DOMESTIC USE OF ELECTRICAL ENERGY FROM WIND ENERGY IN BOTSWANA

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This paper presents an examination of the possibility of using wind turbines generating electricity for households in the remote rural areas of Botswana.

On the basis of theoretical consideration of the wind system generating electricity, and the power demands of a typical Botswana rural household, some types of possible advanced systems are recommended. Comparative information is given about the costs of solar (photovoltaic) and wind power systems.

From an analysis of the magnitude and the distribution of the wind in Botswana, conclusions are made about the areas where the wind system for electricity generation could be used during the whole or part of the year.

1. INTRODUCTION

Renewable energy supplies are very important for rural areas with a small population, spread over the country as in Botswana.

Power extracted from the wind can be used principally for water pumping and electricity generation. In the case of electricity generation the wind turbine - generator system compared to water pumping is simpler and cheaper.

Because the wind is not constant the generated energy varies. That is why batteries are charged by the generator to maintain a constant power for use.

In this article consideration will be given to the possibility of domestic use of wind powered electricity-generating machines in Botswana.

2. THEORETICAL BASIS OF THE CONVERSION OF WIND POWER INTO ELECTRICAL ENERGY.

The theory and the design of a wind turbine and electrical generator system involve mechanical and electrical considerations. In order to make the system highly effective, the sizing of the turbine and the generator must be done simultaneously. This is the only guarantee that the two components of the electricity generating system will be coupled together successfully.

The kinetic energy per unit mass of an air stream is:

$$KE = \frac{1}{2} v^2 \quad [J/kg] \qquad (1)$$

The mass flow rate of the air flowing through unity cross-sectoinal area is:

$$m = \rho\, v \quad [kg/s\, m^2] \qquad (2)$$

In the above equations, v (m/s) is the velocity of the air and ρ (kg/m^3) is the density of the air.

The theoretical power of the wind determined per area of $1 m^2$ will be equal to the product of eq.(1) and (2):

$$P_{wind} = \frac{1}{2} \rho v^3 \quad [W/m^2] \qquad (3)$$

In fact, it is not possible to profit more then 59 % of the above theoretical power. Usually only about 20 to 40% of this power is available in practice [1].

The efficiency of the power extraction decreases when:
-the blades of the wind turbine are so close together, or they rotate so rapidly that a following blade moves into the turbulent air created by the preceding blade
- the blades are so far apart or rotate so slowly that much of the air passes through the swept cross-section of the turbine without interfering with the blade.

It is therefore important to match the rotational frequency of the turbine with particular wind speed so that optimum efficiency is obtained.

The power extraction is a function of the time T_b, taken by one blade to move into the position previously occupied by the preceding blade, as compared with time T_w between the disturbed wind moving past that position on the normal air-stream becoming reestablished.

If a turbine has n blades and rotates with ω angular velocity, the angle swept between two blades in time T_b will be:

$$2\pi/n = T_b\, \omega \qquad (4)$$

Meanwhile, the disturbed wind will pass a distance:

$$d = T_w v \qquad (5)$$

where the distance d is a measure of the length of the perturbed airstream upwind and downwind of the blades .

Maximum power extraction will occur when $T_b = T_w$ at the blade tips. Then from eq (4) ~~and~~ (5) will follow:

$$2\pi/n\omega = d/v$$

or

$$2\pi/d = n(\omega/v) \qquad (6)$$

If the equation (6) is multiplied by the blade tip radius R then:

$$2\pi(R/d) = n(\omega R/v)$$

or

$$2\pi(R/nd) = R\,(\omega/v) \qquad (7)$$

where the right hand side member is equal to the peripheral velocity of tip over the speed of the oncoming wind and will be termed λ.

From eq. (7) follows :

$$\lambda = R\omega/v = (2\pi/n)(R/d) \quad (8)$$

Practical results show that $d = 0.55R$ [1] whence

$$\lambda \cong 4\pi/n \qquad (9)$$

Equations (8) and (9) above are important when matching wind turbines with electrical generators. From a mechanical point of view the generator must be small in size, without transmission between itself and the turbine. For speed of rotation say 300 to 600 revolutions per minute and a usual speed of the wind of some couple of meters per second, the power available after the turbine will be in the order of hundreds of watts (see Table 1) .

From electrical point of view, a small generator will produce low power at low speed of rotation but will be cheap.

