: ZESA's capacity plan

(especially in the first few years), that it would seriously affect Zimbabwe's economy and is thus considered unacceptable to Zimbabwe consumers.

The P.V. benefits in Option 1, compared to the Base Case, breaks even for a value of unserved energy equal to EZ$1,3/kWh**, which is very low.

Under Option 2, the interconnection with Eskom involves a lower capital expenditure by ZESA than the second line to Cahora Bassa in Option 1. This is because under Option 2, ZESA would have to fund the line only over Zimbabwe territory (165 km versus 260 km). The production costs are slightly higher under Option 2 because of the imports from Eskom, but the amount of unserved energy is much lower. It is clear that single interconnections with two separate systems give more security than two parallel interconnections to one power station. The load factor along the interconnection with Eskom should nevertheless be low because production costs are lower in Zimbabwe than in South Africa. This means that Eskom will be a provider of last resort.

If self-sufficiency was not a consideration to Zimbabwe and their expansion was dictated purely by economic criteria, the construction of new generating units could be postponed beyond the dates given in Table 2 because Eskom will still have excess generating capacity until about 2010. This would improve the present value of Option 2 by at least a hundred million US$. The extra savings in Option 1 would be less than in Option 2 because the contract between ZESA and Cahora Bassa will end in December 2003.

This case-study shows that the savings that can be achieved by linking two large systems with different characteristics, are always very substantial. The formal agreements between utilities for the construction of the Matimba-Bulawayo interconnection were signed in Harare on 14 May 1993. The target completion date is mid-1995 and provision has been made for a second parallel line at a later stage.

P.V. in US$ million at 1 January 1992	Base Case	Option 1	Option 2
Interconnections	–	2 to HCB	1 to HCB 1 to Eskom
Capital costs Production costs and imports TOTAL	552 360 912	743 491 1 234	658 506 1 164
Unserved energy (1) TOTAL (incl. U.E.)	2 239 3 151	1 020 2 254	39 1 203
Benefit without U.E. Benefit with U.E.	– –	-322 897	-252 1 948

(1) Value of unserved energy (U.E.) based on US$1,0/kWh.

Table 3: ZESA's generation expansion plan (1995-2010)

The Zaire-Zambia interconnection

As mentioned earlier, the single 220 kV line linking Zambia to Zaire has been very useful, but has not been sufficient to optimise the exchanges of energy between the two countries.

In August 1992, a team of five engineers - two from SNEL, one from ZCCM (Zambia Consolidated Copper Mining), one from ZESCO and one from Eskom - began a feasibility study for the reinforcement of this interconnection. The objective was to produce a document of sufficient quality to satisfy potential funding agencies. The work is now complete and the results were presented to the managements of ZESCO, SNEL and ZCCM respectively in July 1993. Once again, the studies were conducted without the assistance of external consultants.

Eskom's involvement in this project has been less intensive than in the Matimba-Bulawayo interconnection because the benefits to South African consumers are less immediate. In the long term, however, Eskom would like to have access to the vast hydro reserves situated in Zaire, as this energy will be less expensive and cleaner than that obtained from new coal-fired stations in South Africa.

Towards a power pool

Advantages of a power pool

Since the various networks combined in such a pool can be considered as one system, savings are possible in a number of areas, for example, investments in future generation (economies-of-scale, more economic projects), more economic use of primary energy sources, better hydro-thermal co-ordination, lower operating reserves, peak load diversity, lower unit start-up costs, and more flexible maintenance scheduling. The reliability of supply in the combined system would also improve and the frequency will be more stable, because the size of one generator compared to the size of the whole system will be less than when the various systems are isolated.

The degree of integration in planning and operation will determine the amount of money that will be saved. However, as utilities reduce their costs, they also lose some of their independence and at some stage they need to decide where the best compromise between these two conflicting objectives lies.

There is also the law of diminishing return regarding the size of a pool. Additional savings are considered to become marginal when the combined peak demand of the pool exceeds 30 000 MW. On the other hand, it is also recognised that the higher the diversity between the systems, their primary energy sources, their load profiles and their sizes, the higher the incentives to have such a pool. On this basis, the incentives to create a pool among utilities in Southern Africa are very high.

Conditions for membership

Regular contact is being maintained with the other utilities in the region (ZESA, BPC, ZESCO) and several discussions about a future power pool have taken place. Eskom's approach is that any utility in charge of an area of supply (or control area) could become a member of the power pool, provided that it satisfies the following conditions:

(i) must own transmission facilities rated at 220 kV or higher, and generating facilities which produce at least 100 MW sent-out electrically linked to the interconnected system;

(ii) have an area of supply with more than 1 000 consumers and operate on 24-hour basis;

(iii) have at least one interconnection at 132 kV or higher voltage with a member, and have at least one agreement in place for two-way energy or capacity trading through that interconnection;

** One Economic Zimbabwe Dollar (EZ$) is assumed equal to US$0,2.

(iv) must be able to satisfy the technical and credit worthiness criteria applicable to all members.

Although it would be more economic to treat the whole pool as one integrated area, such an objective seems too ambitious at this stage and it is felt that a loose pool with one control area per country is more realistic. Such an arrangement could lead to savings equal to between 80% and 85% of those savings which would result from a fully integrated pool.

To realise these savings, it is necessary to specify the obligations of each member and how these obligations will be fulfilled. These obligations must also take into account import agreements contracted previously by the pool members (e.g. SNEL-ZESCO etc.)

Operating and Planning Committees

In order to correspond with what is done elsewhere in the world, an Operating Committee will have to be created which represents all the utilities of the pool.

The responsibilities of this committee will be to investigate what kind of arrangements would be most suitable under particular circumstances (e.g. wheeling charges, etc.) and how the AGCs (automatic generation controls) should be set and controlled to achieve maximum benefits, whilst taking into account transmission and other constraints. The Operating Committee should report to the Executive Committee, which should consist of the Chief Executives of the member utilities.

Next, a Planning Committee must specify common criteria (e.g. security of supply for generation, redundancy and stability criteria for transmission, thermal limits etc.) and indicate what are the most attractive projects for new generation and interconnections within the pool. Another function of the Planning Committee will be to design and recommend tariff structures and guidelines which take into account the common interests of the members. Among these would feature the structure and formulae for the calculation of wheeling charges. As with the Operating Committee, the Planning Committee should be made up of representatives of sufficient status in their own utility and should report to the Executive Committee.

Implementation

In February 1993, BPC and Eskom signed a contract for the exchange of electricity between the two utilities. Although it covers relatively small quantities of energy, the agreement has all the features of a power pool and it is believed that BPC has already saved substantial amounts of money with the new arrangement. The agreement is only between BPC and Eskom and does not involve ZESA because BPC must operate its 220 kV system split.

In May 1993, ZESA, BPC and Eskom signed an inter-utility agreement which, in effect, creates a loose power pool between the three countries, beginning in 1995, and replaces the existing agreement between BPC and Eskom. This agreement will be implemented once the Matimba-Bulawayo line is commissioned.

Informal discussions have also taken place with Swawek where they too indicated their interest in joining a power pool in the region. They are not entirely satisfied with the time-of-use tariff presently in force under which Swawek is treated as an end-consumer.

In August 1992, a workshop was organised by SNEL and Eskom to discuss future interconnections. This workshop was attended by all the utilities in the region who freely expressed their views on the matter. Utilities were keen to have more interconnections between their systems, but also pointed out that it was impossible to ignore the will of the various governments for whom job creation, self-sufficiency and social objectives were sometimes overriding.

For this reason, it may be necessary to show first that a loose power pool with a limited number of utilities works well and can bring substantial economic advantages, before it is extended to new participants.

Another obstacle is the difficulty experienced by most utilities in the region to equip their control centres and their large generators with the computers, telecommunication equipment and AGCs that are required to operate effectively in a power pool environment. The problem is mainly a lack of skilled manpower and money. However, the benefits are so large that no utility should be stopped by this comparatively minor problem.

Conclusions

(a) The few existing interconnections in Southern Africa have already played a major role in the past. The benefits resulting from the interconnections were particularly obvious when calamities (e.g. droughts, wars) occurred.

(b) The various systems in Southern Africa differ vastly in size, primary energy sources and production costs. At present, there is a large excess of primary energy and generating capacity in the region but there are shortages in other areas.

(c) As a result of (b), a wise course of action would probably be to slow down or defer plans for the construction of new power stations and instead build high voltage interconnections between utilities. The deferment of new power stations should be replaced by imports from neighbouring utilities.

(d) The diversity between the various systems provides a strong incentive to create a power pool in the region. Experience overseas indicates that all conditions are met to ensure that a power pool in Southern Africa will be a very profitable venture for all.

(e) The first steps for the creation of a power pool in Southern Africa are already in place between South Africa and Botswana. A more significant step will be the commission of the 400 kV Matimba-Bulawayo line early in 1995.

(f) At this stage, the best course of action would probably be to have a loose pool with few participants and to show that it works well. Only then should the pool be extended to new members.

Plans and projects often change with circumstances. However, if sufficient interest in the power pool is shown by new players, plans can be accelerated to accommodate prospective members.

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(These are both pre-feasibility studies, which may only be released with the permission of the relevant utilities.)

Simulation of PV pumping systems

*** M DAVIS**

The high cost of photovoltaic (PV) pumping equipment means that it is important to size systems so that the water supply meets the demand within an acceptable level of reliability. The range of pumping systems available and the complex manner in which these systems operate makes it difficult to devise simple and accurate sizing techniques. The approach taken here is the full simulation of the operation of a system using pump simulation software. The result is a practical design and sizing tool which can be used to estimate the daily water delivery of a pumping system.

Keywords: photovoltaic water pumps; simulation; sizing; rural areas

Nomenclature

TMY = typical meteorological years
POA = plane of array
LCB = linear current booster
MPPT = maximum power point tracker

Introduction

Photovoltaic-powered pumping systems have important application in rural village water supply, small-scale irrigation and stock watering. They are commonly used in remote areas where there is no access to grid electricity, and are most cost-effective where the water demand is small (typically less than 200 m^3/day). The technology requires minimal routine maintenance and has the potential to be both reliable and durable.

Since the output of a particular PV pumping installation is related to the daily irradiation, the reliability of the water supply is dependent on weather patterns. The high capital cost of the PV array and the pumping equipment itself means that it is important to carefully size the system so that the supply meets the expected demand with an acceptable level of reliability.

The irregular nature of weather patterns and the often complex manner in which a PV pumping system operates make it difficult to develop simple and accurate sizing techniques which can predict the frequency of the water supply meeting the demand. Consequently, a full simulation of the performance of a pumping system, using actual weather data and pump performance characteristics, is necessary to achieve the required results. Encapsulation of such a simulation procedure in a computer program can provide a useful tool to assist in the sizing and selection of PV pumping equipment.

This paper will describe the operation of a PV pump simulation program developed as a practical design and sizing tool.

Simulation structure

There are four components to the full simulation of a PV pumping system. These are represented in Figure 1.

(1) Simulation inputs

The user-defined inputs are those specifications which the user can choose. They include: (i) the site locality; (ii) site conditions, such as, pumping head and array type; and (iii) the system configuration.

The associated database inputs refer to information associated with some of the user-defined inputs. These would include the weather data for the site locality, the characteristics of the PV modules selected and the characteristics of the pump sub-system.

(2) Simulation processing

The simulation processing involves a number of discrete steps. These can be summarised as:

- ***Generation of plane-of-array irradiance and PV cell temperature.*** The source irradiance data should be in the form of hourly values for the global and diffuse component on the horizontal. These can be used to calculate the direct, diffuse and reflected components of irradiance received on the tilted surface. A thermal model can be used to estimate the PV cell operating temperature.
- ***Modelling of the PV array output.*** The output function of the PV module is a function of irradiance, cell temperature, module type and array configuration. A mathematical model is used to generate this function from the module characteristics and environmental conditions.
- ***Modelling of the pump/motor load curve.*** PV pumping systems can be classified into a limited number of different generic types. For each type

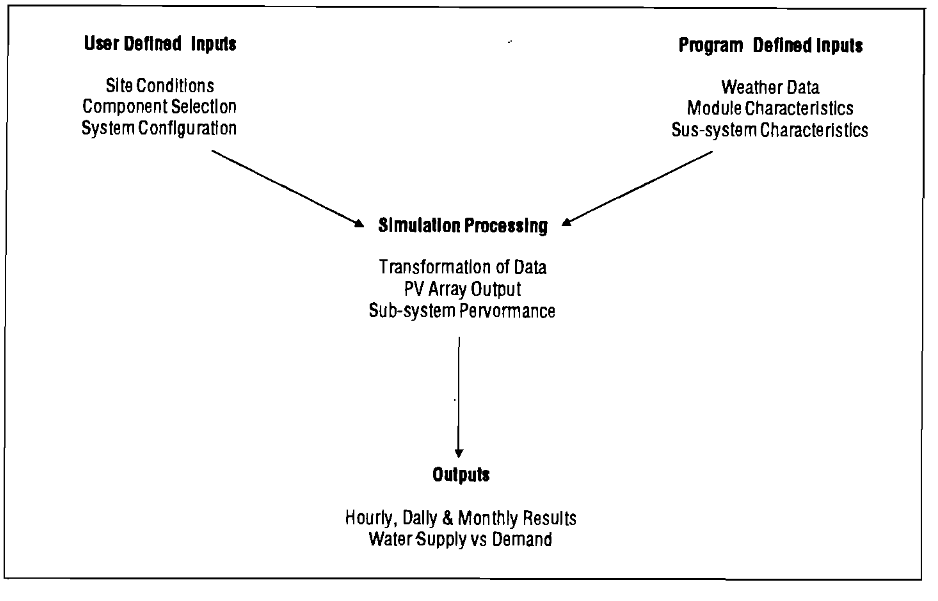

Figure 1: Simulation structure

* Energy for Development Research Centre, University of Cape Town, Private Bag, Rondebosch 7700, South Africa

the electrical load can be modelled as a function of operating head.

- ***Matching of the pump/motor load to the PV array supply.*** The electrical load is matched to the PV array output function to produce the operating point.
- ***Computation of hourly flow rate based on sub-system efficiency.*** The efficiency of the sub-system can be described as a function of input power for a range of different heads. Using the function for the installed head, it is possible to calculate the output power from the operating point. This can then be used to calculate the instantaneous flow rate.

These simulation procedures are executed on an hour-by-hour basis while the pump is running, i.e. while there is sufficient irradiance to run/start the system.

(3) Results from the simulation

The results of this type of approach include hourly flow rates, daily totals and monthly averages of water delivery. Using this data, a day-by-day matching of supply against demand can be done. With a month-by-month average daily demand and a specified tank size, the reliability of the system can be estimated.

System state modelling

Implementation of a complete simulation requires a number of mathematical models to be used. Firstly, the weather data must be presented in a form that is useful and representative. Secondly, this weather data must be transformed into the inputs required for the PV array output model, i.e. the plane of array (POA) irradiance and module cell temperature must be calculated. The electrical output function of the PV array must be calculated as a function of the environmental conditions. Lastly, the operation of the pumping sub-system must be modelled.

