STAND ALONE SMALL LEVEL POWER SYSTEMS BASED ON UTILISATION OF AGRICULTURAL RESIDUE (BENECKE SYSTEM)

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ABSTRACT

Stand alone small level power systems as a route to low investment decentralized systems with low gestation period is a worthwhile proposition which is being considered and implemented in many third world countries. When the concept of mini-grid is associated with renewable sources of energy such as solar, wind, hydro and biomass, small-decentralized power generation systems lessen the often over-dependence on fossil fuels. Fossil fuel are used at excessively and lead to warming problem due to net carbon-dioxide transfer into the atmosphere besides being a cause of unhealthy trade balance for developing countries. This paper describes a stand alone 0.5 MVA steam powered generator system, which utilizes agricultural residues as fuel. A complete technical description of the system is given. The economic and social impact of such a set-up is also given.

1. INTRODUCTION

In the Ugandan context The government's rural electrification strategy envisages reduction of inequalities in national access to electricity and the associated opportunities for increased social welfare, education health and income generating opportunities and the target is to attain 400,000 new connections over a period of 10 years. This will increase from 1% to 10% the percentage of rural households with access to electricity.

Renewable Energy Sources

Only a very small fraction of Uganda's renewable energy potential is being exploited presently. In the remote areas away from the grid, renewable energy can be provided in a very cost effective manner, mainly by using biomass, hydro and geothermal resources. Amongst the renewable energies, wind power cannot qualify for stand-alone power generation in Uganda. Its main problem is the low wind speed encountered close to the equator. Apart from areas around Lakes and Mountains, the average wind speed in Uganda doesn't reach 3.5 m/s.
Solar has two main setbacks: high initial investment costs and the natural inability of generating power at the adequate level to power motors and other heavy consumption equipment.
This leads to two other major renewable, namely mini-hydro and bio-resource. Micro-hydro can be used only where there are water discharges at acceptable heads. These are often in remote locations and it is not obvious that there are communities available to use the electricity generated.

Bio resource

The Government's Rural Electrification policy contributes to the achievement of the international goals for the containment of greenhouse gases fixed in the Kyoto-Protocol. Government will have to make maximum use of the potential of bio resource available in the country for attracting grant support from financing sources related to the Kyoto-Protocol.

Bio resource, which is essentially stored solar energy, does not suffer from the disadvantages of fuels such as diesel or coal. It is some times argued that bio resource is a weak solar energy converter (photosynthetic efficiencies – 1.5-2%). One nonetheless must keep in mind that agricultural residue is related to food production and is an almost free-of-charge fuel.
The fact that societies must have food to survive ensures the sustainability of this technology. Bio residue productivities need only to be matched to local demands in the new concept of stand-alone systems. This is entirely possible and hence bio residue option has to be given serious thought, particularly in the Ugandan context being an agro-based economy.

Utility of Bio resource based power generation in the Ugandan Context

Uganda needs to produce more food to feed its own people, the refugees the country so gracefully accommodates, and to meet the need to export food to its neighbouring countries to combat scarcity and famine in the region. The by-product of this effort will be the bio resource that will fuel the stand-alone power systems. This bio residue is already available in great quantities in Uganda.

Properties of Bio residues

Generally, bio residues have low energy[1] content, 10 - 19 MJ/kg [Mukunda *et al.*] compared to petroleum (about 45 MJ/kg). In addition, their ash and moisture contents are high. These properties are some of the challenges that restrict their use as an alternative to fossil-based fuels. The tables below summarise the properties of the common bio-residues. Table 1 gives the expected properties as quoted by different authors, while Table 2 gives the actual results of the tests carried out on samples of sawdust and coffee husks taken from Hima Cement Factory, Kasese, Uganda. The samples were tested in Sweden at Umeå University for the elemental analysis and at SGAB for a detailed analysis of the ashes. This test reflects the actual situation regarding the properties of bio residues in Uganda.

[1] This refers to the lower heating (or calorific) value of the fuel

Table 1: Properties of common biomass residues.

Residue	*LHV, MJ/kg*	*Ash content, %*
Coffee husks	16.4	11.4
Rice husks	15.5	20.5
Bagasse	18.0	3.9
Maize cob	18.9	1.5
Sawdust	18.8	1.6
Cow dung	12.8	N/A
Groundnut shells	19.7	4.4
Cotton straw	17.4	3.3

Source: *Mukunda 2001*

Table 2: Results of analytical tests on bio residue samples from Hima Cement Factory, Kasese - Uganda.