The Power developed by the electrical generator is defined as the product of the work done per revolution by the number of revolutions per second. Therefore the work done per revolution is

$$W = P\,(kW) / N\,(rev/s) \qquad (10)$$

It can be shown, as in [2] that the work absorbed per revolution by the generator is equal to:

$$P(kW) / N(rev/min) = D^2\, l\, (\pi^2/60 \times q \times B_{av} \times 10^{-11}) = C_0 \times D^2\, l \qquad (11)$$

where: P (kW) is the power developed by the generator, N (rev/min) is the speed of rotation of the generator , D (cm) is the rotor diameter , l (cm) is the rotor length;
C_0 is a coefficient called "output coefficient" , q and B_{av} are specific electric and magnetic loading constants respectively.
The "output coefficient " for direct current machines is given in graphs as a function of the output energy (kW min/rev) [Fig .1]

We will use a practical case to illustrate the above method.
For a speed of a wind of 5m/s, the power generated by a 2- blade wheel with a radius of 2m and efficiency of the wind energy conversion of 30%, is 300W. At a speed of rotation of 150rev/min the DC Generator coupled directly to the wind turbine, will have approximate dimensions of 15cm length and 10cm diameter.(Table1, case 3).This system will not be expensive and would satisfy the requirements of a rural household (Table 4) .

Table 1 gives 12 practical cases of application of the above method. In the same table is shown how wind turbines and generators are calculated together.

3 SURFACE WINDS IN BOTSWANA

On the basis of the theory of wind powered electrical generation two questions are arising: What are the winds in Botswana and are they sufficient to satisfy the reqirements for electrical power of a typical rural household of Botswana.

Characteristics of Botswana wind are given in Tables 2 and 3 .

Table 2 shows the Mean Monthly Wind Speeds in m/s for Gaborone, Mahalapye, Fransistown , Maun , Shakawe , Ghanzi and Tshane areas measured at 5m over the ground.

Table 3 gives the average annual value of the winds in m/s at 2m, 5m and 10m heights for the same places.

The values in Table 2 and Table 3 are calculated using the empirical formula [1]:

$$v_2 = v_1\,(h_2/\,h_1)^{0.28} \qquad (12)$$

where v_1 and v_2 are wind speeds at heights of h_1 and h_2 respectively.

Analysing Table 2 and Table 3 , a general conclusion could be made , that the winds in Botswana are not strong.

Nevertheless, by connecting batteries to the turbine-electric generator system small electric energy can be stored through twenty four hours, and then supplied for lighting , refrigerators , TV sets , radio and any appliances which need to be powered only for couple of hours . On the other side, in some cases at strong winds, few hours only are enough for charging the battery.

4. ELECTRIC POWER REQUIRED BY A RURAL, HOUSEHOLD IN BOTSWANA.

In Table 4 below is given some information about the electrical power requirements for a typical rural household in Botswana.

Table 4

TV set - 90 Watts
Radio - 45 Watts
Neon light - 45 Watts (3 x 15W)

It is logical that all devises in the table will not work simultaneously. A mean value of about 105W will be consumed when the TV set is working with one neon light switched on, as example through 3 - 4 hours in the evening and an energy of about 300 Wh to 400 Wh will be consumed. This requires a work of the turbine generator system for charging the batteries as follow from Table 1: for case 2 through about 4 hours, for case 3 - through 1hour, for case 4 - 10 min.

5. POWER PRODUCED AND CONDITIONS OF WORK OF SOME WIND TURBINE - ELECTRIC GENERATOR SYSTEMS

Here will be shown advanced Wind Power Systems, produced by Companies with outstanding experience in the area of wind turbine generators design and exploitation [4] , [5] .

Wind Turbine Generator WTG250 is produced by NAPS, Finland. This machine is suitable for charging of small to medium size battery. It starts the charging of the battery at a speed of the wind of 2.2m/s.
Wind Turbine Generator WTG50 produced by NAPS too, is suitable for small batteries: The charging of the battery starts at a speed of the wind of 1.8 m/s.

Both, WTG250 and WTG50 produce 250W and 50W respectively at a speed of the wind of 9.83m/s. They have small dimensions with diameter of the wheel of 1.83m and 0.91m respectively .The two machines can be mounted on a mast of standard 90mm outer diameter water pipe , with 4 or 8 guy wires. Both machines are gale protected.