(1) Weather data representation

The source weather data was given as hourly averages for every hour of the day at each location. The variables available are: global and diffuse irradiance on the horizontal; wind speed and ambient temperature.

This source data was used to create typical meterological years (TMY) for each available location. A TMY provides hourly values of the four weather-variables listed above. These values are sequences of actual weather data that are selected to represent as closely as possible, the long-term climatic conditions for a particular location.

(2) POA irradiance modelling

In order to simulate the output of a PV array, it is necessary to know the irradiance incident on the array. This quantity can be estimated from the global and diffuse components of irradiance on the horizontal. The POA irradiance is comprised of three components - the direct, diffuse and ground-reflected irradiance.

Calculation of the direct component is relatively straightforward using the geometrical relationships between POA direct irradiance, the direct irradiance on the horizontal and the solar incidence angle on the tilted plane.

The ground-reflected component is the smallest of the three components. It is assumed to source from the global irradiance on the horizontal, reflected isotropically from an infinite plane in front of the array. The albedo of the surrounding surface is used to calculate the level of reflection. This model is adequate for most PV installations. Exceptions might be where the array faces a stretch of water or snow.

The diffuse component is the largest potential source of computational error. It can be modelled either isotropically or anisotropically. The isotropic model assumes that the intensity of the sky diffuse radiation is uniform over the entire sky dome. This assumption is reasonable for low irradiation conditions found during overcast skies. However, for clear or partly clear conditions, this model underestimates the diffuse component. Anisotropic models attempt to incorporate the effects of increased diffuse irradiance around the sun and near the horizon. The anisotropic model used in the simulation is the enhanced Perez[1] model.

(3) PV cell temperature model

The model used to estimate the PV module cell temperature is the iterative thermal algorithm developed by Fuentes[2]. This model requires a minimum of input and has been found to have an error of less than 5° C[3].

The model calculates an initial estimate of cell temperature. This value is then used to compute a second estimate. This process is repeated until the difference between the current estimate and the previous one is less than a specified value.

(4) PV array output model

The analytical model developed by Rauschenbach[4] was used to describe the PV module output function. The parameters of the module that are required include the open-circuit voltage, short-circuit current and the maximum power point voltage and current, all for a base I-V curve at a specified POA irradiance level and cell temperature; and the variation of these parameters with POA irradiance and cell temperature, assumed linear.

For a particular POA irradiance (Q) and cell temperature (T), values for the open circuit voltage (V_{oc}), short circuit current (I_{sc}) and maximum power point voltage (V_{mp}) and current (I_{mp}) are estimated from the base values and their variation with irradiance and temperature. These values are then used to estimate the module current (I_{pv}) for a specific operating voltage (V_{pv}):

$$C_2 = \frac{\frac{V_{mp}}{V_{oc}} - 1}{\ln\left(1 - \frac{I_{mp}}{I_{sc}}\right)} \qquad C_1 = \left[1 - \frac{I_{mp}}{I_{sc}}\right]\left[\exp\left(\frac{V_{pv}}{C_2 V_{oc}}\right) - 1\right]$$

$$I_{pv} = I_{sc}\left[1 - C_1\left(\exp\left(\frac{V_{pv}}{C_2 V_{oc}}\right) - 1\right)\right]$$

Sub-system characterisation

The modelling of the operation of the pump sub-system, i.e. the entire system (excluding the PV array), is done in three steps. Firstly, start-up and stopping conditions are established for the system; secondly, the electrical load curve of the controller/motor/pump is modelled; and thirdly, the efficiency of the sub-system is defined by the profile of efficiency against input-power. This characterisation leads very directly to the simulation procedures: it is established whether the pump is running; the load curve is then matched to the supply function of the array to determine the operating point; this defines the sub-system input power which can be used in conjunction with the efficiency function to calculate the system output.

Where a pulley system is used to drive the pump, the electrical load will be a function of the pulley ratio selected. In these cases, the system must be characterised for an appropriate pulley ratio.

(1) Generic types of sub-system models

Different pumping systems work on different operating principles. The type of operation depends on the selection and operation of components in the system. For example, a system using a centrifugal pump will operate differently from one using a positive displacement pump and must be modelled differently.

There are seven different models incorporated in the simulation. Each model describes a different generic type of system. The models defined are:

— directly coupled DC system with centrifugal pump;
— directly coupled DC system with positive displacement pump;
— DC motor with positive displacement pump and linear current booster** (LCB);
— DC motor with maximum power point tracker (MPPT) and either type of pump;
— AC motor with fixed voltage inverter and either type of pump;
— AC motor with MPPT and either type of pump;
— AC system with shallow cycle batteries and either type of pump.

(2) Start-up and stop conditions

A pumping sub-system attached to a PV array will start when the array current reaches a certain threshold value and stop when the array current drops below a different threshold value. For positive displacement pumps, the starting current is required to overcome start-up torque and will be higher than the stopping current. For centrifugal pump systems, the starting current will correspond to the threshold speed at which the pump starts to deliver water. In these cases, the starting and stopping currents will be similar.

These threshold values are dependent on installed static head, i.e. the higher the head, the greater the start-up current required. Thus the starting and stopping currents must be specified as a function of installed head.

The model operates by checking the maximum array current and comparing it to the starting current and the stopping current. A simple logical check establishes whether the pump is running. Calculation of the flow rate only proceeds if the pump is running.

An exception to these general principles is where batteries are used. In these cases even very low current from the array (at a correspondingly low irradiance level) is cycled through the batteries. In these types of systems the concepts of starting and stopping current are not relevant.

(3) Modelling the load curve

Each generic type of system has a different type of motor/pump load curve which must be used to compute the operating point of the system. Each type of load curve can be characterised by a set of parameters which define the operation of the sub-system at a particular head.

The load curve of a directly coupled DC system with centrifugal pump is shown in Figure 2. It can be fitted using an exponential curve. The parameters used to define this model are:

— head;
— the parameters of the curve: $I = A_0e^{bV}$, i.e. A_0 and b;
— the minimum and maximum voltage over which this load curve is valid.

A directly coupled DC system with positive displacement pump is configured similarly to the previous model, with the exception that a positive displacement pump is used. The load curve of this system is a straight line as shown in Figure 3. The parameters used to define this model are:

— head;
— the parameters of the straight line: $I = I_0 + mV$, i.e. I_0 and m;
— the minimum and maximum voltage over which this load curve is valid.

In a DC system with positive displacement pump and LCB, the booster is used to interface the DC motor with the PV array. A LCB is usually reserved for use with a positive displacement pump. The load curve of this system is a constant voltage line, up to a critical current when the system switches over to a directly coupled system, i.e. a straight line function. The parameters used to define this model are:

— head;
— the voltage set point of the LCB;
— the parameters of the straight line: $I = I_0 + mV$, i.e. I_0 and m;
— the minimum and maximum voltage over which this model is valid.

Where a DC motor and positive displacement pump are connected to the array via

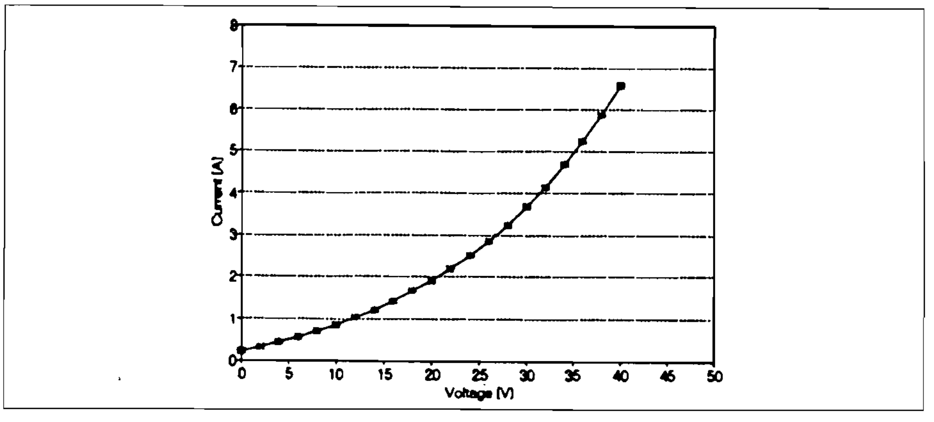

Figure 2: Directly coupled DC system with centrifugal pump

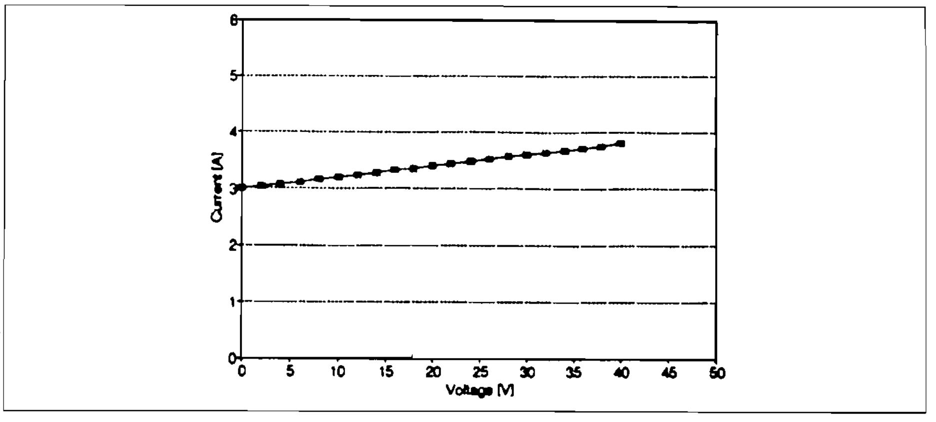

Figure 3: Directly coupled DC system with positive displacement pump

** A linear current booster is a DC/DC converter which operates to chop the voltage and boost the current.

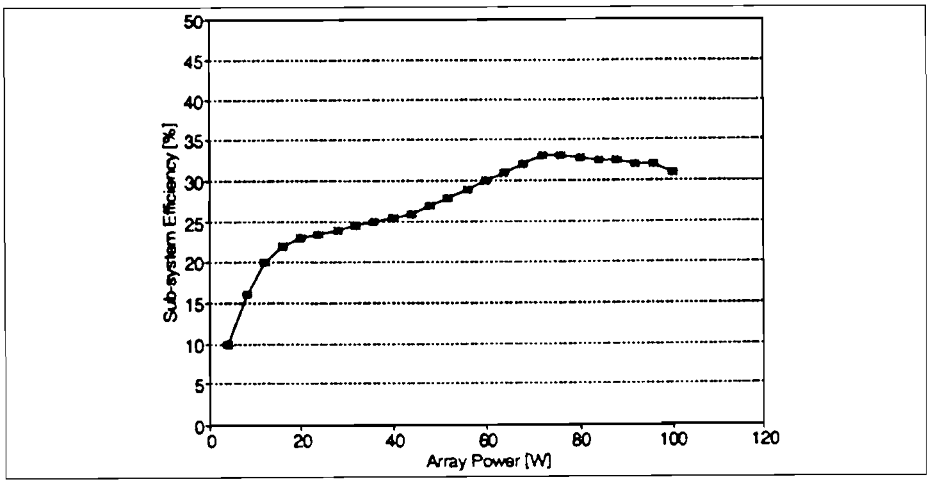

Figure 4: *Efficiency profile*

a MPPT, the tracker operates to keep the operating voltage at the optimum power voltage. Where an AC motor is used, an inverter is required to condition the DC power from the array. The inverter can either operate at a fixed voltage, which defines the system operating point or incorporate maximum power point tracking. The only parameters required to define this system are the inverter set point (where applicable) and the voltage limits.

An AC system which uses shallow cycle batteries is qualitatively different from those discussed above. The PV array charges a set of batteries, when the battery voltage reaches an upper limit, the inverter switches on and runs the AC motor and pump at constant power. The current drawn by the inverter is taken directly from the array and topped up by discharge current from the batteries. The total current drawn is a function of the installed head. This discharge cycle continues until the battery reaches a lower set point. At this point the inverter switches off and the charging cycle recommences.

The parameters required to define this system are:

— head;
— inverter current draw;
— battery cycling efficiency;
— the battery charge and discharge voltage ranges.

(4) The efficiency profile

The efficiency profile is a set of efficiency and power points. The efficiency refers to the operating efficiency of the sub-system, i.e. the ratio of hydraulic power output to the electrical power supplied by the array. The data should cover the full spectrum of powers at which the system is likely to operate. The set of points should be given for a range of heads.

The reason for specifying the efficiency as a power profile is that, in most cases, the sub-system efficiency is not constant. Instead it will be sensitive to the power input to the electronic device or the motor. An example of an efficiency profile is provided in Figure 4. This profile is modelled by two quadratic functions splined together. This profile must be modelled for a range of discrete heads.

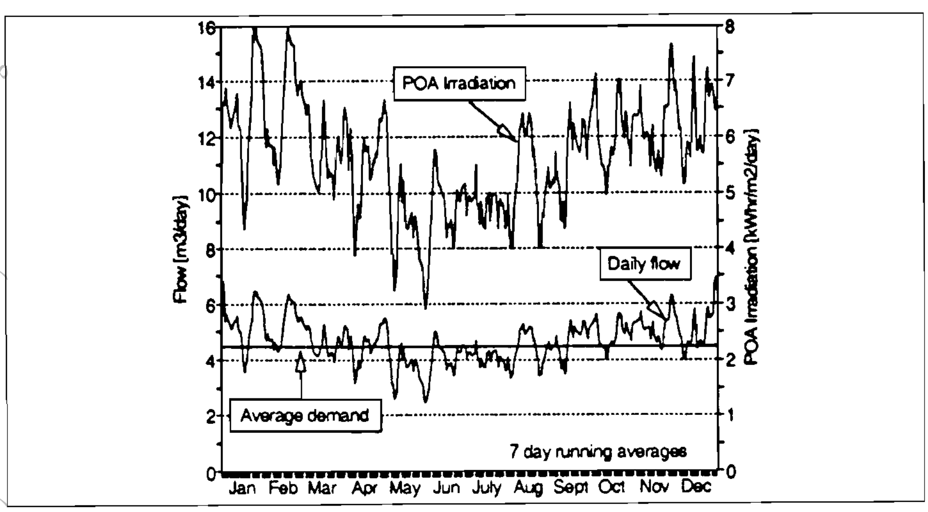

Figure 5: *Simulation results over a full year*

An exception to this is the model describing an AC system with shallow cycle batteries. In this case the sub-system is always run at constant power and the efficiency need only be described as a function of head.

Simulation and outputs

For each hour in the day the simulation follows the following three categories of procedures. Firstly, the input data is identified and transformed. POA irradiance is calculated from values on the horizontal and the cell operating temperature is estimated. Secondly, the operating point of the system is computed. If the pump is running, the motor/pump load is compared to the array output function, and the operating point is calculated as the intersection of the array supply function and the sub-system load function. Lastly, the actual flow rate for that hour is calculated. The operating point defines the input power to the sub-system which can then be used, with the sub-system efficiency model, to calculate the output power. Knowing the head, it is possible to compute the flow rate.

