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Rural Electrification in Botswana – A Single Wire Earth Return Approach

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Abstract: Botswana is a land-locked Southern African Country covering some 582,000 km^2 area. With a population of some 1.5 million people, its average population density is about 3 people per km^2. It is even less than this figure in the rural areas of the country. The rural villages are dispersed and very sparsely populated, thus making electrification on the national scale problematic. Because of these factors, single wire earth return (SWER) system and solar photo voltage system could be considered as potential solution to rural electrification in Botswana. The paper analyses the two systems, compares the barriers to their widespread adoption and estimates the cost of each of the systems. The paper concludes by proposing the single wire earth return system as more cost effective than the stand alone photo voltaic system and recommends that SWER should be developed and adopted to solve rural electrification problems in Botswana. Countries with similar rural population pattern could also adopt the SWER system.

Key Words: Rural Electrification in Botswana – Solar PV and SWER System

Introduction

Due to determined and sustained efforts by the Government of Botswana, overall access to electricity by households in Botswana has increased from under 10% in 1990 to about 22% in 1999. Rural access to electricity has similarly increased from 3% in 1999 to about 12% in 1999. These increases are higher than the access figures for many countries in both the sub-region and in Africa in general. Nevertheless, providing electricity to the widely dispersed and sparsely populated rural areas wherein about 65% of the total population lives continues to be a major national issue.

Government of Botswana energy policy in the National Development Plan 8 – NDP 8 (National Development, 1997/98)- is aimed at providing a least cost mix of supply, which reflects total life cycle cost and externalities such as environmental damage. Given the overall national policy objectives of economic efficiency, social equity, environmental quality and sustainability and security, the following are the energy policy objectives for NDP 8:

- Economic efficiency of the energy supply industry to ensure that energy services are supplied at least cost to the economy and to enable energy users to have access to appropriate diversified and efficient energy services;
- Social equity which will enable increased access by all households and community services to adequate and affordable energy services;
- Environmental quality and sustainability of energy extraction, production, transport and use, so that both the environment and people's health and safety are not compromised;
- All energy users should have security in their access to energy, and hence national security in energy sources, services, and management.

On the basis of NDP 8, efforts are been made to include rural areas in the overall electrification of the country. To achieve these objectives, and also considering the dispersed and very sparsely populated nature of the rural villages of Botswana, standalone solar pv systems have been installed in some villages in Botswana. This has been possible due to the high insolation level in the country. Botswana receives more than 3 200 hours of sunshine yearly with an average daily radiation on a horizontal surface of 21 MJ/m^2.day, thus making the country one of the highest solar radiation zones in the world. An estimated 4 450 000 PJ/year solar energy falls on the entire land area of Botswana and with a useful energy conversion efficiency of only 10%, the solar energy resource is an astronomical 445 000 PJ/year (EFCG, 1999). However with the development of SWER technology, it has become necessary to consider and compare the cost effectiveness, security reliability and sustainability of the two systems; PV and SWER, with the aim at recommending a more applicable and cost effective technology for use in the rural areas. This task is considered in the subsequent sections of the paper.

Rural Electrification: Grid Electrification in Botswana has traditionally been restricted to the eastern part of the country where there is relatively higher population densities. Given the long distances and the generally low load densities, other population centers in remote regions such as those in Western Botswana will take longer to electrify.

Under the general policy objectives of economic growth, social justice and sustained development, the Government in 1975 initiated its rural electrification programme with financial assistance from the Swedish Internatioinal Development Agency (SIDA). Under the programme, villages are connected to the national grid based on technical, social, financial, and economic analyses of each project. To qualify for electrification, a project should have a reasonable internal rate of return as recommended by the nation's power utility; the village should also satisfy other technical criteria such as proximity to the distribution and transmission lines, population size, geographical spread, economic activity engendered, etc. When found viable, both the Government and the power utility jointly fund the project on an equal sharing basis.

Concern about the slow rate of electrification, and encouraged by the progress made in solar photovoltaic, Government established the National Photovoltaic Rural Electrification Programme (NPVREP).