Another Wind Wheel System is LJ3600 produced by BJ - Steel, Denmark. This is a multipurpose Wind Turbine. It is suitable for water pumping and battery charging. The diameter of the bladed wheel is 3600mm and the height of the tower is 9500mm. This machine produces up to1.5kW at 8m/s wind speed. The start - up is at about 4.5m/s wind speed.

In Table 1 are given some practical cases according to which wind systems may be projected or chosen.

6. CONCLUSIONS

Using the data given in Tables 2 and 3, and the characteristics of the above wind turbine generator systems, the following conclusions can be done:

In Table 2 the monthly wind speeds which can be used for electricity generation must be bigger than 1.8m/s. This criteria of the wind speed is that at which the WTG50 starts the charging of the batteries. In Table 3 the mean annual wind speeds at 5m over ground is used which we consider reasonable from technical and economical point of view.

In Gaborone region WTG50 and WTG 250 can be used at a height of 5m over the ground, through the months August , September , October and November.

In Mahalapye region there are no suitable conditions for electricity generation using the suggested above machines.

In Francistown region, the Wind Power System can be used during the whole year , except May and June , at a height of 5m over the ground. Suitable systems are as WTG250 and WTG50.

Maun - the wind is suitable during the whole year . The systems as WTG250 and WTG50 can be used at 5m height.

Shakawe:- no suitable conditions.

Ghanzi - suitable time is from January up to April (incl.) and from August to December (incl.).

Tshane - the winds are suitable during Jan - Apr. and Aug.- Dec.

For all the regions above use of systems similar to WTG250 and WTG50 is possible.

Some information about monthly and daily variation of the winds at Sua-Pan Synoptic station as example ,is available in the Department of Meteorological Services in Gaborone. From this information could be concluded, that during some days, the wind reaches a speed of more than 2.25m/s and lasts from 0 to 5 hours, while during the other hours the wind speed is only about 1.5m/s. This is to support the idea that some small periods could charge batteries for further use even in areas with low winds.

Finally we can state, that the use of Electricity Generating Wind Systems is possible in many regions of Botswana. There will be a profit when small, advanced and cheap systems are used.

Some comparison could be done to the solar power systems. In Botswana the solar power is well developed but it is surprising that the wind power is not so popular.

The cost of a 50W solar panel is P1200 and with controller (P415) , stand (P95) , inverter (P565) and battery (P415) the total price will reach P2690. (Information taken from Sunkist Botswana). At 200 watts, the system will cost about P 6290 (4 panels cost 4800 plus the other installation parts).

The wind systems WTG 50 and WTG 250 cost less than P 4000 (imported price).From Table 1 can be seen that turbines producing 70 to 300 W power at 5 m/s wind speed (cases 2 and 3) and turbines producing 150 to 600 W at 10 m/s wind speed will have generators with sizes of about 15 cm. length and 10 cm. diameter. These small direct current generators could cost not more than P 1000.The turbines with plastic blades and simple locally available water pipe support must cost not more than P 800. With regulator of say P 400, battery of P 400 and inverter of P 500,the total cost will be of about P 3000.

A very new USA made WTG -" Air Wind" [6] at wind speeds of 3 to 11,2 m/s is producing up to 200 W (at 12.5m/s - 300 W). Its imported price is 1200 USD (about P 4000).

The authors consider that if a production of WTG systems could be organised in Botswana, it is very probably that the machines producing 100 - 200 W will cost less than P 2000 to 3000.

The world practice shows that the wind machinery producing electricity is cheaper than the solar facilities producing electrical power.

The authors could suggest that it will be useful if some authority, as example the Ministry of Works and Communication of Botswana, buys some different, advanced, small and easy mountable WTG systems and distribute them to the meteorological stations of the country. The energy generated must be measured during a period of one year at least. The results will show how much the use of the wind energy in Botswana is efficient and suitable for domestic use in the rural areas of the country.

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8. REFERENCES

1. J.Twidell , A.Weir, "Renewable energy resources" . ELBS – 1987, Great Britain, Cambridge.

2. Albert E. Clayton , "The performance and design of direct current machines" Second Edition , London , Pitman & Sons LTD, 1949.