The load curves and efficiency profiles are characterised for discrete heads. If the installed head matches one of the heads used in the data specification, then the above linear procedure can be used to calculate the flow rate. However, if the installed head lies between two recorded heads, then the instantaneous flow rate is calculated for both of these heads. The results are then interpolated to derive an estimate of the flow rate at the installed head.

The results of each hour's simulation include POA irradiance, the operating point, the sub-system efficiency and the flow rate. The POA irradiance and flow rate can be totalled and averaged to provide daily totals and monthly averages. Values for the total sub-system daily energy efficiency can be obtained.

A useful analysis is a comparison between the supply and water demand on a day-to-day basis. This allows an evaluation of a suitable size tank as well as an estimation of the frequency of water supply failure and the periods at which this is likely to occur.

Example results using a DC motor, diaphragm pump, LCB and 225 Wp array at 47 m are presented below. Weather data are from Port Elizabeth in South Africa and a tank size of 8 m^3 is assumed.

Data requirements

This type of simulation exercise requires detailed and extensive information concerning weather conditions, PV module characteristics and sub-system performance.

Weather data must include global and diffuse irradiance on the horizontal, wind speeds and ambient temperatures on an hourly basis. Data from twelve meteorological monitoring sites around Southern Africa were processed into twelve TMY data sets.

PV module characteristics can be obtained from manufacturer's specifications or can be independently tested. A database of module performance characteristics for most commercially available products was established to link into the simulation software.

Sub-system performance must be characterised slightly differently for different types of systems. In general, starting and stopping conditions, load curves and efficiency profiles are required. This level of information is more detailed than that usually supplied by manufacturers, and it was necessary to test a wide range of equipment. Performance tests were performed on five different diaphragm pump and DC motor systems; two line-shaft progressive-cavity and DC motor systems; one DC brushless motor with MPPT and centrifugal pumps; and one AC system with shallow cycle batteries. The tests were performed at a wide range of heads and were designed to measure all the performance parameters required for the simulation.

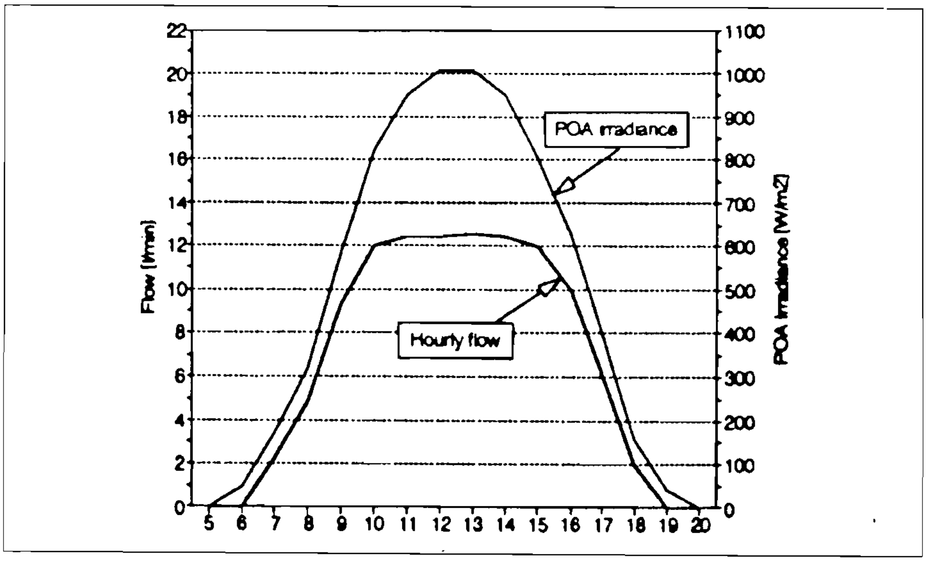

Figure 6: Hourly results for one clear day

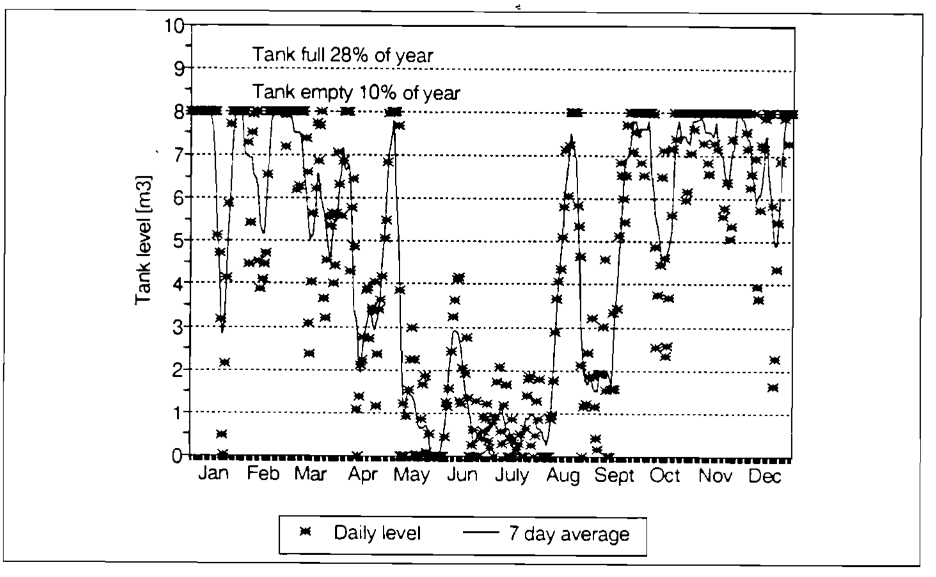

Figure 7: Tank levels over the year

Limitations and sources of error

There are a number of limitations inherent in the simulation procedures. These are to be found in the modelling of the weather data, the performance of the system at low irradiance conditions and the specification of the demand. Sources of error can be found in the weather data, the PV output model, as well as the pump performance models.

(1) Limitations in the weather data

The concept of a typical meterological year is used to create a year's cycle of weather data that is representative of long-term trends. However, weather is inherently variable and no two years will ever be the same.

The TMY data has been designed to include data where the monthly daily-averages are close to the long-term averages. Also, since an important characteristic is day-to-day variability in the weather, the process of constructing TMY data has attempted to select months where the distribution of day-to-day values is similar to long-term trends. However, if the critical characteristic is sequences of low irradiation conditions, i.e. if the inability of the system to meet demand is critical, then the TMY data may not be representative.

(2) Inaccuracies in the PV array output model

In cases where the operating voltage is below the maximum power voltage, the use of the model is voltage controlled, i.e. an input voltage is used to calculate an output current. In this portion of the curve, the error in the estimated current is less than 3%[3]. Where the operating voltage is greater than the maximum power point, the model is current controlled, i.e. an input current is used to calculate an output voltage. In this case the error in the estimated voltage is less than 6%.

(3) Inaccuracies in the load curve models

The load curve models for positive displacement pumps with DC motors were found to be accurate for higher voltages. At low voltages the load curve tended to deviate from the linear model. This only affects the simulation of systems which do not use linear current boosters.

The model for AC systems using shallow cycle batteries is qualitatively different from the other models. There are two sources of inaccuracies associated with

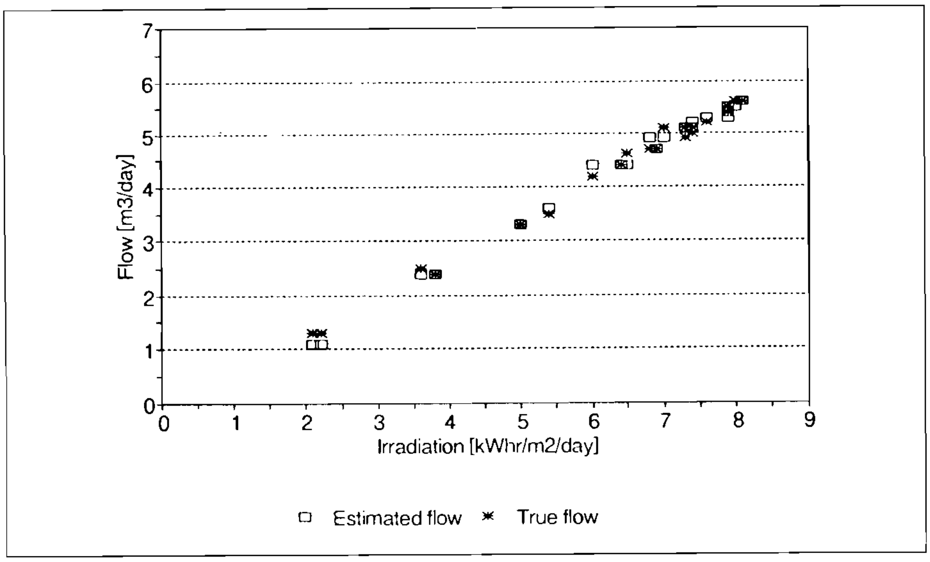

Figure 8: *Validation of simulation results against monitored results*

this model. The first applies to situations where battery charge and discharge cycles are longer than one hour. This may occur where the charge and/or discharge currents are slow. Long charging times may occur either where a very small array is charging the batteries or under low irradiance conditions when array output is low. Long discharge times may occur when the array can supply all or most of the current drawn by the inverter. In these cases the model will not accurately match the water delivery of the system on an hour-by-hour basis, although the differences should be minimised over a full day. A second source of uncertainty is in the performance of the batteries. The model assumes a consistent battery cycling efficiency. However, this will be affected by battery degradation, temperature and the charge/discharge current. Laboratory-based battery performance tests indicated that this variation in cycling efficiency would be less than 7%.

(4) Errors due to variation at start-up

There are a number of factors which affect the exact time of start-up. For systems that do not use batteries, the pump will commence delivery when sufficient current is available from the array to overcome the starting torque of the pump and the inductive surge of motor start-up.

Positive displacement pumps and in particular, progressive-cavity type pumps, are known to have high starting torques. There are a number of factors, many of them difficult to determine, which can affect the starting torque of these pumps. The temperature of the water, wear in the stator, the presence of grit and the static water level in the borehole can all affect the torque required to start the pump. The model used in the simulation assumes that the start-up current is constant and no account is taken of factors which may affect the start-up from day to day.

(5) Errors due to variation in the head

The simulation assumes that the pumping head remains constant from day to day and during the course of each day. However, there are a number of factors which may affect the overall head. The head which the pump operates against is the sum of the static head and the head loss due to friction. The head loss will vary as the flow rate changes during the course of the day.

Where a system is pumping water from a borehole, the behaviour of the water level in the borehole can be an important variable. Firstly, there may be seasonal and annual changes in the level of the water-table. Secondly, the borehole draw-down may vary over the course of a day as water is pumped out.

(6) Errors due to uncertainties in the load

The simulation exercise produces daily estimates of water delivery. These are used with estimates of average water demand and a specified tank size to calculate the frequency with which the tank is empty or overflows. However, just as the water supply will fluctuate from day to day, so will the water demand. This variation in demand will affect the frequency with which the tank is emptied and is not taken into consideration here.

Validation

An attempt was made to validate the accuracy of the simulation program by comparing the results against the performance of a field installation. A diaphragm pump with DC motor and LCB was installed in a borehole and connected to a 225 Wp PV array. The pumping head was 47 m and the system was monitored for 24 days.

Figure 8 shows the results of the comparison. The average daily flow was 5 m^3/day and the absolute difference between the actual daily flow and the predicted flow was always less then 0,2 m^3/day. Except for low daily irradiation levels of less than 2,5 kWh/m^2/day, the percentage error was always less than 5%. Using a t-test it was shown that there was no significant difference between the two sets of data.

Conclusions

Full simulation of PV pumping systems represents the most accurate technique which can assist in the design and sizing of installations. However, the approach is information-heavy and requires detailed information about weather conditions, PV module characteristics and sub-system performance. The investment in obtaining and processing the necessary information, together with the use of the simulation software, can help lead to greater confidence in the application of PV pumping technology under local conditions.

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*The SADC experience related to the production and utilisation of biomass fuels: Socio-economic problems and lessons learnt

**BK KAALE

This is the second part of a two-part paper*** which focuses on the role of biomass fuels within the SADC energy economy. This paper outlines some of the main socio-economic and environmental problems associated with the scarcity of biomass fuels within the region. It also attempts to summarise lessons learnt with regard to the production of biomass fuels, and suggests possible future courses of action.

Keywords: biomass fuels; SADC; socio-economics; environment; agroforestry; woodlots; fuelwood; charcoal

Introduction

A review of past efforts regarding the production of biomass fuels on a sustainable basis in the SADC region, most of which started in the early 1970s, indicates that trees are grown for a variety of uses and not only as a source of fuel. This emphasises the need to combine fuelwood production with other tree-growing purposes. With regard to the efficient utilisation of biomass fuels, the development and dissemination of improved charcoal stoves in the urban areas of some of the SADC countries is gaining momentum. However, in the rural areas, the use of improved wood-burning stoves is reported to be slow. In Tanzania, Zambia and Malawi the improvement of traditional earth kilns for charcoal production is proving to be successful.

The main lessons learnt with regard to biomass fuels in the SADC region in the future include the need to integrate their production and utilisation with other land uses, and strong political support, together with a realistic provision of financial support, to enhance local initiatives to sustain them and protect the environment.

General problems

Although biomass fuels are the major source of energy for most rural and low-income people in the developing world, the potential supply of fuelwood is dwindling rapidly. It is estimated that, for more than a third of the world's population, the real energy crisis is a daily scramble to obtain fuelwood to meet domestic uses[9].

In aggregate terms, fuelwood scarcity is site-specific, but it is expanding rapidly, covering more areas and affecting more people. Some of the problems associated with biomass fuels scarcity in the SADC region are discussed below.

Problems for women and children

Evidence from many SADC countries indicates that women and children are presently having to spend more time collecting fuelwood which was, in the past, readily available close to homesteads [3,22].

Lowering of living standards

Due to an acute fuelwood scarcity, people have been forced to use low-quality biomass fuels such as, agricultural residues and animal wastes, which result in the lowering of their standard of living. For example, agricultural residues and animal wastes account for about 26% of total energy used in Lesotho. This is attributed directly to an acute scarcity of fuelwood in the rural areas[29].

Some of the reasons why agricultural residues and animal wastes are regarded as low-quality biofuels are that:

(a) they produce more smoke than wood; (b) they have an unpleasant smell, and (c) they burn more quickly, thereby necessitating intensive fire management. Also, it is difficult to simmer bulk foods in appliances heated with these fuels, which may result in the under-cooking of the food. Thus the society perceives these fuels as inferior and they are used only as a last resort[29].

Decline of agriculture production

Nkaonja[23] reported that there is a progressive decline of food crops in Malawi, particularly in areas where people have switched from fuelwood to crop residues and kraal manure. Similar observations were reported by Mnzava[19] in Tanzania and by Walker[34] in Botswana.