The National Photovoltaic Rural Electrification Programme –NPVREP: The NPVREP is a loan scheme financed by the Government of Botswana through the Energy Affairs Division of the Ministry of Minerals, Energy and Water Affairs. An approved applicant pays 15% down payment on the assessed total cost of the PV installation while the Government loans the applicant the balance of 85% over a four - year period at prime interest rate. The Rural Industrial Innovation Center (RIIC), a Government Parastatal, implements the programme. To apply for the loan, prospective NPVREP beneficiaries are encouraged to (ERL, 1985; Energy Policy of Botswana, 1996 and Botswana Power Corporation, 1992):

- Form a group with people in their village who are similarly interested
- Complete an application form individually
- Pay P72 deposit (about US$12) on the submission of the application form. This amount goes towards part of the 15% down payment required on the cost of the installation
- Pay 15% of the assessed total cost of installation before installation commences. The idea of the group is simply one of economics of scale, whereby items are bought in bulk for the group
- Sign a group contract binding on the group members
- Repay the loan on a monthly basis for up to four years.
- A P12 (about US$2) penalty fee is imposed for failure of each monthly payment as due.

The loan covers insurance costs against theft, damage from natural disasters, and repayment upon the death of the beneficiary.

Solar Pv System

Limitations to Widespread Development

Theft of The panel: Theft of solar photovoltaic panels poses perhaps the greatest thread to widespread adoption of the technology in Botswana. This is especially true for unattended PV installations belonging to public institutions such as the Botswana Telecom, the Botswana Railways, and the Department of Water Affairs. The problem is not as acute in the domestic sector which has a better chance of close supervision.

Scarcity of Financial Schemes: Individual homes wishing to utilize solar PV technology especially in the rural areas run into the problem of affordability and scarcity of financing schemes. The only scheme available is through the sole effort of the Government.

Balance of System Reliability: Besides theft, reliability of the Balance of System (BOS) appears to be the next greatest threat to sustainability and dissemination of solar PV technology in Botswana. The most troublesome components appear to be the inverter and the regulator.

Sustained Training of PV Contractors and Technicians: The Energy Affairs Division together with the Rural Industrial Innovation Center, which is the implementing agency for the National Photovoltaic Rural Electrification Programme have put up in place a training programme for solar PV contractors and Technicians. The programme covers such topics as specifications, inspection of works and certificates, schedule of works, quotation forms completion, ect. All specific to solar pv installations. The yearly enrolment figures are low hence leading to inadequate number of trained technicians in the field.

Codes of Practice and Technical Standards: Lack of codes of practice and technical standards are of concern. Standards are currently being developed as voluntary standards for the solar photovoltaic industry in Botswana. The Botswana Bureau of Standards together with the Energy Affairs Division and other stakeholders are working jointly on the development of the Standards.

Economic Consideration

Market Distortion: Implied subsidies for grid-based service to rural consumers while being a justifiable social or development goal, make solar PV system appear economically unattractive. For Botswana, current pricing structure make stand-alone solar pv electricity in the rural areas to cost between 444t/kWh (US 74 cents/kWh) and 486 t/kWh (US 81 cents/KWh) for 100W systems (Energy Policy of Botswana, 1996). These costs are based on conservative estimates on depreciation and maintenance and repair costs.

These costs cannot be compared with the existing uniform national tariff structure which, for energy charge is between 42 and 63 t/kWh (US 7 and 9 cents/kWh) depending on the consumer. The highly subsidized national electricity tariffs renders the PV system non competitive.

An estimate of the cost per unit of extending the national grid to three villages approximately 3, 100, 240 km from the nearest national grid yields 48, 132 and 156 t/kWh (8, 22 and 26 US cents/kWh) based on energy and 20 yearlong infrastructures.

From this economic analyses, it could be concluded that it is more economical to extend the grid system to villages provided that such extensions meet the power quality and energy transmission guidelines (Energy Policy of Botswana, 1996).

High System Capital Costs: Solar PV home system are generally considered to offer a fast and least-cost means of providing decentralized rural electrification under two conditions:

- In locations where consumers are dispersed and the load density is low even though the grid may be nearby
- In locations where the grid is more distant and the possibility of an early grid extension is rather remote

Although these conditions are fulfilled for many rural areas of Botswana, there is the issue of high system capital cost and affordability. Average costs in rural areas of Botswana are as presented in Table 1. (ERL, 1985 and Botswana Power Corporation, 1998)

Table 1: Cost of Installation

System Size, W	No. of Installations	Average Cost, Pula	App. Cost in US$
50	14	4511	761
100	64	8518	1420

From this economic analyses, it could be concluded that it is more economical to extend the grid system to villages provide that such extensions meet the power quality and energy transmission guidelines.

SWER System: Although SWER is not mentioned in the rural electrification policy, it is worth considering it for SWER technology has been implemented successfully in many developing countries (Da Silvia, 2000 and Louw, 1998) and in developed ones as well. For example, 20% of the Australia's distribution lines use SWER technology to service economically and effectively small communities distributed over vast areas. Booster converters, which converts single phase to three phase are employed when there is need to run a three-phase equipment (Hardy-R, 1998).

