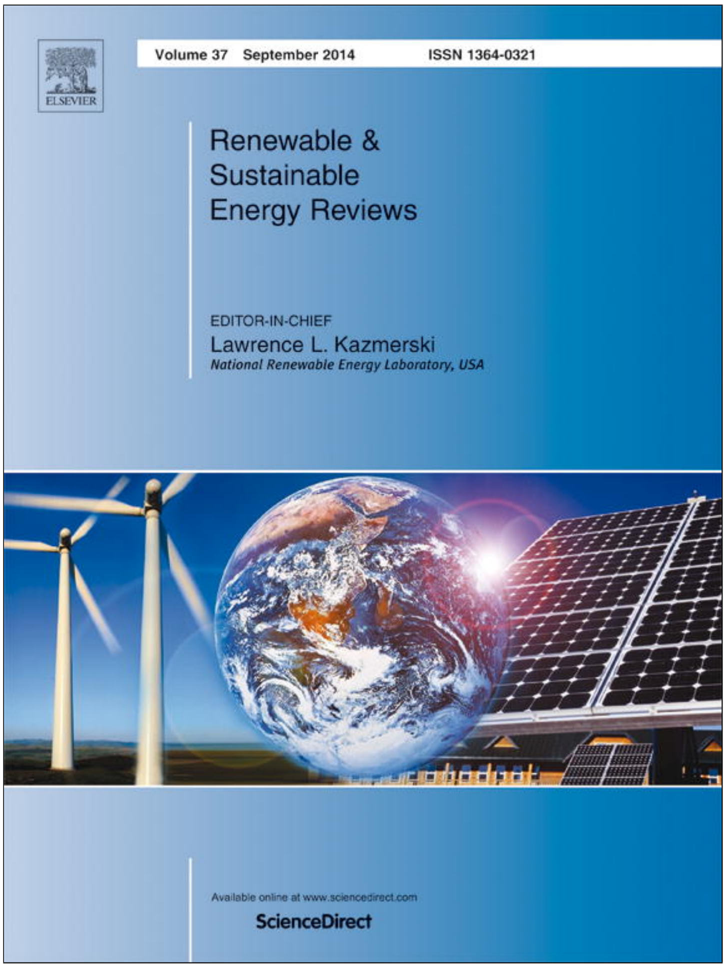
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A survey of innovative technologies increasing the viability of micro-hydropower as a cost effective rural electrification option in South Africa

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ABSTRACT

The aim of this paper is to provide a survey of different innovative technologies that can be applied to the micro-hydropower system to make it cost effective for rural energy supply. Electrical, mechanical, civil or electronic technologies that can increase the viability of micro-hydropower as a cost-effective energy source for remote and isolated communities in rural South Africa are presented. The motivation behind this study is that there are a significant number of potential sites in South Africa where micro-hydropower is a viable energy option to provide reliable and low cost energy and where conventional schemes are not appropriate.

Contents

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1. Introduction

Regardless of the rapid urban growth that Africa has experienced over the last 20 years, the majority of Africans still reside in rural areas. Provision of adequate energy services in these areas is therefore of vital importance.

In the particular case of South Africa, the number of people in rural areas without access to electricity is estimated to be more than 75% [1]. The other 25% of these rural communities are electrified by the extension of local distribution grids. However the high price of the lines as well as the resulting cost of electricity delivered is making this supply option to be non-ideal for small isolated remote areas [2]. Another popular alternative for electricity generation is the use of standalone diesel generators. This option has the benefit of generating power on demand and have a very low investment cost. However its permanent reliance on diesel fuel for operation as well as the pollution emittance makes this options very expensive and not environmental friendly [3]. As a result, the cost of energy produced in isolated areas of South Africa is much higher compared to the other locations in the country.

A study on energy policy has been performed in 1998 by the Department of Mineral and Energy (DME) [4] and the results have shown that South Africa has good potential to develop and use renewable energy sources such as wind, solar or small-scale hydropower for electricity supply of small rural and isolated communities with low energy demands. This renewable potential can positively contribute to the DME's, setting a target of 10,000 GW h of renewable energy production by 2013 [5].

For areas where adequate water resource is available, micro-hydro is the best supply option compared to other renewable resources in terms of cost of energy produced [6]. Some other advantages of using micro-hydropower are:

- the water resource used is free;
- it is a long-lasting technology with very low running costs;
- the energy available can be readily predicted and power is usually continuously available on demand;
- development of a micro-hydropower scheme would benefit local economy;
- micro-hydropower plants can achieve very good efficiency, making them to be among the most efficient energy conversion technologies;
- most micro-hydropower plants are run-of-river system, resulting in no inundation of land and less civil works.