Sample	*Elemental Analysis*[1]			
	V.M[2], %	LHV[3] MJ/kg	M.C[4], %	Ash %
Coffee husks	69.4	16.44	14.1	11.4
Saw dust	80.1	18.77	58.4	1.6

Source: *Nturanabo, 2002*

[1] Analytical tests carried out at SLU, Avdelning för kemi och biomassa, Umeå, Sweden
[2] Volatile matter
[3] Effective Heating Value
[4] Moisture content

Availability and present uses of bio residues

Uganda's position as a predominantly agricultural country ensures that there is an abundance of non-woody biomass resources in form of crop residues. The major ones are maize cobs, bagasse, coffee and rice husks. Another major residue is sawdust arising out of the processing of timber.

According to a National Biomass study carried out in Uganda, every hectare of maize cultivated produces an average of 3.7 tons of agricultural residue per annum. From this figure, it can be estimated that maize crop residue amounts to 2.4 million ton per annum at present maize production of 1.2 million ton per annum. These are presently used as fuel for domestic cooking and as manure. If the national maize crop residue were to be used as fuel for the pilot project presented in this paper we could have around 90 MVA of available energy for the rural area. This amount of energy is more than 35% of the national energy production.

Statistics obtained from the 2002 census shows that approximately 64000 hectares and 11000 hectares of maize is cultivated during the first and the second seasons respectively giving rise to an average of 138,750 tons of agricultural residue at least 50 % of which can be utilized to produce electricity. All of it may not be available at specific locations where the stand-alone power system may be installed but this problem can be overcome by encouraging the farmers to enhance the area of cultivation in the specific locations.

Bagasse is being utilised on a big scale by the three sugar industries (Kakira Sugar Works, the Sugar Corporation of Uganda Limited (SCOUL) and Kinyara Sugar Works) in meeting or supplementing their internal energy requirements through the generation of combined heat and power (cogeneration). On average, 3.35 tonnes of bagasse is produced per tonne of sugar. In 1999, bagasse production was 425,238 tonnes, against 126,937 tonnes of sugar [Background to the Budget, June 2001]. Kakira Sugar Works (1985) Ltd., the biggest of the three, has a crushing capacity of 2500 tons of canes and generates 750 tons of bagasse per day and 3 MW of heat and power. SCOUL has a crushing capacity of 26,500 tons of cane per month and generates 30 MW from their bagasse. The excess 350 tons of bagasse per month is burnt out in the fields. Kinyara Sugar Works generates 1.7 MW from their internally generated bagasse (500 tons per day). The excess bagasse is burnt.

Hima Cement Factory uses coffee husks on a large scale (24 tons per day) in the *calcination* of lime. In addition, two brick and tile factories at Kajjansi (Entebbe Road) - Uganda Clays Ltd. and Kajjansi Clay & Brick Works, use 140 tons and 100 tons per month respectively, in their kilns. Other uses include making of charcoal and as manure in the coffee and banana plantations. The former use is being threatened by the emergence of the notorious coffee wilt disease. Coffee husks is available from over 500 coffee factories in Uganda. Coffee exports presently stand at 3 million bags (180,000 tons) [Background to the Budget, June 2001], ensuring plentiful supply of coffee husks as a bio residue.

Sawdust has been used as a fuel for improved cooking stoves, but due to the slow pace of dissemination of the technology, the utilisation is still very low, almost negligible. There has been an attempt by Hima Cement Factory to use sawdust alternately with coffee husks (sampled in Table 2), but handling and high moisture content have hampered the process. On a small scale, sawdust is used in brick making, but again the technology is yet to gain acceptance by the local construction firms. It is estimated that there are over 70 sawmills located in various forests. These, together with urban timber workshops yield about 500 m^3 of sawdust per year.

Rice husks is produced at small mills as well as at the major rice scheme at Kibimba (Tilda Limited), which is presently generating over 10,000 tons of rice husks per annum working at 80% of their installed capacity. The Olweny Swamp Rice Irrigation Project (OSRIP) with a production capacity of 500 tons of rice per annum converts to about 100 tons of husks per annum. There are also many rice mills in Uganda, most of which are found in the Eastern Region, with over 20 mills in Mbale town alone. These produce about 150 tons of husks per annum. In Kaliro town and the surroundings, a further 100 tons per annum is produced. The major rice schemes are presently transporting the husks to the fields and burning them there to improve on the soil nutrients. The small milling companies on the other hand do not have fields where to dispose of the husks since they deal only in processing. As a result, small mountains of husks have emerged in the neighbourhood of the rice mills, posing serious environmental problems and consuming space that could be used for development. Fine husk, which comes out during the last polishing stage, is used as an ingredient in chicken feed. The utilisation is low and mainly at an experimental level. Other uses cited include manufacture of ceiling boards.