Past studies indicate that, in principle, only detailed site-specific analyses can determine the impact of the removal of agricultural residues from the fields. In a few cases plant residues can be removed from agricultural land without serious environmental consequences. However, in many cases, removal of crop residues will cause severe soil erosion, which will, in turn, result in a loss of the soil's nutrients, its water-retention capacity and organic matter. Pasztor *et al.*[24] reported that residue removal increases the rate of water run-off between 10- and 100-fold. Organic matter acts as soil conditioners, hence their removal can be detrimental to the soil.

Nevertheless, agricultural residues and animal wastes provide an opportunity for poor people to meet their energy needs without exhausting their fuelwood

* Based on a paper presented at the 8th SADC Energy Ministers' seminar on the sustainability of traditional fuels and environmental protection in the SADC region, held in Windhoek, Namibia, 17 June 1993.

** Technical Advisor, Ministry of Water, Energy and Minerals, P O Box 4735, Dar es Salaam, Tanzania

*** The first part of this paper was published in the *Journal of Energy in Southern Africa*, Vol. 5 No. 2, May 1994, pp. 47-50 supply. But few studies have been undertaken to quantify these amounts, especially the proportion that can be used for energy without seriously affecting the soil's fertility. Evidence from Indonesia suggests that the total biomass available for fuel may be four times greater than for fuelwood alone[11].

Health hazards

The burning of agricultural residues and animal wastes, particularly in open fires, poses a serious health hazard for those (mainly women and children) who are exposed to the smoke. This is believed to be an important cause of ill-health and death in many developing countries. The main observed health effects include: acute respiratory infection, chronic obstructive lung disease, low birth weight, cancer, and eye infections[24]. Some of the pollutants emitted through the burning of agricultural residues and animal wastes are: hydrocarbons, aldehydes, aromatics, carbon monoxide and nitrous oxides.

Consumption of uncooked food

Scarcity of fuelwood influences the amount of food supplied or cooked. If there is less fuel available, consumption of uncooked and reheated foods may increase (for example, in Nepal), which may result in a rise in disease. Infants in particular are severely affected as they are unable to easily digest uncooked foods. On the other hand, there has been a reduction in the consumption of certain staple foods, like beans, which require long cooking hours, in countries such as, Tanzania, Guatemala, Mexico, Somalia, Ethiopia and Lesotho[21,24].

Economic hardship

Fuelwood, which used to be fetched free by poor people, is increasingly becoming a commercial commodity in most rural areas, consequently creating severe economic hardship for the poor[13].

Vicious circle of poverty

The removal of too much tree cover from a particular area in order to meet fuelwood demands threatens the very land-, water-base and the food production potential of the people. Consequently, this locks them into a vicious circle of poverty, soil deterioration and environmental degradation[10,20].

Lessons learnt from past efforts to sustain biomass fuels in the SADC region

Background

In general, all SADC member states have initiated national and local programmes to increase biomass fuel production and improve utilisation efficiency. A review of the ongoing national programmes, most of which started in early 1970s, was undertaken by the SADC Energy Sector between 1989 and 1992. Some of these lessons are highlighted below.

(1) ***Consideration of socio-economic factors***

The most successful and sustainable tree-growing efforts in the region are those based on local initiatives. To obtain support for these initiatives, it is important for energy planners to take into account local socio-economic conditions, a few of which are discussed below.

(i) Wood as a multi-purpose product

Wood is used for many purposes. As such, trees and their products are integrated into an often complex resource and social system. Wood products can rarely be isolated and dealt with adequately in terms of single products or single technologies[3,13].

People normally collect dead wood and branches for fuelwood. They rarely cut down living trees, unless it is for commercial purposes, or there is a severe fuelwood scarcity. To avoid cutting down a tree, traditional tree management systems, like pollarding and heavy pruning, are practised.

In general, fuelwood will be available in any area with abundant tree resources or wood products. Similarly, where a fuelwood scarcity exists, the availability of other wood products such as, poles and sawn timber, will also be scarce[14].

Any technique which leads to the production of wood can contribute to fuelwood production, directly or indirectly. Table 1 provides a summary of possible productive and protective services offered by trees.

(ii) Identifying people's needs and understanding the fuelwood problem

It is important to listen to what people define as their primary needs and to try to meet them. It is also necessary to understand the cultural factors underlying fuelwood production at a specific location, as problems related to fuelwood are inherently local.

Fuelwood scarcity is one of many problems being experienced by local people in the SADC region. However, the severity of the problem depends on local conditions. Therefore it is important to understand the local perspective on fuelwood scarcity and the need to sustain its supply.

PRODUCTIVE SERVICES		
Medicine Fuelwood Dyes Clothing Soap Weapons Nectar from bees Fibres Substitutes for toilet paper	Poles Charcoal Perfumes Insecticides Corks Construction timber Sticks (discipline) Water coagulants (Purification)	Fodder Fruits Adhesives Poisons Tannin Oil/Lubricants Stimulants Thatching materials for houses
PROTECTIVE SERVICES		
Protection of water catchment areas	Provision of shade to people, animals and crops	Soil stabilisation
Soil enrichment through mulching	Local climate amelioration	Wind breaks
Boundary demarcation	Provision of privacy	Provision of convenient areas for meetings in the rural areas

(Source: [13,15,31])

Table 1: Possible services provided by trees

As fuelwood can be obtained as a by-product from trees grown for timber, poles or other purposes, people prefer to grow trees for more economic reasons than simply for fuelwood.

Although women and children are responsible for collecting fuelwood, their priorities when planting trees are (1) food (i.e. fruit trees); (2) income; and (3) fuelwood. Cecelski[5] reported that for most women experiencing an acute fuelwood scarcity, their top pre-occupation was the need to find solutions to their desperate food and income deficits.

The absence of trees does not necessarily imply a shortage of household energy. Other biomass resources, like agricultural residues and cow dung, can be used.

(iii) The need for multi-sectorial efforts

The fuelwood scarcity needs to be analysed, not merely as an energy shortage but as a subset of the socio-economic and cultural crises in land-use and development patterns. As such, energy plans and implementation strategies for the fuelwood sub-sector must consider the functional roles of fuelwood in the total economy. Hence the need for close multi-sectorial collaboration between the sectors dealing with land-use, energy and environmental protection.

(iv) The need for the people's participation

The task of ensuring local tree cover is so great that it can only be tackled in an essentially self-help scheme by the people themselves. In principle, no project can succeed in the long run if it does not have the full enthusiasm and commitment of the local people - those most likely to reap its benefits. Direct action by the local people is the most cost-effective way to sustain fuelwood supply and environmental protection at local and regional level.

(v) Land tenure, opportunities and constraints

Many SADC states have customary systems of ensuring land tenure to their societies, but such systems are not formalised according to Western standards[7]. In many cases, customary land tenure systems provide an opportunity for tree-growing[13]. Experience has also revealed that it is very difficult to change existing land tenure, whether formal or customary[3]. For success, it is wise to base project designs on existing tenure systems and if changes are required, these should be considered as long-term objectives for the total land management of the area in question.

Population growth has created land pressure, making some people landless. These people experience difficulty in planting trees on land which they neither own nor control.

(vi) Political and financial support

The success of grassroots fuelwood programmes depends on strong and active political support at all levels, with provision of catalytic financial support. The remarkable success of tree-growing attained by some member states, namely, Malawi and Tanzania, is due to active political support which has facilitated the formulation of integrated national and local strategies for sustaining fuelwood production, backed by financial commitments.

Technical factors

Based on past studies, it has been found that most of the technical factors discussed below have a major impact on biomass fuels production, hence the need to consider them in the planning and implementation of biomass fuels programmes.

(i) The selection of appropriate species

It is crucial to select species which can grow successfully and provide the desired end-products to the society. It is wise to start with local species which are used to the climate, edaphic and biotic factors of the area. A variety of different species should be encouraged in order to minimise possible disasters caused by insects or diseases.

The number of species planted or protected by farmers in their farms and communal woodlots is surprisingly high. A survey in the Babati District, Tanzania, revealed that over 110 different species were being grown by farmers. About 70% of the species was indigenous, the rest exotic. Most of the indigenous species were already used to local conditions, being drought- and termite-resistant, while many of the exotic species were not termite-resistant. A balance of indigenous and exotic species should therefore be maintained[2].

(ii) The selection of tree-growing technologies suitable for local conditions

Existing wood production technologies based on community priorities, capabilities and limitations should be developed first. Changes and modifications to local practices should be based on field research and demonstrations.

(iii) The combination of extension services with demonstration plots

Extension services alone rarely convince people to grow trees. Demonstration plots and examples of successful tree-growing by reputable individual villagers are essential supplements to extension services.

Examples of successful and sustainable tree-growing efforts and the improvement of utilisation efficiencies in the SADC region

Raising of plants

Methods used for raising plants include nurseries, direct sowing of seeds in the field, use of wildings and cuttings.

(i) Nurseries

The raising of seedlings through nurseries requires some initial knowledge of nursery techniques. Different types of nurseries can be established. Successful ones through local initiatives include:

(a) Individual small-scale nurseries

Some individuals have initiated the establishment of small-scale nurseries to produce seedlings for their own use or for sale. As they are usually self-reliant, utilise local resources, and seedlings are produced close to planting sites, they are cheap to establish and sustain through local initiatives[6,10].

Sigino Village in the Babati District of Tanzania, is an example of where individual tree nurseries have been successful. Since 1986, the demand for tree seedlings in the village was higher than what could be obtained from official Forestry Department nurseries. In order to overcome this problem, the villagers decided to grow their own seedlings. By the end of 1989, Sigino Village had attained a sustainable supply of tree seedlings through participatory efforts with minimal catalytic support from the government[13].

(b) School nurseries

Some schools with an adequate water supply have established tree nurseries. The children are taught to raise seedlings as a part of their science courses. A system of "learning by earning" has been introduced in some countries, particularly Malawi and Tanzania[19,23]. The system encourages schools to raise large quantities of seedlings and to sell them to the government or non-governmental organisations (NGOs). In this way, schoolchildren can earn money while learning. School nurseries have a high demonstration impact and they are cheap to operate.

(c) NGO nurseries

These are usually established close to planting sites, and use some paid labour, supplemented by the people's participation in order to reduce costs. As they operate at grassroots level, they have a high demonstration impact on the local people[34].

(d) Centralised government nurseries

These nurseries produce large quantities of seedlings from a single site, and are operated by trained foresters and paid labourers. They are important in the arid zones where there is limited water supply, as they can be established close to water reservoirs. However, based on the experiences of many countries, the raising of seedlings for the general public through central government nurseries is generally expensive and unsustainable[2,17].

(ii) The direct sowing of seeds in the fields

Some of the seeds of various tree species can be sown directly in the fields, instead of having to be grown first in a nursery. Some of the tree species which can be sown directly in the fields include: *Mangifera indica* (mangoes), *Acacia mearnsii* (Black wattle), *Leucaena leucocephala*, etc. The success of direct sowing depends on an abundant seed supply, rainfall distribution, and protection of the seedlings in the field[19].

(iii) Cuttings

Some tree species can be propagated by means of cuttings. This is an important method of growing trees in areas where the raising of seedlings is difficult because of water scarcity or where there is a danger that young seedlings could be damaged by animals. Cuttings are normally used for home and kraal fences. Knowledge of desirable species is essential, which local people have, with respect to indigenous species in their area. For example, it is reported that species commonly propagated by means of cuttings in the Babati District, Tanzania, include: *Commiphora africana*, *Commiphora zimmermanni*, *Datura arborea*, *Dracaena usambarensis*, *Euphorbia spp.*, *Ficus spp.*, and *Jatropha curcas* [2]. It was also found that tree-growing by means of cuttings was a common practice in the Dodoma, Singida and Arusha regions in Tanzania[6].

Field establishment technologies

The most successful field establishment technologies include: individual plantings on farms (agroforestry), school plantings, institutional woodlots, and the management of communal natural forests through traditional laws and beliefs.

(a) Tree planting by individuals

People have realised that tree crops in the future will have to be obtained from farmed land, as communal lands, which are the main source of free wood crops are under pressure, due to population growth and, in some cases, they have disappeared. This has led many individual farmers to plant trees as a crop on their farms (agroforestry).

> "The main lessons learnt with regard to biomass fuels in the SADC region in the future include the need to integrate their production and utilisation with other land uses, and strong political support, together with a realistic provision of financial support, to enhance local initiatives to sustain them and protect the environment."

Individual tree-growing on farms provides a unique system whereby trees are not grown only on poor land which is not arable for other crops, but on good land which enhances productivity. In many cases, joint tree/crop/livestock production and environmental protection provides better returns than monoculture production systems[16].

Agroforestry enable farmers to obtain productive and protective services from trees on agricultural land. It provides an opportunity for intensifying land-use in particular, in areas with a high population growth.

(i) ***Some site-specific examples of successful individual tree planting through agroforestry***

All SADC member states are currently promoting individual tree-growing through agroforestry, as it has been recognised that "the rural fuelwood energy has only one main strategy for survival and sustainability, namely, to integrate its production with other land uses". A few examples from Malawi, Mozambique, Tanzania and Zambia are discussed below.

(1) Malawi

Various individual tree planting (agroforestry) programmes are being undertaken in Malawi. Some of the most important ones are:

(a) The National Tree Planting Day Programme which started in 1976, with its main objective of intensifying individual tree-growing. It is commemorated annually on 21 December, which is a public holiday for tree planting. The average annual number of trees planted through this programme is about 25 million[28].
(b) The Carlsberg Brewery Company Tree Planting Programme, which sponsors two tree seedlings per each bottle top of Carlsberg beer collected by tree growers. Through this system, the company supported the planting of 4 million trees in 1988 and 7 million trees in 1989. Current figures are not available. However, the company's contributions to tree-growing are reported to be increasing annually[23].

(2) Mozambique

The main policy and strategy for sustaining fuelwood supply in Mozambique is through the people's participation. However, the long civil war has minimised people's efforts in tree-growing and the management of their natural forests[25]. Nevertheless, some few site-specific efforts are ongoing.

(a) In 1985, a programme was started to encourage the peri-urban dwellers of the main towns of Mozambique to plant trees by means of agroforestry to intensify their subsistence farming.
(b) The Canadian University Service Overseas (CUSO) is assisting farmers in individual tree planting in Chokwe. They are conducting extension services, raising multipurpose tree species, and encouraging farmers to conserve indigenous trees on farms. Tree planting is also

taking place in Umbeluzi with NGO support.

(3) Tanzania

Successful individual tree planting can be found in all regions of Tanzania and this is the main strategy used by the government to sustain fuelwood and environmental protection through participation by the people. The Babati District in Arusha region, where some villagers have achieved a sustainable fuelwood supply from their own planted trees provides a good example, particularly, Bashnet Village.