The principal areas to implement micro-hydropower systems in South Africa are mostly rural settlements without access to electricity; this makes the load requirements, the water resources as well as the site specifications different from one place to another [7]. It is also known that the amount of energy extracted from a site is dependent on the water flow as well as on the water head available from a site. This implies that for sites with very low elevation or with no water flowing, it is almost impossible to extract energy using conventional micro-hydropower. Consequently micro-hydropower plant requires custom-made equipment for each site, resulting in an increase of the investment cost and complexity of plant development and hindering the potential deployment of micro-hydropower systems. These are severe technical and economical issues having huge impact on the life-cycle cost that need to be addressed to better the development of practical and reliable micro-hydropower plants [8,9].

As a contribution to find the solution to the technical and economic limitations discussed in the paragraph above, this paper will review available and growing technologies that increase the viability of a micro-hydropower plant as a cost effective energy source for South African rural areas not connected to the local grid. This will assist local communities having potential sites in the selection of the most economical equipment to develop micro-hydropower plants well suited to their specific needs.

2. Micro-hydropower situation in South Africa

South Africa has a significant hydropower potential that can be used for electrical power generation from small to large scale [10]. From a study conducted by the DME, it has been pointed out that no major development in the local hydropower industry has been made for almost 30 years. However, there are recent developments such as the Sol Plaatje hydropower station (3 MW) commissioned in November 2009 on the existing Sol Plaatje dam, as well as the run of river Merino hydropower station (4 MW), situated on the Ash River, constructed in November 2011 [11]. Apparently, the overall hydroelectricity generation represents only about 5% of present total installed generation capacity [12]. Table 1

Table 1
Hydropower potential in South Africa.

Size	Type	Installed capacity (MW)	Estimated potential (MW)
Macro hydropower (larger than 10 MW)	(i) Imported	1450	36,400
	(ii) Pumped storage for peak supply	1580	10,400
	(iii) Diversion fed	–	5200
	(iv) Dam storage regulated head	662	1520
	(v) Run of river	–	270
Small hydropower (from a few kW to 10 MW)	As above (iv) and (v)	29.4	113
	Water transfer	0.6	38
	Refurbishment of existing plants	8.0	16
	Gravity water carrier	0.3	80
Sub-total for all types		3730.3	53,837
Excluding imported from abroad		2280.3	17,437
Excluding pump storages using coal based energy		700.3	7237
Total “green” hydro energy potential available within the border of South Africa			**7237**

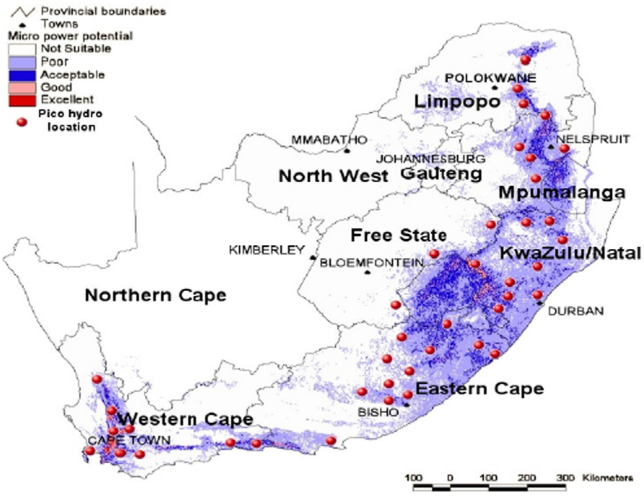

Fig. 1. Small scale conventional hydropower distribution in South Africa [15].

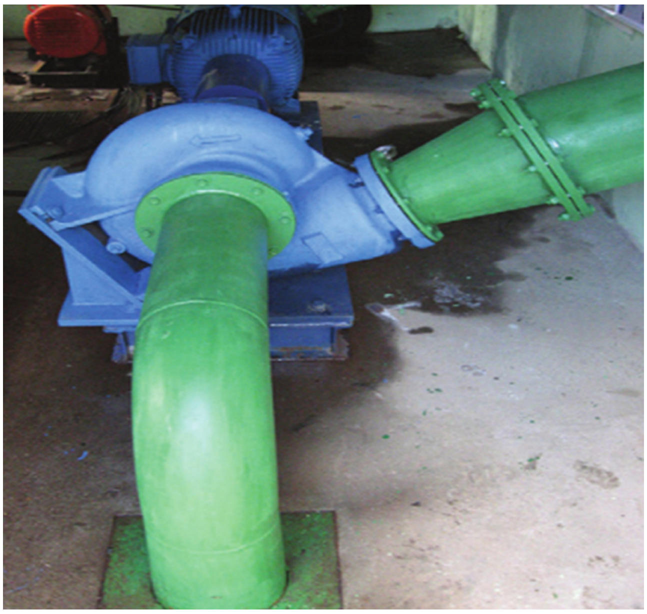

Fig. 2. Installed pump as turbine [23].