Technical Characteristics of SWER: SWER is a single- phase system in which the neutral side of the connected loads is joined to earth. There is no continuous conductor between the source and the neutrals. The neutral current flows, via electrodes into the mass of the earth. A single wire is run from one of the medium voltage (33 kV or 11 kV) phase conductor to the substation or transformer supplying the load. At least three metal rods are driven 2 or 3 meters into the ground to provide the earth connection (Code of Conditions, 1990).

The main purpose of SWER is to power relatively small, but relevant loads over long distances at the least possible cost. In this respect, SWER offers a significant cost saving compared with conventional solutions in transmission and distribution systems. SWER cuts by more than half the number of conductors and insulators to be used. It also reduces labour requirements for the line construction. It allows for lighter poles and wider spacing to be used as conductor clashing can be disregarded.

Isolation Substation: Isolation substation is the main component in the SWER system. Without SWER isolation transformers, the return current would flow back to the main zone transformer resulting in high voltages being applied to equipment. SWER requires an under-strung earth wire for safety reasons whenever the lines come closer to a village, and consumer facilities. All equipment and cubicles within the substation yard must have their casings carefully earthed to avoid unduly step and touch voltages. The substation must be covered with gravel and fenced.

SWER Transformers: Manufacturers, such as ALSTOM, produce SWER transformers from 16kVA to 25kVA. These are special isolation transformers. SWER transformers can also be manufactured up to 400kVA, 33KV primary and 19kV secondary with an off circuit switch on the primary voltage.

Earthing: The effectiveness in the design of SWER is the dependence of the earthing system. Schematic earthing system is shown in Fig. 1 Ground connection must be implemented at each distribution transformer and the substation(s). The earth connection shall have a resistance not greater than 5 ohms. Also the earth resistivity should be less than 1000 ohms -meter.

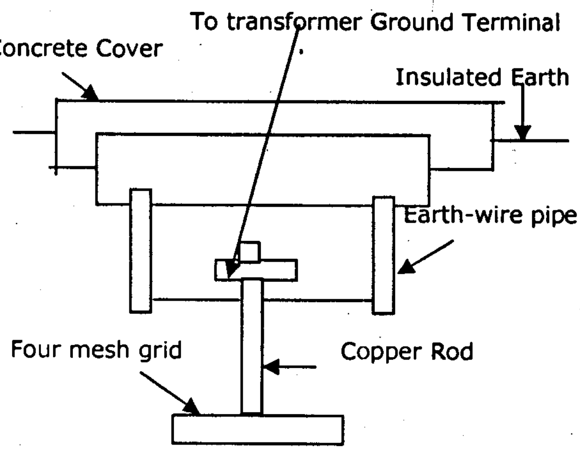

Fig. 1: Schematic Earthing System of SWER

Justification for SWER Application in Botswana: Rural Areas In Botswana Are Widely dispersed and sparsely populated. Therefore they satisfy the criteria for the application of SWER technology. However to ensure that the earth resistivity of these areas fall below 1000 ohm-meter as required, measurements were carried out in different locations of Botswana and at different climatical conditions. Computer program was written to authenticate the results. The measured and the computer results are presented in Tables 2, 3, and 4 (Anderson, 2000).

Table 2: Soil Analyses and Moisture Content

Location	Soil Type	Moisture Cont.,%
Gaborone-Village	Sandy Clay Loam	22.53
Gaborone-Extension 2	Loamy Sand	9.93
Gaborone-Kgale View	Sandy Loam	14,63
Lobatse-Woodhall	Clay mixed with Black Cotton Soil	4.32
Lobatse-Peleng	Calcerite Clay(grayish brown)	3.12
Lobatse-Boswelatlou	Silty Sand	6.34
Jwaneng Unit 1	Kalahary Silt	<1
Jwaneng-Unit 4	Kalahari Silt	<1
Jwaneng Unit 5	Kalahari Silt	<1
Jwaneng Unit 6	Kalahari Silt	<1

Table 3: Results of Earth Resistance Measurement - Copper Coated Steel (19mm)