Table 3: Availability of bio-residues

Residue	**Availability**	**Remarks**
Coffee husks	280,000 tons p.a	12,000 tons p.a commercially used
Rice husks	10,350 tons p.a	Mainly in Eastern Uganda. No commercial use. Costs of disposal
Cow dung	30,000 tons p.a	Against a population of 36,432 cattle
Saw dust	500 m^3 p.a	No commercial value. Disposal costs
Bagasse	425,000 tons p.a	About half is not utilised

***Source:** Background to the Budget, June 2001*

Figure 1 shows a map of Uganda with the location of the main agricultural residue producers.

2.PILOT PROJECT

This paper considers regions of Uganda which are far from the national grid, and where there exist high potential for utilizing bio resource for production of cheap electricity.

Figure 1 – Main Agricultural Residue Sources

Some factors such as:

a) Exponential growth of energy consumption
b) Fast depletion of fossil fuels
c) The lack of purchasing power
d) The lagging development of new energy resources and technologies
e) Growing public and institutional demand for energy and material conservation and environmental protection has called for the development of a more rational plane for energy economy.

The project envisaged for low cost stand-alone power generation in this proposal is based on production of electricity using steam boilers that will drive the two steam turbines connected to the shaft of two 250 kVA generators

Table 4: Approximate Bio residue requirements for numbers of hours of machine operation to produce 0.5 MVA

No. of hours Operation/day	Total Steam Requirement (kg per day)	Bio residue Requirement (metric tones/day)	Annual bio residue requirement (metric tones)	Area of maize to be cultivated (hectares)	No. of farmers to be engaged in cultivation @ 2 acre per head
6	36000	9	3285	888	1097
8	48000	12	4344	1184	1463
10	60000	15	5475	1480	1829
12	72000	18	6570	1776	2194
14	84000	21	7665	2072	2560
16	96000	24	8760	2368	2926
18	108000	27	9855	2664	3292
20	120000	30	10950	2960	3657
22	132000	33	12045	3256	4023
24	144000	36	13140	3552	4388

Features of the machinery
The machinery consists of a boiler, type CCB-350, capable of producing 7000 kg of steam per hour fuelled by agricultural residues (such as maize cobs) and fed through a silo and a feeding system to the furnace/boiler. The water required for the boiler, which will be drawn from swamps/rivers, will be pre-treated by passing through a 200 litre capacity chemical tank for chemical treatment to avoid erosion of the turbine blades and rust in the boiler tubes. The steam drives two Benecke MVB 300 Steam turbines, attached to two generators each producing 250 kVA.

The compact fume-pipe boiler type CCB-300 with water-pipe pre furnace is a versatile boiler, which has a maximum, permitted working pressure of 16 bars. It can work with most biomass such as wood chips, rice husks etc at a maximum fuel moisture content of 55%. The boiler is supplied with an automatic water feeder system, exhauster for gas exhaust, primary air fan electric control panel, multi cyclone filter, chimney, air pre heater, cast iron mobile grates with hydraulic drive, negative pressure control of the furnace, automatic ash extraction facility, semi automatic bottom discharge, automatic fuel feeding, all electric controls by means of PLC and the suppliers will also provide a chemical treatment system attached to the boiler for treatment of the inlet water.

A turbine/generator MVB-300 will need 1500 kg of fuel to produce 3000 kg of steam. Two such engines will be needed to produce 0.5 MVA.
Table 4 gives the requirement of bio residue for the system at various levels of operation

3. APPROXIMATE NUMBER OF HOUSEHOLDS OR OTHER LOADS THAT CAN BE SERVED WITH 0.5 MVA POWER THROUGHOUT THE YEAR

Category 1:
14076 Households with the lowest level of consumption: 3 Lights 8 watts (compact fluorescent lamps) + one radio x 10 Watts for four hours a day

Category 2:
6493 Households with small loads I.e. 4 x 8 Watts lights (compact fluorescent lamps) for 4 hours, + one radio at 10 Watts for 6 hours, + 1 black and white TV at 35 Watts for 4 hours.