below gives a summary of the hydropower installed as well as potential in South Africa [13].

The rural Eastern Cape, Mpumalanga and KwaZulu-Natal provinces have access to water resources with good potential as shown in Fig. 1. This can sustain the development of micro-hydroelectric installation for their domestic consumption.

The US department of energy estimates that there are 6000–8000 potential sites in South Africa for micro-hydropower of different flow and head ranges. For example the upper Tugella catchment has a total of 76 possible sites with a potential for the installation of 152 units [14].

However, the implementations of micro-hydro schemes with conventional civil works, hydraulic, mechanical and electrical equipments have been proven expensive and uneconomical in local rural areas. To address this problem, alternative technologies need to be introduced and popularized in South Africa to support the development and deployment of cost effective micro-hydro power stations for rural power supply.

We have to notice that Fig. 1 and Table 1 do not take into consideration the potential power production from unconventional micro-hydropower plants and recent technologies which can make a greater contribution to the South African energy sector compared to the ones from traditional micro- and pico-hydropower plants.

3. Micro-hydropower technologies

In conventional micro-hydropower the water passes through the penstock and strikes the turbine blades where hydraulic power is converted to mechanical power. The turbine is coupled to a generator converting the mechanical power into electrical power. This whole process can be expressed using the following equation:

$$P = \rho \times g \times H \times Q \times \eta_{Tot} \quad (1)$$

where P is generator electrical output power (W); η_{Tot} is total electromechanical conversion efficiency (%); ρ is water density (kg/m^3); g is gravity (9.81 m/s^2); Q is water volume flow rate (m^3/s); and H is effective water head (m).

As the demand for a low-cost, reliable and uninterrupted electricity supply in remote and rural areas increases, it is vital to pay good attention to technologies that decrease the technical problems while increasing the viability as well as the cost-effectives of micro-hydropower stations.

A number of modern technological solutions have been developed to reduce the overall costs of micro-hydropower and make it suitable for rural applications in South Africa.

This paper will review the following technologies:

- low-cost penstock;
- micro-hydro turbines;
- induction generator and controllers;
- hydrokinetic systems;
- hydro aero power;
- battery-based systems;
- modular systems.

4. Low-cost penstock

The penstock is one of the most costly elements in the micro-hydropower financial plan; for high-head plants it can even reach as much as 40% of the budget [16]. An optimized design and material selection is imperative to reduce the cost of the penstock to be used. The following factors must be taken into account in penstock selection:

- pressure;
- smoothness of pipe interior;
- type of joining;
- weight and ease of installation;
- design life and maintenance;
- costs.

The penstocks in mild steel are the most used; however high density polyethylene (HDPE) pipe has also been used. For heads below 75 m the cost of installed HDPE penstock is almost half as compared to that of using mild steel penstock. The explanation for this is its low cost, ease of carrying, ease to join and install in particular on steep hills. It can be covered underground or built up on surface. For pressures above 700 kPa the penstock in mild steel would be much more competitive.

For rural application, the proportion of the penstock cost in the whole micro-hydropower project can be further reduced when wooden penstock are used [17]. Wooden pipes have already been used in Germany and they lasted between 50 and 100 years. They are currently being manufactured in USA as well as in Canada. The advantages of wooden penstocks can be described as follows:

- all parts can be produced locally in South Africa, creating new jobs;
- the bulkiness and weight of the components to be transported on the site is considerably reduced;
- the wooden penstock can be mounted onto wooden cradles which are set in a gravel bed. The necessity for cement, which will mainly be used for penstock support, is considerably reduced;
- the wooden penstock can be laid in a wavy line; no special curves are required;
- no special skills or power tools are required for assembly;
- wooden penstock of any particular length can be manufactured without any flanges.