(a) Bashnet Village is one of the few villages in the semi-arid zone of Tanzania which has managed to grow trees and meet its fuelwood and poles demand from individually planted trees. The village has vast, undulating grasslands, with virtually no natural woody vegetation at all. Most of the villagers are predominantly herdsmen. In the 1930s, *Acacia mearnsii* (black wattle) was introduced into Bashnet by the government, and the villagers were encouraged to grow the species for fuelwood, poles and environmental protection. Currently, each household has a black wattle plot sufficient for its fuelwood and building materials needs. Plot sizes range from 0,1 ha to 0,4 ha on average, although larger ones are not uncommon.

(4) Zambia

Individual tree planting is encouraged here, with financial and technical assistance from the International Committee for Research in Agroforestry (ICRAF). Ongoing activities include: identification of tree species suitable for agroforestry purposes, the development of suitable agroforestry techniques, and the transfer of those techniques to farmers.

(a) Large numbers of trees are planted by individuals on the national tree planting day (15 December) and throughout the national tree planting month, which is between 15 December to 15 January. For example, between 1985/86 and 1988/89, a total of 2,8 million trees were planted.

(b) NGOs and donor agencies are contributing effectively to tree-growing efforts in Zambia. The Children's Christian Fund, based in Lusaka, has been actively engaged in individual tree planting at Katuba and in the peri-urban areas of Lusaka. For example, in 1989, they managed to plant about 10 000 trees. Donors supporting individual tree-growing programmes include: SIDA, IDRC, the Commonwealth Development Corporation (CDG) and the Danish Development Agency (DANIDA).

(ii) ***School tree planting***

Trees are increasingly being planted along school avenues and boundaries and, where land is available, as woodlots. School tree planting has played an important role teaching the children methods of tree-growing and management. It is a cheap and most effective educational means of growing trees. Successful school tree planting on a significant scale can be found in Botswana, Lesotho, Malawi, Swaziland, Tanzania, Zambia and Zimbabwe. Trees planted at schools are normally used for shade or ornamental purposes, and they are harvested for fuelwood or poles.

(iii) ***Woodlots***

Woodlots are small plantations, ranging from one hectare to many hectares. They are intended for the production of poles, fuelwood, timber and possibly other wood products. Occasionally they are used for rehabilitating degraded land. The successful establishment of woodlots by institutions, commercial farmers and development associations has been achieved in Botswana, Lesotho, Tanzania and Zambia.

(1) Botswana

The Kweneng Rural Development Association of Botswana, has managed to establish 200 ha. of fuelwood and poles woodlots at Kopong. Species planted include: *Eucalyptus grandis, E. camaldulensis* and *E. tereticornis*.

(2) Lesotho

The intensive establishment of woodlots for fuelwood and poles production started in 1973, with the commencement of the Lesotho Woodlot Project (LWP). It was co-financed by the Anglo de Beers Forest Services Lesotho Ltd, the Overseas Development Administration (ODE) and the World Food Programme (WFP).

By the end of 1991, an area of about 10 250 ha. of woodlots had been established in over 350 sites, as Government Forest Reserves[29]. Some of the woodlots have reached maturity. However, the Forestry Division is experiencing difficulties selling the wood from the mature woodlots because of inaccessibility problems for trucks and the absence of a proper plan to sell the fuelwood. Officials in Lesotho have concluded that the woodlots have effectively contributed to environmental protection but they are not contributing much to alleviating the fuelwood scarcity[22]. The further establishment of government woodlots in villages has been suspended because of management problems being experienced with the existing woodlots. Instead, individual tree planting (agroforestry) is advocated.

(3) Tanzania

Woodlots have been established in various areas (for example, in the Shinyanga region) by the Forestry Department for demonstration purposes and for testing the performance of new tree species in most regions of Tanzania. Institutions like prisons and schools, have also established woodlots for meeting their fuelwood demand.

(4) Zambia

Commercial farmers in Zambia, especially tobacco and coffee farmers have formed a "Commercial Farmers Bureau" for tree-growing. Tobacco farmers in the Choma and Kalomo districts have established woodlots of Eucalyptus species for curing Virginia tobacco. Sizes range between 10-30 ha. Coffee farmers have also planted trees as wind breaks[1].

Management of natural woodlands and forests through traditional laws and beliefs

Through traditional laws and beliefs, villagers in the Babati District, Tanzania, have managed to conserve patches of natural forest without policing. The forests have been conserved for traditional functions, but they also provide fuelwood in the form of dead branches and trees. A detailed study conducted in the Babati District[12] on the conservation of natural forests, provided the following key lessons:

— Traditional management of natural forests is based on the common beliefs shared by the community. Through these beliefs, people embark on difficult tasks with great confidence. Traditional beliefs affect decisions on land usage and environmental protection.

— Understanding traditional beliefs and taboos, and utilising them as the starting-point for improving the management of communal natural forests, will enhance the development of socially and technically viable programmes, which can be implemented by the local people within their indigenous cultural land management practices.

— Management of natural forests should be geared towards sustaining the people's life by providing them with all the possible products that can be obtained from their natural forests, through improved management.

Natural forests have been conserved as a meeting-place and the place where traditional dances are performed. In Babati, these forests are known as "Haymanda". Riroda Village has a good example of such forests[12].

Natural forests are also protected for water catchment. The people believe that the spirits, which are responsible for providing water to the people, live under the forests. If people cut down the trees the spirits get annoyed and stop providing water, resulting in drought. They also move to other areas. It is believed to be very difficult to get the spirits to return again, hence the need to conserve the water catchment forests for perpetuity. Sabilo Village is a good example of protected natural forest utilised for water catchment.

Sometimes it is difficult for outsiders to understand how traditional laws and beliefs operate for conserving natural forests. Local knowledge and wisdom are regarded by outsiders as superstition and reminiscent of primitive customs. However, it is increasingly being acknowledged that the utilisation of local knowledge is a pre-requisite for the successful management of communal natural forests through self-reliance.

For example, Walker[34] reported that, in the past, local chiefs in Botswana were very successful at managing natural woodlands. Conservation was encouraged through the creation of taboos and beliefs. For example, species like *Peltophorum africana, Boscemia albitrunca* and *Zyziphus mucronata* were not cut because of a widespread belief that heifers belonging to those people responsible for cutting down these trees would only produce male calves.

After independence, the powers of chiefs in many areas were delegated to government officers who had little interest in managing the natural woodlands. As a result, there is now uncontrolled clearing of natural woodlands.

Improvement of utilisation efficiency

Efforts have been initiated in all SADC member states to improve the utilisation efficiency of fuelwood. They include: the introduction of improved charcoal stoves, wood-burning stoves, and improved charcoal production technologies.

The wide dissemination of improved charcoal stoves is reported to be taking place in urban areas of Tanzania, Malawi, Zambia and Zimbabwe. However, adoption of improved wood-burning stoves in rural areas is reported to be a slow process in all member states.

"Research results indicate that it is only through the people's participation, with effective multi-sectorial co-ordination, strong political support and the provision of catalytic financial support, that the SADC region can sustain its biomass fuels supply."

Efforts to improve charcoal production technologies are continuing in Malawi, Zambia, Tanzania and Mozambique. The improvement of the traditional earth kilns, widely used in the region, is the top priority because of its low initial investments. With proper kiln management the recovery efficiencies of improved traditional kilns are comparable with those of metal and brick kilns.

The introduction of metal and brick kilns has received little acceptability by traditional charcoal producers, mainly due to high initial capital investments and the need to have concentrated and defined sources of fuelwood.

Conclusions

Based on the facts provided in this article, it can be concluded that:

— Biomass fuels will continue to be the main source of energy in the SADC region, particularly for the household sector. Urgent efforts are therefore required to formulate effective strategies to sustain biomass fuels in the region, otherwise acute household energy scarcities will be experienced by the majority of the population, accompanied by environmental degradation. These factors will erode ongoing efforts and result in a vicious circle of poverty.

— Research results indicate that it is only through the people's participation, with effective multi-sectorial co-ordination, strong political support and the provision of catalytic financial support, that the SADC region can sustain its biomass fuels supply. As has been mentioned, some villages in Tanzania and Malawi have already attained sustainable biomass fuels supply through local initiatives. The dissemination and sharing of successful field experiences in fuelwood production technologies could enhance this process.

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Energy from landfill and sewage gas in South Africa

* T M LETCHER AND * * F F KOLBÉ

This paper discusses the realistic production and exploitation of methane gas as an energy source from deep landfills. More briefly, the paper also examines the use of sewage gas for power generation in South Africa. The paper does not include a cost breakdown as this was the topic of a paper previously published[13].

Keywords: methane; landfill gas; sewage gas; waste-derived fuels

Introduction

The production of methane gas from deep landfills is a natural process resulting from the biodegradation of organic material by a consortium of bacteria[1]. The landfills act as large bioreactors. This process also produces carbon dioxide and the overall reaction can be summarised as:

$$2(CH_2O)_n \longrightarrow nCO_2 + nCH_4 \qquad (1)$$

with carbon dioxide and methane produced in equal amounts[2] and making up most of the gas known as landfill gas (LFG). Trace amounts of volatile components such as fatty acids, mercaptans (sulphur-containing compounds) and hydrogen sulphide are also produced in the breakdown of biological material. The characteristic unpleasant smell of LFG is attributed to these components[3].

The only component of LFG which can be exploited is the methane[4]. This component burns in the air with the simultaneous release of energy:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O \; \Delta H^\theta = -890 \text{ kJ mol}^{-1} \qquad (2)$$

The same process which can lead to the harnessing of a renewable energy source is also responsible for dangerous explosions. Unless steps are taken, LFG will migrate from the sites where they are produced, posing an environmental hazard[5]. In Europe and in the U.S.A. it is mandatory to pump and flare LFG from landfills[6]. No such law exists in South Africa.

Linked to the production of methane gas in landfills is the formation of organic acids. These acids dissolve out metals such as, iron, mercury, zinc, copper, lead and cadmium from waste material and together with the degradation products of the organic material, form a solution known as leachate[7]. It is toxic and can have COD values as high as 60 000 mg L^{-1}. Leachate poses an enormous threat to the environment especially in regions with high rainfall[8].

With the rapid increase in urbanisation in South Africa and the encroachment of housing estates near established landfill sites, the production of leachate and LFG from these landfills is a cause of great concern. One way to reduce the problem is to ensure that the biodegradation within the landfill takes place as rapidly as possible so that the land can be rehabilitated (for playing fields, parks etc.) without the fear of noxious gases, explosives or leachate contamination[9]. These issues can be linked to the production of LFG for use as a "renewable" energy source.

The rate of methane production is central to the whole process as methane is the final product in the biodegradation of the long-chain carbon polymers that form the backbone of vegetable material. A knowledge of the properties that influence this rate is thus essential in attempting to speed up the degradation process[10].

The exploitation of LFG is based on Equation (2)[11]. In the U.S.A. and in the U.K. the exploitation (mainly for electricity production) is driven by the statutory requirements to pump LFG from landfill sites[12]. South Africa does not have such legislation and furthermore, the low price of electricity in South Africa compared to that in Europe does not justify large-scale programmes of electricity generation from LFG. There is however, also a case for using LFG for heating purposes (and also for cooking) in a Third World environment[13].

The formation of methane in landfills

The organic matter in landfills is largely municipal solid waste (MSW) and consists of cellulose, carbohydrate, protein and lipid material[14]. This is decomposed by the consortium of bacteria in many stages beginning with the aerobic bacteria, which cleave the large biopolymers and long chain carbon-chain molecules and ending with the methanogenic bacteria which produce the single carbon compound - methane[15]. The aerobic bacteria do not produce methane and its overall reaction can be summarised as:

$$(CH_2O)_n + nO_2 \longrightarrow nCO_2 + nH_2O \qquad (3)$$

Most large landfills end up with the refuse piled 20-30 metres high. As a result anaerobic conditions (no oxygen) exist within the landfill and the overall equation can be represented by (1)[16].

The reactive nature of bacteria can be partly explained by their small size and consequently enormous external surface area. Man has a surface area to mass ratio of about 0,16 $m^2 \, kg^{-1}$ whereas bacteria have a ratio of about 6 000 $m^2 \, kg^{-1}$.

The amount of methane formed

The maximum possible volume of methane gas from a tonne of dry organic plant material as calculated from Equation (1) is 416 m^3 at 25°C and atmospheric pressure[17]. Other workers in the field have come to a similar conclusion[11].

The amount of organic, biodegradable material in landfill varies from site to site and depends largely on the ratio of domestic waste to industrial waste and builders rubble. Domestic refuse contains between 65-75% w/w or organic, putrescibles, paper and cardboard as given in Table 1[18].

* Dept of Chemistry, University of Natal, King George V Avenue, Durban 4001, Kwazulu-Natal, South Africa

** Stewart Scott, P O Box 784506, Sandton 2164, South Africa

	FRG 1985	Netherlands 1985	Oslo 1985	Rome 1985	Madrid 1985	Umlazi 1993	Grahamstown 1991
paper/ cardboard	22,7	22,7	38,2	25,0	15,0	29,7	31,0
organic, putrecibles	45,6	53,0	30,4	53,0	50,0	48,0	40,0
plastic	8,4	6,8	6,5	6,5	5,0	10,6	11,0
glass	12,8	8,1	7,5	10,0	9,0	5,0	16,0
ferrous	3,7	2,5	2,0	2,5	3,0	3,6	5,0
miscellaneous	3,9	3,7	15,4	3,0	18,0	2,9	5,0
reference	18,0	18,0	18,0	18,0	18,0	20,0	19,0

Table 1: Analysis of domestic refuse (% w/w) from various cities and countries[18]

Degradability	Mass[11] fraction in an average site	Waste type	t½ / years dry site	wet site
readily	0,2	Food and soft plants	1,0	0,7
moderately	0,4	leaves etc.	5,0	2,0
slowly	0,4	paper and wood	15,0	5,0

Table 2: Classification of biodegradable refuse in wet and dry sites in South Africa

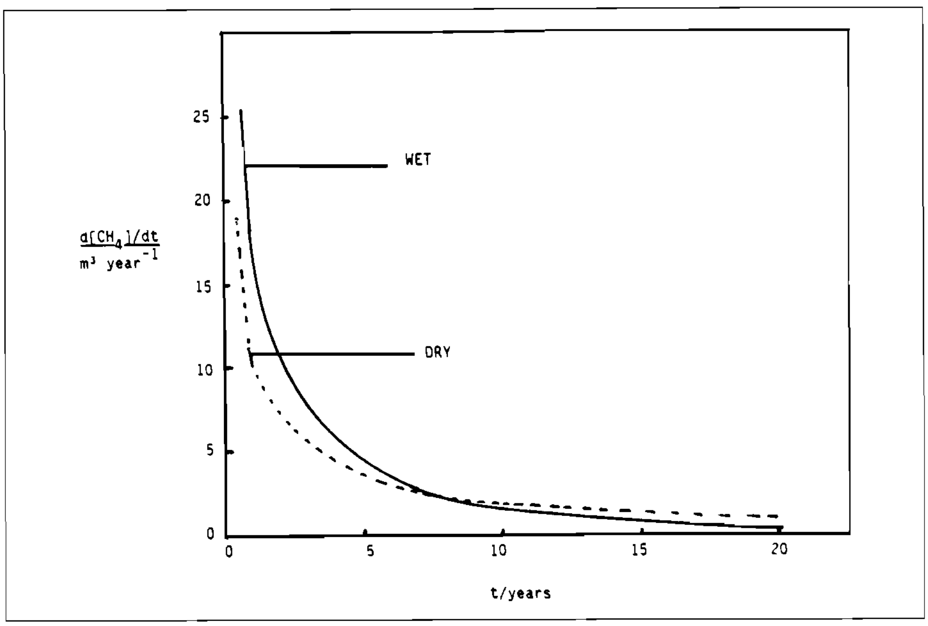

Figure 1: The rate of methane ($d[CH_4]/dt$) formation as a function of time (t) from 1 tonne of MSW for wet and dry sites using a first order kinetic model