Location	Length,(m)	Wet Season R(Ω),ρ(Ω-m)	Dry Season R(Ω), ρ(Ω-m)	Moisture Cont. (%)
Gaborone Village	1.5 1.2	20.8 30.2 32.3 42.2	31.2 49.1 38.3 50.1	22.5
Kgale-View	1.5 1.2	15.3 24.0 18.5 23.8	18.2 28.6 20.8 27.2	14.6
Extension 2	1.5 1.2	29.4 46.3 33.9 44.3	38.4 60.4 20.8 27.2	9.93
Lobatse				
Peleng	1.5 1.2	176.6 277.1 201.3 263.5	175.8 184.5 200.2 218.4	3.12
Woodhall	1.5 1.2	312.8 492.6 331.2 361.3	312.8 328.4 330.8 360.9	4.32
Boswelatlou	1.5 1.2	111.8 187.i 141.6 185.3	120.8 190.2 142.6 186.7	6.34
Jwaneng				
Unit 1	1.5 1.2	150.3 236.7 180.2 245.5		<1
Unit 4	1.5 1.2	151.8 239.0 162.8231.1		<1
Unit 5	1.5 1.2	148.2 233.4 164.3 215.1		<1
Unit 6	1.5 1.2	152.8 240.6 168.4 220.4		<1

Table 4: Computer Results by the use of
Copper coated steel (19mm)

Location	Resistivity, ρ(Ω-m)	ResistanceR(Ω),
Gaborone		
Village	30.24	19.2
Kgale-View	24.00	15.3
Extension 2	29.40	29.4
Lobatse		
Peleng	277.9	176.0
Woodhall	492.6	312.8
Boswelatlou	187.1	118.7
Jwaneng		
Unit 1	236.70	150.2
Unit 4	239.00	151.8
Unit 5	233.41	148.2
Unit 6	240.60	152.8

The earth resistance was modeled using the following expression (Van Coller, 1994)

$$R = \left(\frac{0.370\,\rho}{L}\right) \text{Log}_{10}\left(\frac{4000\,L}{d}\right) \text{---} \quad \text{sss1}$$

Where d is the diameter of the electrode.
L, is the length of the electrode ρ, is the resistivity of the soil in ohm-meter
The program was written in PASCAL language (William, 1994) on the basis of equation 1
Soil resistivity measured at different locations in Botswana indicates that the values throughout the country fall below the maximum value of 1000 ohm - meter required for the application of SWER technology. This assertion paves the way for SWER application in Botswana.

Standards for SWER: Botswana does not have yet any functional SWER. However a technical standard regarding safety should be in place to ensure that the application of SWER will not cause any safety hazards. As New Zealand has functional SWER and developed standards, it is proposed to adopt such standards for

Table 5: Separation between SWER and other Communication Circuits in Meters

Lengthnof parallel communication circuits	Minimum From	Average Communication	Separation Circuits	
	ρ = 5	ρ = 47	ρ= 200	ρ = 1000
8	220	640	1350	3060
16	300	1000	2000	4570
24	400	1230	2430	5790
32	480	1430	2900	6860
40	540	1600	3240	7460

ρ = earth resistivity in ohm- meter

Botswana. The New Zealand standards for SWER application are:

Transformers: Single wire earth return systems are to be supplied from double-wound transformers (isolating transformers). These circuits are to supply only double-wound step-down transformer having either three-wire 280/240 V or two-wire 240 V secondary operating as for the multiple earthed-neutral systems.

Earthing Arrangements: Isolating and step-down transformer windings connected to SWER circuits shall be insulated from their tanks. The connection with earth shall be made externally by means of duplicate conductors of stranded copper each having a cross section of not less than 16 mm^2 . The duplicated conductor shall be installed unbroken and without joint, using different routs, and shall have separate and independent attachment to the earth electrode. The earth - connection shall be of resistance not greater than 5 ohms to earth and shall be so installed as to prevent danger from voltage gradients at ground level, so as to eliminate step and touch potentials.

Load Current: The maximum permissible load current in any return circuit shall not exceed 10 amps.

Protection: The overload protection of earth - return circuits shall be such as to reduce to a minimum the risk of a conductor remaining alive after it has fallen owing to any circumstances.

Separation from other Services: The minimum separation between any conductor of earth-return circuit and any open wire overhead communication line shall be 80 meters, except at crossings.

No earth-return circuit conductor shall be erected parallel to any open wire overhead communication line so that the normal induced longitudinal voltage in the communication line exceeds 2 volts rms

The minimum separation between any conductors of an earth return circuit parallel with any open wire communication circuit shall be in accordance with Table 5.