5. Micro-hydro turbines

The water turbine is one of the key and costly elements of micro-hydro power plants depending on the particular requirements of any given site. The current micro-hydro conversion system is based on impulse turbines and on reaction turbines. Their major issue is the low efficiency obtained (typically 30–60%) when they are used in micro-hydropower schemes [18].

The application of commercially available micro-hydro turbines is conditioned by the water head, flow, pressure, and the need for the penstock adaptation, which can make them inappropriate for application in a number of potential sites. Therefore, it is crucial to identify and propose a range of suitable micro-hydro turbines for power generation in rural South Africa.

From the research work on power generation feasibility analysis conducted by [19], the two suitable options below have gained an importance and can therefore be considered in the present study as ideal choices for South African micro-hydropower sites. The key factors regarding the choice are the equipment and installation simplicity.

5.1. Pump-As-Turbine (PAT)

Using a centrifugal Pump-As-Turbine (Fig. 2), with the direction of flow reversed, is an attractive option for micro-hydro power generation particularly in rural mountainous locations [20]. Pumps are relatively simple machines with no special designing and are readily available in most developing countries.

The use of pumps instead of turbines is an ingenious and cost-effective alternative because of the following reasons [21]:

- PATs are mass produced and cost less than traditional turbines; this can reduce considerably the capital cost of the plant;
- they have uniform quality plus simple construction and durability;
- pumps are relatively simple machines with no special design and are readily available in most developing countries in different sizes, head and flow rates;
- a reverse running pump turbine also has almost the same efficiency as the pump which is competitive with other turbine types;
- a small number of parts enable easy maintenance, operation and inspection.

The range of higher efficiency of PATs is between 13 and 75 m of gross head covering the range of various types of conventional turbines. The cost per kilowatt produced decreases with an increase of the head. There are PATs in the range of 1.7–160 kW presently in operation; some have been working continuously for more than 25 years [22].

The only disadvantage of PAT is that its operation is very dependent on flow rate, not accommodating for high fluctuations of flow. Cases where control method uses Electronic Load Controllers (ELCs) discussed in the Section 7 below may eliminate the issues related with the flow variations.

5.2. Propeller hydro turbine system

Propeller turbines are low head (from 0.6 to 1.5 m) and high flow rates (from 0.0035 to 0.0130m^3/s) axial turbines which have been mostly used in small and mini hydro power plants. Due to the recent developments linked to an increase of turbines' efficiency, their application is currently being extended to the area of micro-hydro power generation[24].

An increased number of propeller hydro turbines have been implemented all over the world, because they are low-cost and easy to mount. These turbines were designed to supply enough power to a typical family in rural areas. Propeller hydro turbines are available from 200 W to 20 kW [25].

6. Induction generator

Squirrel cage induction generators used in micro-hydropower production are ordinary induction motor running in self-excited generator mode. For this, its stator windings need to be connected with a well sized capacitor bank and their rotors driven by the turbine [26].

Induction machines are robust and for powers less than 20 kW are less expensive than synchronous generators and readily available in the market as 2, 4, 6 and 8 pole machines. Some other advantages of using an induction generator are [27]:

- reduction in the size and simple construction;
- robustness;
- self-start capability (directly linked to the proper sizing of the turbine used) and control mechanism;
- ease of maintenance;
- self-protection against severe overloads and short circuits;
- low investment cost.

This generator is a suitable option for standalone micro-hydro-power; moreover it is also the best candidate for grid connected operation mode. Due to low power ratings uncontrolled turbines are ideal to be coupled to these generators, which maintain the input power constant [28].

Because micro-hydro plants are mostly well suited for providing power to single-phase rural and isolated loads, three-phase induction generators can be used instead of single-phase due to their lower cost of per kilowatt (kW) produced [29]. Three-phase induction generators can provide energy to single-phase loads by converting their three-phase power into single-phase power with suitable techniques. The techniques applied for the conversion of three-phase to single-phase when supplying a single-phase load are called Smith connections [30].

However, the main problem encountered when using self-excited induction generator is the difficulty in maintaining the frequency and voltage constant at varying consumer loads. Induction generator controllers can be used as a solution to this problem; these will be discussed in the section below.

Fig. 3. Installed freestream Darrieus hydrokinetic turbine [38].

Fig. 4. Windmill and storage tank for hydro aero power [41].