Note:

In dry sites, the following equation was used:

$d[CH_4]/dt = [(75)(0.693)(0.2)/1]exp(-0.693\ t/1) + [(75)(0.693)(0.4)/5]exp(-0.693\ t/5) + [75(0.693)(0.4)/15]exp(-0.693\ t/15)$

In wet sites the following equation was used:

$d[CH_4]/dt = [(100)(0.693)(0.2)/0.7]exp(0.693t/0.7) + [(100)(0.693)(0.4)/2]exp(-0.693t/2) + [(100)(0.693)(0.4)/5]exp(-0.693\ t/5)$

Municipal solid waste (MSW) usually contains a large fraction of domestic and garden refuse which is biodegradable (between 70% and 80%). The water content of the biodegradable material (paper, cardboard, organic material and putrecibles) is about 20-40% w/w[19,20]. Thus from every tonne of MSW deposited the maximum volume of methane that can be produced is about 200 m³ of methane gas measured at 25°C and 1 atmospheric pressure. This figure is supported by other workers in the field[21]. It has been estimated that at least 10% of the biodegradable material is decomposed in the initial aerobic stage and is thus lost for methane generation[19,20]. It is most likely to be higher than 20% in wet and hot sites. Furthermore, not all the biodegradable material decomposes. This is particularly true in dry areas where the "bacterial soup" does not reach some of the organic material (especially paper, which does not have a plentiful supply of natural bacteria)[11]. In these sites it has been estimated that as little as 60% of the total biodegradable material is actually decomposed to methane in a reasonable time (10-20 years). In wet sites it is estimated that 80% is decomposed.

Finally, it is not always possible to collect all the LFG from a landfill site and some will diffuse into the atmosphere and surrounding areas. A reasonable estimate for South African dry sites is that 70% of the LFG can be collected, with pumping it should be over 90% for wet sites. Thus, 1 tonne of MSW will produce about 75 m³ of methane gas in dry sites and about 100 m³ in wet sites at 25°C and 1 atmospheric pressure.

Rate at which methane is produced

The rate at which methane is formed in landfills depends on many factors which include: refuse composition, moisture content, depth of landfill, landfill temperature, nutrient content, toxic components, pH, water infiltration and precipitation, atmospheric pressure, landfill cover material, and the shape of the landfill and topography of the site. These have been discussed elsewhere[21].

A simple but effective method for analysing the rate is the first-order rate model used by Hoeks[23], Letcher[11], and other workers[24]. This method[11] assumes that the limiting nutrient for methanogens is the biodegradable organic waste:

$$dP_t/dt = - kP_t \quad (4)$$

where P_t is the quantity of biodegradable material at time t and k is the rate constant, which for first order reactions is

$$k = \ln 2/t_{1/2} \quad (5)$$

where t is the half life of the decomposing material. As defined previously,[11] the rate of methane (CH_4) formation is given by:

$$d(CH_4)/dt = \sum^{i} [(R)(0.693)P_{oi}/t_{1/2i}] \exp(-0.693t/t_{1/2i}) \quad (6)$$

where i is the ith type of refuse, P_o is the initial mass of the refuse type (t=o) and R is either 75 m^3 $tonne^{-1}$ or 100 m^3 $tonne^{-1}$ depending on whether the site is a dry or a wet one.

In this work[19,20] three types of organic material have been defined (Table 2) each with their own half life which has been determined by Hoeks[23] and estimated by Letcher.

Equation (6) has been used to determine rate of methane production. Typical rates of methane production for hypothetical wet and dry sites in South Africa, accepting 1 tonne of refuse per year are given in Figures 1 and 2. The details of the analysis are given in the caption to the figures.

Energy exploitation from LFG

Equation (2) defines the maximum heat energy that can be obtained from burning 25 litres of methane gas, (1 mole) i.e. 890 kJ. Relating this, by way of an example, to a dry landfill site accepting one tonne of refuse per year, every year, application of Equation (6) shows 54,5 m^3 of methane gas will be produced in the 20th year (see Figure 2). The maximum energy that can be obtained from this amount of gas is 1 940 MJ/year. The power obtainable from the hypothetical wet and dry sites accepting 1 tonne of refuse per year every year for twenty years is given in Table 3 where the figures refer to the power production in the 20th year.

Throughout this paper, 20 years was used as a reasonable figure which relates to some of the older landfills in South Africa. It is not a "steady state" situation as referred to in a previous publication[11] but is not far from it.

The realistic power (assuming 33% efficiency) obtained from landfills accepting 100 000 tonnes of MSW per year every year is given in Table 4 and has been extrapolated from Table 3. The realistic

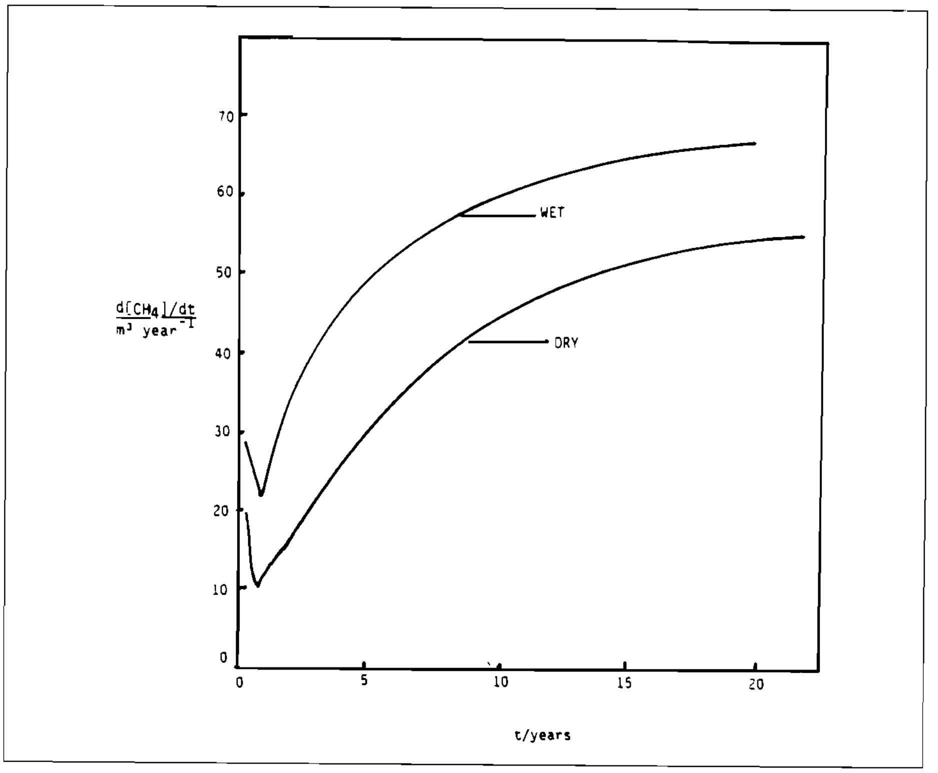

Figure 2: The rate of methane formation from hypothetical landfill sites (wet and dry) accepting 1 tonne of refuse each year for 20 years

Site	Methane produced in 10th year (m^3 $year^{-1}$)	Methane produced in 20th year (m^3 $year^{-1}$)	Maximum power in 20th year (MJ $year^{-1}$)	Maximum power in 20th year (Watts)	Realistic electricity production 33% efficiency (Watts)
wet	59,3	67,0	2 385	76	25
dry	42,5	54,5	1 940	61	20

Table 3: Power produced in the 20th year in a hypothetical landfill accepting 1 tonne of refuse per year, every year for 20 years

Site	Realistic electricity production **(33% efficiency)** MW	Realistic heating power **(66% efficiency)** MW
wet	2,5	5,0
dry	2,0	4,0

Table 4: The power obtainable from landfills in their 20th year (wet and dry) accepting 100 000 tonnes of MSW per year every year

Total population	MSW (tonnes per year)	Maximum power production (MW)		Realistic power production (electricity) (MW)	
		Wet	Dry	Wet	Dry
10^6	0,33 x 10^6	15,0	12,0	7,5	6,0

Table 5: The power production of LFG generated from the refuse of 10^6 people in the 20th year

Note: Assuming each person is responsible for 0,33 tonnes of refuse per year every year for 20 years. The "steady state" situation would result in 8,4 and 6,7 MW of electricity for wet and dry sites respectively as opposed to 7,5 and 6,9 MW of electricity as calculated in the last column.

Population	Gas production (m^3 day^{-1})	Max. energy per day (MJ day^{-1})	Max. power produced (MW)	Realistic power (heating) (MW)	Realistic power (electricity) (MW)
1 x 10^6	30 x 10^3	1 068 000	12	4	8

Table 6: *Power produced from anaerobic sewage units*

Area	Population (10^6 people)	Estimated pop. supported by landfill (10^6 people)	Estimated population supplying A D sewage treatment units (10^6 people)	Realistic power (LFG) (electricity) (MW)	Realistic power sewage (electricity) (MW)	Realistic power (LFG) (heating) (MW)	Realistic power (sewage) (heating) (MW)
PWV	10	7	5	47	20	94	40
Durban	4	2,5	2,5	21	10	42	20
Cape Town	2	1,5	1,5	10	6	20	12
Other	15	5	3	–	–	66	24

Table 7: *Power generation from both LFG and sewage gas in South Africa*

Durban	Dumping rate (tonne year^{-1})	**PWV (cont)**	Dumping rate (tonne year^{-1})
Shongweni (Waste Tran)	100 000	Platkop	100 000
Bull-bul Drive (Chatsworth)(Waste Services)	200 000	Alberton	100 000
Umlazi (Waste-Tech)	300 000	Alberton (Eden Park)	100 000
Basasar Road (Durban Municipality)	460 000	Benoni	50 000
Pinetown	50 000	Pretoria North	200 000
Westville	50 000	Mamelodi	50 000
Kloof	50 000	Soweto	50 000
Others (small)?	200 000	Boksburg	50 000
		Germiston (Simmer and Jack)	50 000
Cape Town		Germiston (Rooikraal)	100 000
		Verwoerdburg	100 000
Vissershoek	150 000	Kempton Park	100 000
Coastal Park	140 000	Springs	50 000
Swartklip	200 000	Witbank	50 000
Others (small) ?	100 000	Alexandra	50 000
		Bedfordview	50 000
PWV		Nigel	50 000
Robinson Deep	700 000	Midrand	50 000
Mongolus	300 000	Krugersdorp	50 000
Nuffield	100 000	Goudkoppies	50 000
Marie-Louise (Roodepoort)	100 000	Others (small) ?	200 000
Kye-Sands (Randburg)	200 000		
Linbro Park	200 000		

Table 8: *Dumping rates at the larger landfill sites in South Africa*

Area	No. of sites	Total dumping rate = A (tonne year^{-1})	Methane prod. Rate (m^3 year^{-1})	Realistic energy production (MW)
PWV	13	2 400 000	54,5 x A	48
Durban	4	1 000 000	67,0 x A	25
Cape Town	3	500 000	54,5 x A	10

Table 9: *Methane production and electricity power production from the larger landfills in the three main population in South Africa.*

Note: *Only landfills accepting more than 100 000 tonnes of refuse/year have been used and a "residence" time of 20 years has been assumed.*

heating power (e.g. boiler heating) has been calculated assuming a 66% efficiency.

It has been calculated by many workers[11] that each person in the Western World is responsible for between 0,33 tonnes and 0,75 tonnes of refuse (MSW) each year. Assuming the lower figure for South Africa, the power production from LFG generated from the refuse of 10^6 people is given in Table 5.

Energy exploitation from methane from sewage

In South Africa sewage may be treated in one of two ways - either by aerobic (Equation 3) or by anaerobic decomposition (Equation 1). The chemistry of the anaerobic sewage treatment process is identical to that of the landfill process, although sewage gas (SG) contains a slightly higher methane percentage as a result of the high water content which allows more of the carbon dioxide to dissolve.

Aerobic decomposition is usually reserved for the smaller treatment plants accepting less than 10 M*l* of sewage per day. Treatment plants larger than this usually use anaerobic decomposition[25] and are thus in a position to collect the SG. It has been estimated that 30*l* of methane are produced per person per day from anaerobic sewage treatment plants[25]. The volume of methane produced and the power that can be obtained from a population of 10^6 is given in Table 6.

Energy obtainable from LFG and SG in South Africa

Exploitation of LFG for electricity production and also sewage gas in South Africa is really confined to the larger centres of the PWV area, the Durban area and Cape Town and its environment[13]. Smaller communities can effectively exploit LFG for heating purposes as has been done in Grahamstown[26]. The power production can be calculated by analysing each landfill site or by a rough calculation based on the population[27]. Firstly, the latter method has been used to calculate the possible power generation in South Africa and the results are given in Table 7. The calculations are based on the results in Tables 5 and 6.

The other way of assessing the methane potential from South African landfills is to obtain data on the landfill sites themselves. This is not a simple task as the decomposing rate and depositing rate at most sites in South Africa is not well known. The information given in Table 8 has been obtained by communication with many municipalities and site operators and also from a recent summary (involving 20% of South African landfills)[28].

Using the data of Table 8 together with the information from Table 4, the estimated methane production rate and power from the large sites (100 000 tonnes refuse per year) has been calculated. The results (Table 9) are very similar to the results obtained in Table 7. However, Table 7 was based solely on the size of the respective populations in those areas. The calculations show that no more than 80 MW of electricity can be obtained from LFG and no more than 40 MW of electricity can be obtained from SG in South Africa.

Conclusions

No mention has been made of the cost of exploiting methane gas from anaerobic digestion. This has been the subject of previous work [13] and not the brief of this paper.

The estimated power that can be generated in South Africa from LFG (<80 MW) and from SG (<40 MW) is small when compared to the power of a coal-burning power station in the Eastern Transvaal or a hydro-electric power station in the Drakensberg (1 000 MW). The only advantage of the energy produced by anaerobic digestion is that it is obtained from a non-fossil fuel (a "renewable" source) and from the burning of an environmentally unfriendly gas. The figures produced here (Tables 7 and 9) are conservative but do compare with the power generated in the United Kingdom[12] by similar sized landfills.