Category 3:
588 Households with 10 x 8 Watts lights (compact fluorescent lamps) for 4 hours, + one radio at 10 Watts for 6 hours, + 1 colour TV at 100 Watts for 4 hours + one computer at 500 Watts for one hour + 1 Fridge at 120 Watts for 8 hours + 1 VHF radio at 40 Watts for 1 hour

Approximate Number of hospitals with 20 beds that can be powered at an average consumption rate of about 10 kW (10 units/hour) per hospital = 40

Approximate Number of schools and dormitories with 250 students that can be powered at an average consumption rate of about 10 kW (10 units/hour) per dormitory = 40

Approximate Number of maize mills that can be powered by .5 mega watts generator at 25 hp (20 kW = 20 units/hour) per mill = 16

Approximate Number of water pumps at 5 horse power (4 kW- 4 units/hour) per pump that can be run by a .5 MVA power generator = 100.

If a fair combination of all these facilities can be worked out, a 0.5 MVA generator (producing 400,000 units of power per hour-power factor 0.8 inductive) can provide a lot of facilities to a community of 9000 farming families (approximate population of 54,000 souls).

The only cost that is involved in obtaining the fuel for the system is the transportation of the bioresidue from the maize fields to the power station. This is negligible and is worked out under the heading ‘operational costs’ of this proposal.

Power Distribution
Although power distribution does not form part of this study, it is suggested that the most economic method of transmission and distribution of power in the rural area using a stand-alone power generation system as envisaged above will be as follows:

The power generated by the **Benecke** system is stepped up to 19.05 KV using a step up transformer at the powerhouse and then transmitted over a SWER (Single Wire Earth Return) system to the consumers, then stepped down to 415 Volts 3 phase system (using an autotransformer and electronic switching device). This will be the most economic system of transmission and distribution. This forms a stand-alone mini-grid.

4. ENVIRONMENTAL CONSIDERATION

The water discharged from the boiler after use will not be potable any longer basically due to high temperature and small grease content. It should be treated before allowing it into any water body. Making use of small open lagoons for close cycle cooling is the best way of treating this discharged water. There is also the possibility of re-cycling this water to reduce costs on the eventuality of having to pay for this water.

The ash, which will be produced by burning the bio-residue fuel in the boiler, can be used for various purposes: manure, additive in brick making etc. There is no hazard to human health produced by this residual ash. Workers nonetheless should be protected by using gloves and masks against the dust.

The smoke produced by the boiler will be negligible and will be filtered (there is provision for installation of a multi-cyclone filter to minimize the concentration of pollutants before entering the atmosphere).

Environmental Impact Assessment will be mandatory for this project like any other project and a clearance certificate will have to be obtained from the National Environmental Management Authority

5. SOCIO ECONOMIC BENEFITS OF THE PROJECT

1. Provides direct employment to 9000 farming families in producing the required bio residue for fuel.
2. Provides direct employment to at least 10 workers to handle the bio residue and in processing the same
3. Directly enhances the income of the rural population by increasing agricultural production
4. Improves the standard of living by providing electricity to the community which can be used for lighting homes, schools, hospitals and other community based institutions and powering small scale industries
5. Indirectly enhances the economic and commercial activities in the region
6. The provision of electricity for lighting improves the academic performance of rural schools by availing the students with study sections at night. Most of the students work in the fields after school hours.

6. CONCLUSIONS

The system is flexible in that the number and size of steam machines to generate power can be determined according to demand, availability of bio residue and the required number of hours of operation of the plant.
As mentioned earlier the fuel cost is quite low for it consists in basically transport of the bio-residue to the furnace.
Fuel can be made available wherever the plant has to be installed, need not to be imported or transported over long distances.
The system is horizontally integrated with community development i.e. food production, improving the living conditions of the community served by the system by providing additional income and industrial development opportunities
There is enormous opportunity for development of the system in the wake of the depleting fossil fuel reserves, the need for electric power in the Ugandan rural area and the support the World Bank is giving this initiative. Uganda right now could be said to have electricity only in the South. Half of the country doesn't have access to the main grid nor have any sensible off-grid power project in operation.
Besides, there is hardly competition from any alternative system of power generation. As a matter of fact the cost of the KWh for this project is Ush 40 (2 cents of a dollar) while the KWh served by the utility costs Ush 180 (9.5 cents of a dollar).
This project can be replicated wherever agricultural residue is available. Its robustness makes maintenance negligible (one day per year, according to the manufacturers).

7. REFERENCES

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8. AUTHOR(S)

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