7. Induction generator controllers

As stated in Section 6, the main disadvantage of using induction generators for micro-hydro generation is the fluctuating output voltage and frequency supplied to the load. The usual solution is to equip the generator with Automatic Voltage Regulator (AVR) or use hydraulic and mechanical speed governors; similar to large hydro systems they have been used to control the water flow into the turbine as the consumer demand varies. However, these options are costly especially when the generator is intended to be used for small rural applications [31]. Hence some other technologies of controlling the induction generator output have been developed. They have increased the simplicity and reliability while decreasing the costs of modern micro-hydropower plant.

7.1. Dummy load

The load control system on a micro-hydropower can be based on the dummy load principle (resistive or ballast load) [32]. In this case the load presented to the turbine is more or less constant irrespective of the demand side. Thus the rotational speed of the generator is maintained approximately as constant and therefore there is no need to use an electro-mechanical valve on the water flow or variable guide vanes to produce a stable frequency. The cost of the plant is reduced and the reliability is improved as long as the controller design is adequate.

To produce suitable voltage and frequency, the control of the dummy load must be done very meticulously, and these days the control is based on microprocessors. However, such devices are not cost-effective and imply a high level of complexity resulting in complications in repairing and possibly uncertain reliability.

7.2. Electronic load controller

The ELC is an electronic device that maintains a constant electrical load on the generator in spite of changing user load. This permits the use of turbine with no flow regulation and governor control system [33].

The ELC maintains a constant generator output by providing a secondary ballast load with no power required by the main load. Consider the plant running at near full load and governed by an ELC, if some loads are switched off then less power is kept to the plant which causes an increase in rotational speed of the turbine and the output frequency of the generator. The change in speed and frequency is sensed by the ELC, it then adds a dump load of sufficient resistance at the generator output to dissipate power equivalent to that which was switched off. Thus, in spite of change in consumer load the total load on the generator and the turbine remains constant.

Some advantages of using electronic load controller are [34]:

- the use of ELC facilitates the incorporation of simpler and cheaper turbine with less moving part in the micro-hydro architecture;
- no hammer effect from load changes;
- the use of ELC permits lighter, less robust penstock and also imposes less wears and tears on the hydro power plant's mechanical parts;
- ELCs have high reliability, low maintenance and simple operation principle. They can be installed anywhere in the electrical system;
- ballast load can be used as heater for water or households, resulting in 100% load factor of the micro-hydropower plant;
- the typical hydraulic and mechanical devices used to control the water flow in the penstock are more expensive than the ELC.

Therefore for micro-hydro system supplying rural load for which cost-effectiveness is the major factor, electronic load controller is the best way of regulating the induction generator output frequency and voltage.

8. Hydrokinetc systems

Hydrokinetic energy is captured from waves, tides, ocean currents, the natural flow of water in rivers, or marine thermal gradients [35]. Hydrokinetic was originally developed to surmount the numberless problems associated with dams throughout the world. Fig. 3 shows this system erected into the river or stream which results in the following advantages compared to the traditional hydropower:

- no dam or penstock;
- power can be generated at very low speed (50–100 rpm);
- no destruction of nearby land;
- no change in the river flow direction;
- reduction in flora and fauna destruction.

Most of the operation principles of the hydrokinetic turbines are based upon wind turbines, as they extract kinetic energy from water resource but with the possibility of having approximately

Table 2
Summary of modular systems specifications.

Modular system	Manufacturer	Head (m)	Flow range	Power (W)	Voltage (V)	Cost (USD)
LV hydroelectric generators	HI-Power	12–120	0.02–1.5	1200	12–96	1350–1500
HV hydroelectric generators	HI-Power	18–150	0.04–1.5	3600	110–440	2500–6300
Pelton turbines	Harris Hydroelectric	6–180	0.015–0.95	700–2500	12–48	1800–2150
Stream engine	Energy System & Design	2–100	0.04–1.5	1000	12–48	1800–2150
Water buddy	Energy System & Design	15–150	0.011–0.11	350	12–48	1500
LH 1000	Energy System & Design	1–3	0.032–0.065	100–1000		2000
UW 100	Ampair	(Instream)	4 m/s (velocity)	100	12–48	1500
Turgo micro-turbine	Thomson and Howe Energy Systems	20–90	0.008–0.03	1500–5000		2.400–3.200

Fig. 5. LV hydroelectric generators [43].

Fig. 6. HV hydroelectric generators [44].

800 times more energy from the hydrokinetic compared to the wind turbine of the same size and at the same velocity [36].

The extraction is governed by the same equations as for wind turbines; therefore the power theoretically available from a stream of water through a turbine is given as follows:

$$P_a = \frac{1}{2} \times A \times \rho \times V^3 \times C_P \quad (2)$$

where P_a is available power; A is area swept by the rotor blades (m^2); P is density of water (1000 kg/m^3); and V is velocity of water (m/s).