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COMPARATIVE ENERGY COSTS IN SOUTH AFRICAN CITIES RELATED TO HEATING VALUE

AUGUST 1994											
Energy source	Consumer prices			Cost of energy (c/MJ)			*Relative heating costs			Heating value	
	Coast	Inland	Units	C.T.	Jhb	Dbn	C.T.	Jhb	Dbn		
Coal A (Peas)	245,20	68,40	R/Ton	0,88	0,24	0,56	3,41	1,00	2,30	28,0	MJ/Kg
Elect.	20,01	21,92	c/kWh	5,56	6,09	4,84	22,75	24,92	19,81	3,6	MJ/kWh
Heavy Furnace Oil	53,06	67,36	c/litre	1,29	1,64	1,29	5,30	6,73	5,30	41,0	MJ/litre
Illum. Paraffin	85,63	97,53	c/litre	2,31	2,64	2,31	9,47	10,79	9,47	37,0	MJ/litre
Petrol (Premium)	173,00	183,00	c/litre	4,99	5,27	4,99	20,41	21,59	20,41	34,7	MJ/litre
Diesel	143,90	153,90	c/litre	4,02	4,28	4,02	16,46	17,51	16,46	38,8	MJ/litre
Power Paraffin	90,00	101,90	c/litre	2,40	2,72	2,40	9,82	11,12	9,82	37,5	MJ/litre
LPG	102,00	115,80	c/litre	3,72	4,23	3,72	15,24	17,30	15,24	27,4	MJ/litre
Gas											
Cape Gas	45,60	–	R/GJ	4,56	–	–	18,67	–	–	–	–
Gaskor		16,50	R/GJ	–	1,65	–	–	6,75	–	–	–

This table shows comparative energy costs (in SA cents/MJ) in selected South African cities (coastal and inland) based on a range of energy sources. The following criteria were taken into consideration in the calculation of the cost of energy:

(1) Transport costs for coal were obtained from Spoornet. Railage of coal was calculated from Saaiwater to Cape Town and from Saaiwater to Durban respectively.

(2) The energy cost has been calculated on the bulk delivered price for consumers, i.e. includes 14% VAT and other charges.

(3) All figures for electricity have been based on energy requirements for large commercial users.

(4) Electricity prices have been based on typical monthly accounts for large users (see Table 5 in the Energy Price List in *Selected Energy Statistics: South Africa*).

(5) A 75% load factor has been used in the calculation of the Gaskor prices.

(6) The relative heating costs are shown in relation to the cheapest source, i.e. coal in Johannesburg.

(Source: *Selected Energy Statistics: South Africa*, No. 30, August 1994)

Energy news in Africa

Electricity

The Tanzanian government and the Tanzania Electric Supply Corporation (TANESCO) are examining the idea of using the Songo Songo offshore gas field (about 30 billion m^3) to supply the Ubongo power station. Construction of a 200 km pipeline to carry the gas to Dar es Salaam is expected to start early in 1995 and to be completed in 1997. The work will be carried out by Ocelot Tanzania Ltd, Trans Canada Pipelines, and the Tanzanian government. The project is being financed by the World Bank and Ocelot.

The Ubungo project was launched as a priority scheme after the 1992 drought with funding from SIDA (Sweden) and NORAD (Norway). Asea Brown Boveri (ABB) is presently equipping the site with two 20 MW combustion turbines with the possibility of a third being installed later.

With regard to Tanzania's projects for coal-fired power stations, the U.S.A. has offered a $480 000 grant for a feasibility study on a site at Iringa.

The sales of privately generated electricity is also expected to start in Tanzania in 1995 under a scheme which is being financed by the British Commonwealth Corp. (BCC). This London-based firm is putting up $6 million for the construction of a 2,5 MW wood-fired power plant at Kibena, Njombe, which could be used to supply power to the Tanganyika Wattle Co.. The plant is expected to start operating before the end of 1995. Any surplus power from the plant will be sold to TANESCO which will then be resold to the residents of Njombe.

(Source: Modern Power Systems, April 1994
Africa Energy & Mining, 18 May 1994

The Kenyan government has approved an application by the Kenya Power and Lighting Company to increase electricity charges by an average of 74% from the beginning of March 1994. The company cited a projected $3 million deficit by the end of June as the reason for raising tariffs. In September 1993, electricity tariffs were increased by between 15%-60%.

(Source: Modern Power Systems, March 1994)

The Société Nationale Burkinabé d'Electricité (SONABEL) is expected to increase spending by 7,3 billion CFA Francs this year and 8 billion in 1995 in Burkina Faso. These estimates include an outlay of CFA Francs 4,85 billion during the two years on an interconnection with the Ivory Coast. A similar interconnection with Ghana calls for an investment of CFA Francs 6,5 billion, some 50% of it next year and the remainder in 1996. These two interconnections and the renovation of diesel-fuelled power stations could result in World Bank loans to the electricity sector. But the estimates should be revised following the adoption of two projects for micro-hydro power stations that are to be carried out by the end of year, expected to cost a total of about CFA Francs 2,4 billion.

One station of 1 650 kW will have three turbines and will be built upstream from the Douana irrigation dam near Banfora. The second one (540 kV) will have two turbines and is to be built at Tourni. Both will be linked up with SONABEL's western network by a line that is being built between Bobo Diaolasso and Banfora.

Diesel production could also play a leading role if future consumption in Ghana and the Ivory Coast prevents Burkina Faso from relying on interconnections. Such production presently amounts to an installed capacity of about 85 MW.

(Source: Africa Energy & Mining, 30 March 1994
Africa Energy & Mining, 13 April 1994)

Projections by the Uganda Electricity Board indicate that electricity demand in 1995 could necessitate an available capacity of nearly 180 MW for the domestic market (145 MW for Uganda), and to maintain exports to Kenya (30 MW) and Tanzania (4 MW). By the year 2000, installed capacity could rise to 305 MW with the rehabilitation of the Owen Falls hydroelectric power station.

If about 90% of capacity in Uganda is actually available, the country's power stations will be able to meet the a strong surge in domestic demand by 2000, which pre-supposes a capacity of 225 MW. Increased capacity will enable Uganda to keep up its sales to Kenya and increase exports to Tanzania.

(Source: Africa Energy & Mining, 13 April 1994)

Zaire's national utility, Société Nationale d'Electricité (SNEL) still has plans for the western part of the country but they are either limited in scope or long-term in application. SNEL will fund the electrification of four towns in Lower Zaire: Sonabata, Sanga, Kimvula and Kitente, which are situated close to or within a 50 km range of the Zongo and Sanga power stations.

The utility also has a development plan for the same province which involves the rehabilitation of the Inga I and Inga II hydroelectric power stations and the diesel-powered stations at Tshela and Lukula. The Muanda distribution network is also to be developed and the construction of 132 kV high voltage lines from Inga.

Another project is the Bandundu project which concerns a 400 kW micro-hydro-electric power station on the Lwano river that will supply the city of Kikwit.

(Source: Africa Energy & Mining, 13 April 1994)

The Swiss-Swedish group Asea Brown Boveri (ABB) has moved into higher gear in setting up commercial operations in Sub-Saharan Africa in a bid to boost sales to the region, which amounted to $700 million in goods and services in 1993. ABB plans to open new affiliates this year in Botswana and Namibia. It has appointed a marketing director to take up a post in Luanda, Angola. ABB is presently renovating the Luanda power station. However, in the long term, Angola could provide $500 million worth of contracts as part of a five-year programme to upgrade its energy sector. ABB is hoping to corner 50% of them.

ABB has offices or plans to open offices in the following African countries: Mauritius, Mozambique, Tanzania, Ethiopia and Ghana.

(Source: Africa Energy & Mining, 1 June 1994)

Benin has awarded a $200 000 contract to a U.S. firm Gustavson Associates for "a preliminary design and economic feasibility study" on an electric power plant in the region of Porto Novo in eastern Benin that will run on Nigerian gas. The government claims that if a new power station is not built in the country, there could be a major electricity shortage towards the end of this decade. This could occur when Ghana is force to reduce electricity exports to Togo and Benin because of internal demand pressure from its own consumption.

(Source: Africa Energy & Mining, 2 March 1994)

Tanzania is floating a project for a small power station which operates on methane gas extracted from urban waste which has been incinerated. It is hoped that funding will be received from the U.N.'s Department for Technical Co-operation for Development.

(Source: Africa Energy & mining, 2 March 1994)

The Zimbabwe Electric Supply Authority (ZESA) is planning a 660 MW thermal power plant on the Sengwa river, south of Lake Kariba, between 2003 and 2006. The cost of the plant has been estimated at $566,3 million and its three 220 MW units will be commissioned between 2004-2006.

Among its other projects, ZESA plans to increase the capacity of the Hwangue III scheme involving units 7 and 8 on the site (2 x 220 MW coal-fired thermal plant) which will come into service in 1999 and 2000. A study on this project is planned as part of the Power III project co-financed by the World Bank. This plan focuses specifically on the renovation of the first section (4 x 120 MW) and second part (2 x 220 MW) at Hwangue.

In all, ZESA's investments between 1994 and 2006 will amount to $2,8 billion, and it is recognised that this will put a strain on the Zimbabwean economy. Close to 75% of the total cost will be required in foreign currency, representing up to 35% of Zimbabwe's external debt on the basis of current projections.

(Source: Africa Energy & Mining, 13 April 1994)

The state-owned Brazilian utility, Furnas Centrais Eletricas (FCE), is due to sign a consultancy contract with Eskom on its planned extension of the South African power grid. FCE is also interested in exporting its technology to Portuguese-speaking countries in Africa.

(Source: Africa Energy & Mining, 29 June 1994)

Eskom and the Swaziland Electricity Board plan to build a double 275 kV interconnection line in two stages. The line will be 150 km long, of which 100 km will be located in South Africa. Initially it will use limited voltage of 132 kV and will represent the equivalent of 150 MW for Swaziland.

Swaziland has presently 50 MW installed capacity (80% from hydro sources and 20% from diesel generators), and the country already has three 132 kV interconnections with South Africa.

Part of the finance for the project will come from the European Investment Bank and a basic agreement has been reached with the Development Bank of Southern Africa.

(Source: Africa Energy & Mining, 16 February 1994)

Hydro-electricity

The Zambian Electricity Corporation (ZESCO) is looking at the Batoka Gorge project with Zimbabwe even though the country has a substantial surplus in electricity with an installed capacity of 1 800 MW for peak consumption of 1 500 MW. As an alternative to Batoka Gorge, the fitting out of a second hydro site on the Kafue river is being considered. Both these projects are long-term projects.

With regard to short-term projects, the accent is more on stop-gap measures. This was reflected in a contract with ABB for the rebuilding of a diesel power station.

As for the future, Zambia can claim an identified potential of 4 000 MW in hydro-electric resources which currently account for 1 640 MW with installations serving ZESCO's integrated network. The remaining 150 MW corresponds to isolated diesel stations and, above all, the independent production capacity of the copper mining company, ZCCM.

More than half of ZESCO's capacity is based on the 900 MW Kafue Gorge dam that was put back into service after rehabilitation with the help of Sweden, Norway and the African Development Bank following a fire in 1989. The Zambian part of Kariba accounts for 600 MW while Victoria Falls represents 108 MW. Electricité de France is currently studying the renovation of Victoria Falls.

In 1992/93, Zambia's electricity consumption was 6 200 GWh. The mining sector consumed 70% of the total, with commerce, industry and domestic consumption making up another 10%. Some 920 GWh was exported despite the drought in 1992. Commercial energy represented barely 30% of Zambia's electricity consumption in the 1992/93 financial year.

Although Zambia continues to rule out the privatising of the company, it does allow private investors to step into the electricity sector under a new privatisation plan.

(Source: Africa Energy & Mining, 29 June 1994)

Scandinavians are continuing to show interest in contracts for the future Cahora Bassa-Zimbabwe high voltage line and the renovation of the Cahora Bassa-South Africa line. After months of delays with the Zimbabwean interconnection, the prime contractor is a consortium made up of Norconsult and Swedpower. The line will be built by Linjebygg in Mozambique and Balfour Beaty and Retrofit in Zimbabwe. But there are still problems with financing.

A financial deal has been put together for the construction of the line to South Africa. Finance will come from Portugal for the lines ($27 M) and from South Africa for the towers ($48 M).

(Source: Africa Energy & Mining, 18 May 1994

Fuel alternatives

Sasol has an 18-month contract with Brazil to supply that country with 300 000 m^3 of ethanol, a by-product from Sasol's coal liquefaction process. It will be used to supplement the sugar cane-based ethanol produced in Brazil. Brazil has already bought such fuel from the Mossref plant that liquefies Mossel Bay gas.

(Source: Africa Energy & Mining, 29 June 1994)

Petroleum

With the work on the Tanzania-Italian Petroleum Refinery (TIPER) set to finish this year, plans are being considered to double the facility's capacity to 30 000 barrels/day. No price has been set for the new extension but the aim is to export oil products in the region. The domestic market accounts for 20 000 barrels/day, nearly 10 000 barrels/day of which are covered this year by imports of refined products. The present renovation of the refinery will boost its effective capacity to 15 000 barrels/day by the end of 1994. The work will cost about $17 million, to which must be added $2 million for an additional storage capacity of over 300 000 barrels.

The most obvious export market for the TIPER extension is seen to be Zambia.

(Source: Africa Energy & Mining, 18 May 1994)

The development of the Pande gas field to export gas to South Africa and to supply Maputo as well as other towns in southern Mozambique is likely to be ready for start-up shortly after the year 2000.

The project will consist of two phases, the first lasting a year and costing $20,2 M and the second covering six years and costing $28,5 M, all provided from the private sector. Phase One will increase recoverable reserves to 57 billion m^3 through the drilling of three appraisal wells ($10 M) and the re-processing of seismic data which already began with a pre-project loan. Details of Phase Two will be set out at the end of 1995 but will focus on putting a joint venture to deal with the engineering work ($22,5 M). Assistance in reinforcing Enpresa Nacional de Hidrocarbonetos (ENH) ($11,4 M) and bolstering the oil department of the Mining Resources Ministry ($2,2 M) will be spread over the two phases.

The World Bank has estimated that the development, expected to cost between $600 M-$1 billion with the pipelines, will bring in $150 M annually in export revenue (and $40 M to the government) and help to offset the country's heavy trade deficit. However, there is still political uncertainty in Mozambique.