Avantages and Limitations Of SWER

Advantages: SWER technology offers a significant cost saving compared with conventional solutions in certain applications. The main advantages are:

- The system reduces the number of conductors and insulators by more than half when compared with those of a three-phase system
- It allows for higher poles and a wider spacing due to lighter conductors, reduced in numbers
- It reduces labour requirement for line construction due to the reduced number of lines
- The system can also be used to supply a booster (phase-converter), which converts the single-phase into a three-phase system. In this case the single wire substitutes the four wires three-phase standard system resulting in savings.
- SWER can also be upgraded with the introduction of additional isolation transformer as the load increases, allowing phased infrastructure and delayed capital investment
- The use of shorter and lighter poles aids construction in remote areas and different terrain. Besides the visual impact is much less than the conventional system
- A downed conductor from the load side is de-energized. For a three-phase system such a conductor will remain energized.
- The probability of failure of a line is lower than that of a three-phase line.

Limitations

- It is limited to areas where the earth resistivity is within the 1000 ohm-meter range
- The rate of voltage drop as load increases is more than in a conventional system
- The power to be transmitted is limited by current in the earth-return system.
- The interference with telephone lines due to Earth Potential Rise (EPR) makes it mandatory to have large distances between SWER lines and communication lines as presented in Table 5

Economic Consideration: A cost analyses was carried out to compare SWER cost with the cost of extending conventional 33 kV transmission lines to serve a rural area of Botswana with a population of about 200 000. The cost comparison is presented in Table 6. In the Table, line equipment refers to fuses and switches; transformers include power and distribution transformers; grounding include pole-mounted equipment and substation grounding. 20% overhead cost is applied to SWER estimates and 40% to the estimates of the conventional system.

The rates for the estimates were supplied by the Botswana Power Corporation. The assessment indicates that in rural areas low load density, SWER is competitive when compared with conventional power supply to consumers. The highlighted information on SWER is compared with solar photovoltaic system to determine a more appropriate solution for the electrification of the widely dispersed and sparsely populated rural areas of Botswana.

Comparison of SWER with Solar Photovoltaic System

Comparison of the Advantages and the limitations of SWER and Solar PV System: The advantages and limitations of Solar PV stand-alone system have earlier been presented. The main advantage is that it can be utilized in rural areas

Table 6: Cost estimate of SWER and 33kV three-phase System

Item	Estimated Costs SWER	In US $ Conventional
Lines	353 000	635 500.0
Line Equipment	5 000	9 286.0
Substations	67 857	100 000.0
Transformers	123 857	121 500.0
Grounding	97.143	42 000.0
Sub-total	905 571	944 643.0
Overhead	181 114.2	377 857.2
TOTAL	1 086 685.2	1 322 500.2
Savings	235 815	
%age Savings	17.83	

Where the supply of energy by conventional means is not cost effective The limitations to widespread development include; theft to the panels, scarcity of financial schemes, balance to system reliability, sustained training of PV contractors and technicians, codes of practice and technical standards, and high system capital cost

Those of SWER have also been presented earlier. The main advantage is that it can be applied to widely dispersed and sparsely populated rural areas, and it is more cost effective than the conventional three-phase system. The disadvantages are that; it is limited to areas where the earth resistivity is less than 1000 ohm-meter, the rate of voltage drop as load increases is more than in a conventional system, the power to be transmitted is limited by current in the earth-return system, and possible interference with telephone lines.

Comparison of costs: The cost of serving about 200 000 rural inhabitants by SWER technology is US $ 1 086 685.2 (refer to Table 7). The cost of serving a household in the rural areas with a system size of 100 Watts by a stand-alone PV system is US$ 1420(refer to Table 1). If it is assumed that the average wattage of a rural house hold is 100 W, then 2000 W will be required to serve 200 000 inhabitants. The approximate total cost is therefore US$ 2 840 000. (1420 x 2000). The comparison is presented in Table 7

Table 7: Comparison of Costs

System size,	Wattage/ 200000 Household	Stand-alone PVsystem, US$	SWER System, US$
100 W/house hold	2000	2 840 000	1086 685.2

Conclusion

It has been established that the resistivity of soils in Botswana satisfies the criteria for the application of SWER technology. It is therefore technically feasible to apply SWER technology in the rural areas of Botswana.

A study of SWER and Conventional System has shown that the application of SWER Technology in rural areas of Botswana is more economical than conventional system, especially in widely dispersed and sparsely populated areas.

The comparison of Solar Stand Alone PV System with SWER technology also indicates that SWER technology overwhelms Standalone PV systems in terms of limitations to widespread use. It is also more cost effective than Solar systems.

The application of SWER technology in the rural areas of Botswana will eliminate the hazels which applicants for the installation of standalone solar PV systems encounter, and directly or indirectly, the energy policy for rural areas of Botswana would be achieved.

The author therefore recommends the application of SWER technology for electrification in the rural areas of Botswana. Countries with similar rural population pattern could also adopt the SWER system

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