The power coefficient "C_P" has a maximum value of 16/27 or 0.59259 of the theoretically available energy (the Betz limit). In contrast to wind turbines of similar output, the high power densities achieved with streams of flowing water imply that large thrust forces are applied to hydrokinetic turbines. Therefore to protect the blades from damages and taking into account the losses, small-scale hydrokinetic turbines have their power coefficients reduced to around 0.25.

Because hydrokinetic plants use zero head turbines, a greater number of potential sites to implement it can be identified compared to the traditional micro-hydropower. The possibility of using and developing hydrokinetic power to supply reliable, affordable and sustainable electricity to rural loads in South Africa where reasonable water resource is available has been investigated by the authors of the paper [37]. The results have shown that hydrokinetic is the most cost-effective option compared to other renewable energy sources.

9. Hydro aero power

Using a windmill to pump underground water to the surface is a well known technology [39]. This concept has now been taken a step further by the Central University of Technology in Bloemfontein and the Southern Cross Industries to help generate electricity using the operation principle of the large pump storage hydropower schemes [40].

The windmill drives a wind pump which extracts underground water via a bore hole or stream as shown in Fig. 4. The water is then pumped up to a reasonable height above the ground where it is stored in a reservoir tank, then falls down through a hydroelectric turbine which generates electricity sufficient for household needs. This connection can also charge a battery pack fitted to the turbine, which will store energy for future use.

The advantages of this system are:

- the system can be used inland where there is underground water;
- most of the farmers especially in areas of South Africa with almost no flowing water are already in possession of a windmill;
- free clean water is produced as a bi-product for domestic use.

The output power produced is depending on the height of the reservoir as well as on the turbine used.

10. Battery-based systems

In battery-based systems, the generated electric power is used to charge a battery bank. DC appliances can be operated directly from the batteries. Very reliable and cheap inverters are available to convert DC battery power into AC and can be used to power the remaining appliances.

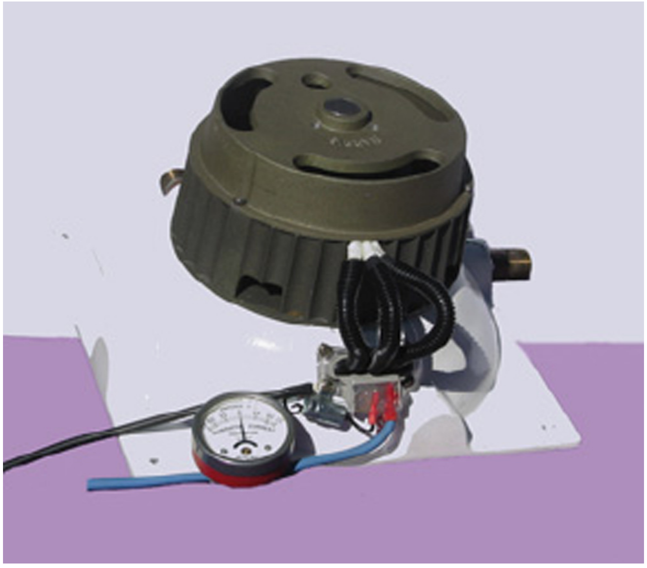

Fig. 7. Pelton turbines by Harris hydroelectric [48].

Because the energy is stored in batteries, the generator can be shut down for servicing without interrupting the power delivered to the loads. Since only the average power needs to be generated in this type of system, the pipeline, turbine, generator and other components can be much smaller than those in an AC system. Furthermore, the micro-hydropower with a constant load connected to it needs very few regulating components; therefore, the cost and complexity of the system can be kept small. The cost of transmission line is also sensibly reduced because the charged batteries can be easily transported from the charging station to the households [42].

11. Modular systems

Micro-hydro modular systems are combination of predesigned turbine, generator and load controllers in a single unit. A wide range of modular system is available in the market but below is a review of those that are suitable for small isolated rural loads based on cost effectiveness and applicability to South African conditions. Table 2 gives a summary of modular systems according to their manufactures, costs as well as operating ranges.

11.1. LV hydroelectric generators

They are composed of a low-voltage brushless permanent magnet generator mounted on a Harris housing with a Pelton turbine. This user-friendly unit, shown in Fig. 5, requires no adjustments and is more efficient than car alternator types over a wide range of head and flow [43]. These systems are available in 12, 24, 48 and 96 V for direct battery charging. 48 and 96 V units allow the use of small gauge wire between the generator and the battery. A charge controller can be used to efficiently step the voltage down for charging and regulating 12, 24, 48 V batteries.