(Source: Africa Energy & Mining, 29 June 1994)

Details of Authors

DAVIS M

B.Sc.(Hons.), M.Sc.(Appl.Sc.)(Cape Town)
Energy for Development Research Centre, Energy Research Institute, University of Cape Town, Private Bag, Rondebosch 7700, South Africa
Tel.: (021) 650 3230
Fax.: (021) 650 2830

Mark Davis completed an Honours degree in Applied Mathematics and then a Masters degree in Energy Studies at the Energy for Development Research Centre (EDRC), University of Cape Town. He has worked at EDRC since 1990, mainly in the area of photovoltaic (PV) systems. He has made a significant contribution to the development of a micro-computer design tool for PV, battery and diesel power systems. He has also conducted field research into the application of PV-powered water pumping systems in the Transkei. Other work in this field includes extensive performance testing of commercially available systems, as well as the development of simulation software and design tools. Recently completed projects include a report concerning the institutional and financial arrangements for successful dissemination of domestic PV systems, and an investigation into the success of a rural electrification project in Botswana. His current focus of work concerns the development of methodologies for the financial and economic evaluation of energy projects.

KAALE B K

B.Sc.(Hons.), M.Sc.
Technical Advisor, Ministry of Water, Energy and Minerals in Tanzania, P O Box 4735, Dar es Salaam, Tanzania
Tel.: (255) (51) 71098
Telex: 41129 or 41726 SINOTA TZ
Fax.: (255) (51) 46881

In 1977, Mr Kaale graduated with a B.Sc.(Hon.) in forestry from the University of Dar es Salaam, Tanzania. He was awarded a M.Sc. in Forestry Planning from the Australian National University, Canberra, specialising in biomass fuels and environmental protection in developing countries. He undertook further postgraduate study between 1982 and 1991, locally and overseas.

Mr Kaale is currently Technical Adviser to the Ministry of Water, Energy and Minerals in Tanzania on the implementation of the SADC Energy Sector Project AAA.5.15 "Improvement of woodfuel end-use efficiency in small-scale rural industries of the SADC region", on a part-time basis. He is also the regional biomass fuels expert for the SADC Energy Sector (part-time).

KOLBÉ F F

B.Sc. (Eng.), M.Sc. (Eng.), Pr.Eng.
Director, Stewart Scott, P O Box 784506, Sandton 2164, South Africa
Tel.: (011) 783 5480
Fax.: (011) 883 679

Mr Kolbé has been involved in various projects related to water supply and waste treatment services, as well as biogas power recovery. Between 1958 and 1965 he was Assistant Water and Sewage Engineer for the Windhoek Municipality in what is now Namibia. This involved the design and construction of sewers and other water and waste treatment plants. Since then he has been engaged in similar work in South Africa, Botswana and Argentina.

In his role as Consulting Engineer, Mr Kolbé has been involved in setting up various installations, ranging from 250-510 kW, which utilised digester gas. He participated in the preparation of the master plan for the collection and treatment of wastewater for the Greater Johannesburg area, and other water supply and/or sewage schemes for the Municipalities of Kempton Park, Nelspruit, Vryheid, Lydenburg, Parys and Balfour respectively.

LETCHER T M

Ph.D., B.Ed., MRSC, CCHEM, MSACI
Professor of Chemistry and Head of the Department of Chemistry, University of Natal, King George V Avenue, Durban 4001, South Africa
Tel.: (031) 260 3106
Fax.: (031) 260 3091

Professor Letcher is currently Head of the Chemistry Department at the University of Natal and President of the S A Chemical Institute (1994-1996). He was previously a lecturer and Associate Professor at the University of the Witwatersrand, Johannesburg (1969-1980), and Head of the Chemistry Department at Rhodes University, Grahamstown (1980-1992).

He has spent sabbaticals at Bristol University, Exeter University, University College (London), Bath University and the Carnegie Mellon University in Pittsburgh, U.S.A.

He has published extensively locally and internationally, on the thermodynamics of liquid mixtures and the exploitation of methane from landfill. His research into landfill gas (LFG) has taken him to many research groups and landfills in Italy, the United Kingdom, the U.S.A., and also India. His landfill gas research includes investigations into the factors responsible for methane generation, including the rate of methane formation, the hazards resulting from LFG, the cost-effectiveness of methane exploitation, and the most effective methods of collecting LFG.

LEWIS W P

C.Eng. FIEE SMIEEE
Associate Director, EPD Consultants Ltd, Marlowe House, Sidcup, Kent DA15 7AU, United Kingdom

Peter Lewis has been involved in the power industry for over 35 years in the U.K. and overseas, and specialises in expansion planning, power system analysis and transmission studies. He has authored several technical papers and provided expert testimony before regulatory bodies. Since the mid-80s, Peter Lewis has undertaken the management of several power system development and interconnection studies in the Middle East and Africa.

In 1989 Peter Lewis prepared a background report on African Regional Power Interconnection Studies (ARPIS) and, in 1992, co-ordinated Phase II of the SADC Energy Project for ESMAP (World Bank). Most recently he has been involved in energy strategy studies in the Baltic under the EC PHARE Programme, and has just completed a report on regional grid networks in Southern Africa as part of an ESMAP exercise on restructuring and reform in electricity supply.

RUBBERS P J E

B.Sc.(Eng.) Louvain Univ. (Belgium), MBL (Unisa)
Power System Planning Manager, Eskom, P O Box 1091, Johannesburg 2000, South Africa
Tel.: (011) 800 3823
Fax.: (011) 800 5136

After having worked for three years in Belgium for a utility, Pierre Rubbers joined Eskom in 1969 where he was involved initially in the planning of the 400 kV interconnections between the Cape or Natal with the Reef.

In 1980, he started the Generation Expansion Planning Department and was in charge of the methodology and computer models used for these activities. In 1989, he joined Eskom's National Control Centre in Germiston and in August 1990 was appointed Acting Interconnected System Manager in the Generation Group. In 1991, he participated in the creation of the Transmission Group and was appointed Power System Planning Manager. His responsibility since then covers the transmission and generation expansion, plus the internal tariffs between Generation and Transmission used by the five Eskom Distributors. He is also responsible for the supply contracts and exchanges of electricity between Eskom and neighbouring utilities.

Forthcoming energy and energy-related conferences: 1994/1995

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Enquiries: Professor O C Iloeje, Chairman, LOC, National Centre for Energy R & D, University of Nigeria, Nsukka, Nigeria

Dr M A C Chendo, Chairman, NOC, Physics Department, University of Lagos, Lagos, Nigeria

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Recent energy publications

ANDERSON C A

An analysis of the regulation of the future electricity supply industry in South Africa. March 1994. 41p.
Report No. EL 9402

The project attempts to formulate a set of recommendations regarding the future regulation of the electricity supply industry in South Africa. The report discusses briefly the structural development of the industry and then analyses the regulatory system.

ANDERSSEN J J

Residential end-use electricity monitoring: Cape Town case study. April 1994. 84p. + appendices.
Report No. ED 9209

The report sets out the findings of a study into residential appliance end-use electrical loads by direct metering. This included devising and testing of various sampling strategies, the development of detail requirements for the minimum instrumentation needed, the field evaluation and testing of available hardware and defining the data processing software required for this type of work. Special attention was given to domestic hot water generation.

CAWOOD W N

Use of solar water-heaters in low-cost housing. February 1994. 38p.
Report No. EO 9137

The report examines the use of various types of domestic solar water-heaters in a low-cost housing environment (Mamelodi). The objectives of the project were divided into socio-economic and technical aspects.

COWAN W D

RAPS suppliers and user support. June 1994. iv. (various pagings).
Report No. ed 9101

The aim of this project was to provide public research-based support for applications of remote area power supply (RAPS) technology in South Africa. The report describes this support and how it was achieved: through offering a design and information service; by distributing manuals and RAPS design software; by active participation in RAPS industry organisations and by supporting the development of appropriate institutional frameworks for wider applications of RAPS in South Africa and the region.

***DE VILLIERS M G and DUTKIEWICZ R K**

Development of a draft manufacturing and mining energy effectiveness strategy for South Africa. Part 1: Industrial energy effectiveness activities worldwide and in South Africa. June 1994. 124p.
ERI Report No. GEN 168
R45,60

In Part 1, energy effectiveness activities in South Africa and in other countries are examined. It looks at the benefits of improved energy effectiveness and states that little has been done in South Africa to promote energy effectiveness. Barriers that exist to prevent effective industrial energy use are identified. The report stresses industrial energy effectiveness throughout.

***DE VILLIERS M G and DUTKIEWICZ R K**

Development of a draft manufacturing and mining energy effectiveness strategy for South Africa. Part 2: The potential benefits of improved energy effectiveness in manufacturing and mining in South Africa. June 1994. 123p.
ERI Report No. GEN 169
R45,60

The main objective of this report is to provide policymakers with an estimate of the benefits of improved industrial energy effectiveness in South Africa. This is accomplished by comparing energy use up to the year 2015 under two scenarios: (1) "business-as-usual" scenario, with no extra energy effectiveness initiatives; (2) "energy effective" scenario, where authorities embark on an energy effectiveness programme from 1995 similar to those of other countries which have successfully promoted energy effectiveness. It compares energy intensities with other developed countries, and also shows how energy savings can be realised.

***DE VILLIERS M G and DUTKIEWICZ R K**

Development of a draft manufacturing and mining energy effectiveness strategy for South Africa. Part 3: A strategic plan for improved industrial energy effectiveness in South Africa. June 1994. 80p.
ERI Report No. GEN 170
R34,20

The purpose of this aspect of the study is to propose an appropriate industrial energy effectiveness strategy for South Africa. It is recommended that a strong central energy effectiveness group be expanded from the Electric Energy Directorate of the Department of Mineral and Energy Affairs. The role of this group and government in industrial energy effectiveness is examined. It also looks at problems, and explores suggested programme in more detail.

*** DUTKIEWICZ R K**

Energy in South Africa: A policy discussion document. July 1994. 156p.
ERI Report No. GEN 171
R51,30

This report has been prepared as an aide-memoire for policymaking in energy in South Africa. An estimate has been made of the energy demand in the future of various energy sources, the scenarios being based on economic growth rates of between 3-5% per annum. Changes have been assumed in the future energy intensities, the values varying with time and with the assumed economic growth rates. Specific aspects covered include energy supply and demand in South Africa, coal, electricity, liquid fuels, renewable energy, environmental factors and policy considerations.

DYKES A R

National energy efficiency policy synthesis study. April 1994. 40p.
Report No. ED 9308

The purpose of the study was to produce a synthesis of current and future policies, attitudes and priorities regarding the effective use of energy in stationary applications. It looks at energy intensity, and sectoral energy use and strategies are discussed. Past and present national energy policies are reviewed. Local and international energy policies are traced and, in particular, the shift in the OECD from energy saving to the protection of the environment as the main motivation for energy efficiency programmes. The report discusses constraints, problems, weaknesses and gaps, and options are listed in order to overcome these obstacles.

FOURIE E *et al.*

Development of a high-energy impact crusher. April 1994. 103p.

The primary objectives of this project were to design, develop and test a production prototype high-energy impact crusher for quartz rock in gold mining applications under operating conditions. It mentions that the project was discontinued because the intended outputs could not be achieved.

HEYL L

Electrification and the electrical appliance manufacturing and distribution industry. March 1994. 48p.
Report No. EL 9401

The objectives of this study were to determine the potential impact of a national electrification programme on the electric domestic appliance manufacturing industry; to determine the structure, size, mark-ups and access to end-users of the formal and informal appliances distribution chains; to assess these distribution chains' respective roles in providing satisfaction, education and awareness at end-user level; and to identify the key issues that need policy attention. The report elaborates on the findings of the study and the conclusions/recommendations.

HOETS P

Acceptability of coal-based low smoke fuels: Phase II. March 1994. 68p. + appendices.
Report No. EO 9204

A major objective of the project was to produce a low-cost, low-smoke fuel for township use in South Africa which would be acceptable to residents and reduce unacceptably high levels of air pollution in townships. Three low-smoke fuels were tested. The study also attempted to determine attitudes to coal and coal stoves, and electricity.

MCLEAN D I

Synthesis of renewable energy in South Africa. May 1994. 29p. Cover title: Energy policy synthesis
Report No. EO 9309; NEPS06.1

The object of the report is to provide a concise summary of the "state of play" in the renewable energy field in South Africa. Comments are included about activities in this field in some neighbouring countries and Australia. All of the applicable renewable energy resources are included, with opinions from knowledgeable experts in each discipline on the potential and problems of each. Constraints on the wider use of the technologies are dealt with and developments are discussed. Comments are given on the possible role of the State in the future, and recommendations are made for future action on a logical priority basis.

PEMBERTON-PIGOTT C

Design and prototype of ox-driven waterpump. March 1994. 41p.
Report No. EO 9134

The purpose of the project was to show that it is possible to localise the production of an ox-drawn borehole pump currently in production in Niger. The report describes the methodology, data and results.

SCOTT R H

Renewable energy applications in South Africa. June 1994. 59p.
Report No. EO 9315; NEPS06.2

The report describes the policies and activities in the renewable energy field in South Africa against the background of international developments. It focuses on the renewable energy resource base and the development and utilisation thereof through effective policies which interlink with other developmental programmes. Consideration is given to such policy options and priorities and, in particular, the future role of the State in this process. Descriptions of the available resources, utilisation; technology, economics and environmental aspects are included and several recommendations made.

TERBLANCHE A P S and POLS A

Characterisation of risk factors associated with household fuel usage in South Africa. July 1994. 43p. + appendices.
Report No. EO 9303.

Data collected on 430 urban and 1 240 rural black children during 1991 and 1992 were used to develop multi-variate risk models. The data were collected as part of the Department of Mineral and Energy Affairs' (DMEA) projects on the "Health and safety aspects of household fuels: Phases I and II". The objective was to integrate data sets if possible and to identify key risk factors related to household fuels predicting upper and lower respiratory tract illnesses. The analysis indicated that the use of wood is worse than coal in rural populations; that there is 30% less chance that children living in formal homes will develop respiratory illnesses compared to those living in shacks; that the degree of ventilation in the cooking area is a key risk factor; that electrification is the most prominent risk minimisation method, but that paraffin is 8 times more beneficial than coal. Rural children reported proportionately higher accident rates related to fuel usage than urban children.

VAN ZYL N J W *et al.*

The cost and affordability of energy for commuter transport. January 1994. 84p. + appendices.
Report No. VE 9203

The main purpose of this research project is to provide guidelines for the Department of Mineral and Energy Affairs and the Department of Transport and transport policies respectively. More specifically, it investigates how these policies will impact on the affordability of transport energy to the commuter with special emphasis on the low-income commuter. To assess the affordability of South Africa's transport energy costs, it was decided to compare trends in fuel prices, consumer price index and wages between South Africa and other First and Third World countries. It also looks at factors impacting on the liquid fuel prices, percentage of income spent on transport, liquid fuels consumed per capita, etc.

All these reports are Final Reports and are the result of research funded by the Chief Directorate: Energy, Department of Mineral and Energy Affairs.

The publications can be ordered from: The Librarian, Chief Directorate: Energy, Department of Mineral and Energy Affairs, Private Bag X59, Pretoria 0001, South Africa, unless otherwise indicated. Prices are available on request from the Department of Mineral and Energy Affairs.

Reports marked * are available from the Information Officer, Energy Research Institute, P O Box 33, Plumstead 7800, South Africa, at the prices indicated.

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