3. Y.P.R. Bhalotra ,"Climate of Botswana" , Part II Department of meteorological Services , 1987 .

4. NESTE (Advanced Power Systems) , Product Information (Specifications and Performance).
   Wind Turbine Generator WTG250
   Wind Turbine Generator WTG50
   NAPS (Finland, Sweden, Norway, Denmark, UK, France, Kenya, Singapore, Hong Kong)

5. LJ3600 , " Wind Wheel System" BJ - Steel , Denmark. Prospectus.

6. Air - Wind, Electricity generating wind Turbine generator systems. Prospectus.

TABLE 1. CALCULATIONS OF WIND TURBINES AND ELECTRIC GENERATORS AT CHOSEN WINDS

Case No	Velocity of the wind V[m/s]	Radius of the wheel R [m]	Number of blades n and $\lambda = 4\pi/n$	Angular velocity ω [rad/s]	Rotational velocity N [rev/min]	Produced power = $1/2 x \rho x V^3 x$ $\pi d^2/4 x 0.3$ [W]	Work done per revolution . P/N [kw.min /rev]	Output coe fficientCo= P[kw]/N[rev/min]x10^6 /D^2l	(Rotor $D)^2$ x (Rotor l) $D^2l[m^3]$	D [cm]	l [cm]
1	2	3	4	5	6	7	8	9	10	11	12
1	5	0.5	n=2,λ=6.28	62.8	600	20	0.033/1000	small			15
2	5	1.0	"	31.4	300	77	0.257/1000	small			"
3	5	2.0	"	15.7	150	307	2.05/1000	1.2	1667	10.54	
4	5	5.0	"	6.28	60	1920	32/1000	2.4	13333	29.8	"
5	10	0.5	"	125.6	1194	153	0.128/1000	small			"
6	10	1.0	"	62.8	600	612	1.02/1000	1.1	909	7.78	"
7	10	2.0	"	31.4	300	2450	8.167/1000	1.75	4571	17.46	"
8	10	5.0	"	12.56	120	15307	127/1000	3.2	39687	51.44	"
9	10	0.5	n=3,λ=4,19	83.8	800	153	0.19/1000	small			"
10	10	1.0	"	41.9	400	612	1.53/1000	1.5	1020	8.25	"
11	10	2.0	"	20.95	200	2449	40.82/1000	2.5	16328	33	"
12	10	5.0	"	8.38	80	15307	191.3/1000	3.4	56175	61.2	"

TABLE 2. MEAN MONTHLY WIND SPEED [m/s] AT 5 m OVER GROUND

TOWN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
GABORONE	1.62	1.47	1.47	1.26	1.15	1.24	1.26	1.81	1.81	2.1	2.2	1.71	1.6
MAHALAPYE	1.1	1.0	0.86	0.7	0.68	0.7	0.8	1.07	1.37	1.58	1.47	1.3	1.06
FRANCISTOWN	2.51	2.47	2.37	2.03	1.76	1.76	1.89	2.27	2.83	3.23	2.83	2.47	2.37
MAUN	2.14	2.14	2.14	2.02	1.97	2.03	2.2	2.47	2.83	3.13	2.73	2.45	2.38
SHAKAWE	1.0	1.0	1.07	0.86	0.86	0.76	0.7	0.8	0.86	1.05	0.94	1.05	0.89
GHANZI	2.4	2.2	2.02	1.81	1.76	1.76	1.88	2.22	2.64	2.9	2.83	2.59	2.24
TSHANE	2.47	2.27	2.08	1.83	1.7	1.76	1.76	2.08	2.4	2.65	2.64	2.54	2.17

TABLE 3. MEAN ANNUAL WIND SPEED [m/s]

GABORONE(1958 - 85)	
AT 2m HEIGHT	1.22
" 5 "	1.58
" 10 "	1.94
MAHALAPAYE(1958 - 85)	
AT 2m HEIGHT	0.83
" 5 "	1.07
" 10 "	1.3
FRANCISTOWN (1958 – 85)	
AT 2m HEIGHT	1.83
" 5 "	2.40
" 10 "	2.89
MAUN(1967 - 85)	
AT 2m HEIGHT	1.83
" 5 "	2.40
" 10 "	2.89
SHAKAWE(1960 - 85)	
AT 2m HEIGHT	0.69
" 5 "	0.89
" 10 "	1.08
GANZI(1959 - 85)	
AT 2m HEIGHT	1.75
" 5 "	2.25
" 10 "	2.77
TSHANE(1959 - 85)	
AT 2m HEIGHT	1.69
" 5 "	2.18
" 10 "	2.64