11.2. HV hydroelectric generators

These technologies are ideals where water is far from the power needs (up to 3 km) or when greater power is required. High transmission voltages can be sent over a mile before being stepped down to battery voltages. These hydroelectric generators use brushless alternators for reliability and versatility (Fig. 6). They produce 110, 220, or 440 V unregulated AC which is stepped down

Fig. 8. Stream engine [49].

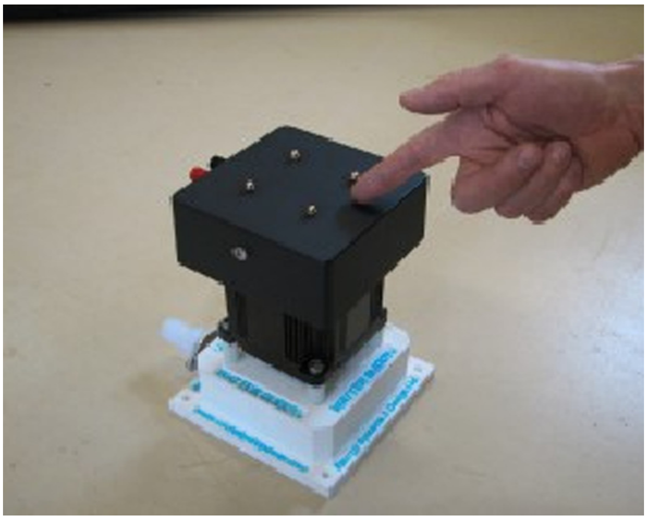

Fig. 9. Water buddy [50].

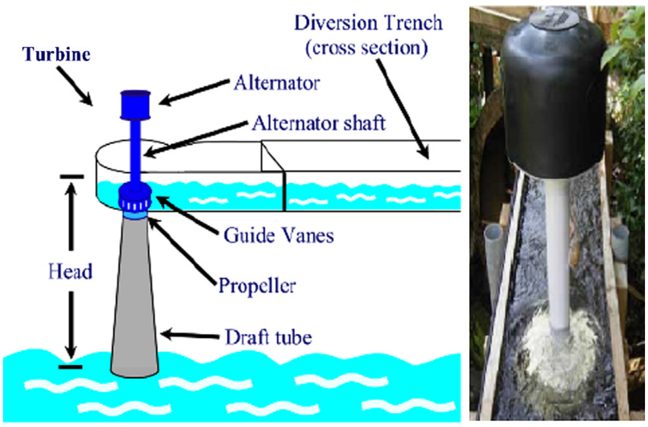

Fig. 10. Low head propeller turbine [53].

with the supplied transformer and rectifier. A diversion-type regulator is used with these units [44].

11.3. Pelton turbine

This hydroelectric system uses a Pelton wheel and a brushless permanent magnet alternator (15–30% more efficient than the

Fig. 11. Submersible turbine Underwater 100 [54].

automotive alternator). They are available in one, two or four nozzles depending on the flow and power requirements (Fig. 7). This hydroelectric system can be custom-built to match the site specifications. It is affordable to most low-income households and its installation, operation and maintenance can be easily done by the local population [45]. Similar designs are shown in the next section

11.3.1. Pelton electric set

The Peltric was developed in Nepal. It is composed of a Pelton turbine with a vertical shaft coupled directly to the induction generator [46].

11.3.2. Low-cost DC pico-Hydro system

This system was developed in Colombia. It is composed of a small Pelton wheel with a horizontal shaft coupled to a 12VDC vehicle alternator using a pulley belt [47]. Car alternator comes with a voltage regulator; therefore, money is saved by avoiding the need to spend for an additional control system. This system can also provide mechanical power for other applications.

11.3.3. Pico powerpack

The Pico powerpack (PPP) was developed at The Nottingham Trent University. It is a combination of the Pelton Electric Set and the Low-cost DC Pico-hydro system and takes advantages of the two turbines discussed above. In this design a Pelton turbine is connected directly to an induction generator mounted horizontally with an extended shaft (which can drive farming apparatus during its operation to improve the financial viability of the systems) [47]. The PPP is outfitted with capacitors and ELC for AC generation and voltage regulation.

11.4. Stream Engine

The Stream Engine employs a brushless, permanent magnet alternator which is adjustable, enabling the user to match the turbine output to the electrical load. It is equipped with a rugged bronze Turgo wheel, universal nozzles adaptable to sizes from 3 mm to 25 mm, and a digital millimeter which is used to measure output current (Fig. 8). The entire system is made of non-corrosive alloys for long life and durability. A simple change of wiring in the junction box allows this turbine to charge 12, 24 or 48 V battery systems.

A miniature version of the Stream Engine named “Water Buddy” is also available (Fig. 9). This tiny turbine is ideal for sites with good head but with very little flow.

11.5. Low head propeller turbine (LH 1000)

The LH1000 was designed for households in isolated rural areas to produce easy and inexpensive power (Fig. 10). These units have been very successful and currently thousands are installed all over the world particularly in Asia where it is called PowerPal [51].

The system uses an alternator (permanent magnet). With this design, there is no need for brushes and the maintenance that accompanies them, while the efficiency is increased. On the other hand the water turbine used is a low head propeller turbine whose small size and light weight allows it to be installed almost anywhere [52]. This enables the machine to produce power from heads of 0.5 m up to 3 m. The LH1000 is designed to operate in conjunction with battery based power systems, storing electrical power for use at times when consumption exceeds generation.

11.6. Submersible pico-Hydro turbine

The typical example of this design turbine is also known as a submersible UW 100 (Fig. 11), or Jack Rabbit pico-hydro turbine which was originally developed to Power Ocean or river scientific instruments for marine oil exploration or to recharge batteries for yachts [54]. This turbine can be suitable for remote areas because it extracts energy from any 400 mm deep stream with zero head and low flow rate. The UW 100 is a rugged low-speed alternator with high-output sealed in a waterproof housing suited to provide electricity for a typical remote home. A low price can also be achieved if it is manufactured locally.

11.7. Turgo micro-turbine

This Turgo micro-turbine is able to work under variable seasonal flows and different range of heads. These small systems are ideal for remote home-sites; for connecting to existing gravity fed irrigation systems in farms, streams or when utility power is available [55].

This turbine is available in four combinations:

- synchronous generator with direct-drive;
- synchronous generator with belt-drive;
- induction motor with direct-drive;
- induction motor with belt-drive.

Another advantage of the Turgo is that it can work efficiently at different ranges. The direct connected combination is suitable for sites from 20 to 35 m head, while the belt driven one can be used with special drive ratios matching heads ranging from 35 up to 90 m of head.

12. Conclusion

To respond to the requirements of rural and isolated areas for access to electrical power as well as to reduce the emission of pollutants within the environment, the use of renewable energy technologies is now essential for sustainable development. Micro-hydro plant has been demonstrated as the most viable renewable option for the electrification of remote communities compared to other renewable energy sources.

In this paper, the author has presented a comprehensive set of technologies increasing the viability of micro-hydropower plants for South Africa's rural electrification. Thus technologies such as low-cost penstock, micro-hydro turbines, induction generators and controllers, hydrokinetic systems, hydro aero power, battery-based systems or micro-hydro modular systems can be used to increase the cost effectiveness and applicability of micro-hydropower systems while making a significant contribution to the reduction of green house gases and other pollutants emitted in the atmosphere.

Generally, the choice of the adequate technology to be used will be determined by the site conditions, the size of the load as well as the cost of the equipments required to supply energy. From the study above, the following guidelines can be adopted:

- for head below 75 m it is better to use high density polyethylene than usual mild steel penstock, which can be used for pressures above 700 kPa. Locally made wooden penstock can also be used further to reduce the investment cost;
- PAT or propeller turbine can be an ideal choice for rural application because of the simplicity in their design as well as in their installation;
- induction generators are the best choice for low cost standalone as well as grid connected micro-hydro systems;
- for variable speed operation as well as load fluctuation, electronic load controllers can be used instead of expensive hydraulic or mechanical governors;
- hydrokinetic river turbine can be used for generating power from flowing water with zero head sites without civil works;
- hydro aeropower can be used to generate electricity from underground water using a windpump and micro-hydro turbine in areas with no flowing water;
- battery-based systems can be used as back-up systems and to supply AC and DC loads while reducing the size of the micro-hydro system as well as the distribution costs;
- a range of micro-hydro modular system is available in the market; the choice of an ideal option for a specific application depends on factors such as water head, flow, power output as well as the cost of the system.

This paper can be used as a measure to promote the application of cost-effective and reliable micro-hydropower technologies in rural area not connected to the grid and where water resource is available and exploitable.

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