Nollie se Kloof

Renewable Energy Solutions for Off-Grid Guest Houses and Farms

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Summary

Nollie se Kloof is a guest farm in the Ceres district which is not connected to the national electricity grid. In December 2005 the owner has installed a hybrid renewable electricity supply system comprising: a 1000 W micro hydro turbine; 720 Wp photo voltaic array and a 1000 W wind turbine in a 36 V system. A battery bank stores the electric energy. The 2V cells are rated at 726 Ah @ C_{10} HR. The average daily electricity generation is estimated to be 15.7 kWh per day.

The system is sufficient to supply the guest house that sleeps 16 people with the following electric equipment: electric kettle, fridge, freezer, microwave, TV, HiFi and various lights. The total system initial cost was R121,600 including installation.

The system has been working well since its installation. A few suggestions listed in this report, however, could optimize the output from the system.

A micro-hydro power installation, when viable at the site, is a very attractive option for off grid installations, technically and economically.

Introduction and background

The guest house started as a camping place of the current farmer and his family. Cooking was done on an open fire. Later a small ablution facility was built that used gas for warm water and cooking.

A guest house was build on site and in June 2005 the current wind turbine, solar panels and battery bank were installed along with a 2 kW inverter to provide electricity. This installation proved to be insufficient to provide in the electricity needs of the quest house.

In December 2005 a micro-hydro turbine was added to the system and the 2 kW inverter was replaced with a 6 kW inverter. The new system works well and is sufficient to supply the guest house that sleeps 16 people with the following electric equipment: electric kettle, fridge, freezer, microwave, TV, HiFi and various lights.

Objectives

The main aim of the project was to:

- Establish the amount of electric power which each renewable source (wind, solar PV and micro hydro) delivers. Due to the once off visit to the installation only predictions on the energy production (based on info supplied by the owner) will be given.
- The technical viability of each renewable solution for this specific location.
- To identify any methods to improve the system

Methodology

The output of each renewable installation (solar, wind, hydro) was measured and compared to data-sheets supplied by the manufacturers during a once-off site visit. The owner supplied hardcopies of the data-sheets for each electrical equipment. Weblinks to these datasheets are listed in Appendix C.

End-users and end-user area targeted by the project are people living, working and farming at locations that are not connected to the national electricity grid. This case study would form a guide for other similar installations of sustainable off-grid living

Installation

The guest house is located in a gorge (figure A.1 and A.2) about 10 m South of a river that runs in a West-to-East direction (figure 1 and 2). Adjacent to the guest house is a small control room (figure A.5) which houses the batteries, inverter and other electrical equipment.

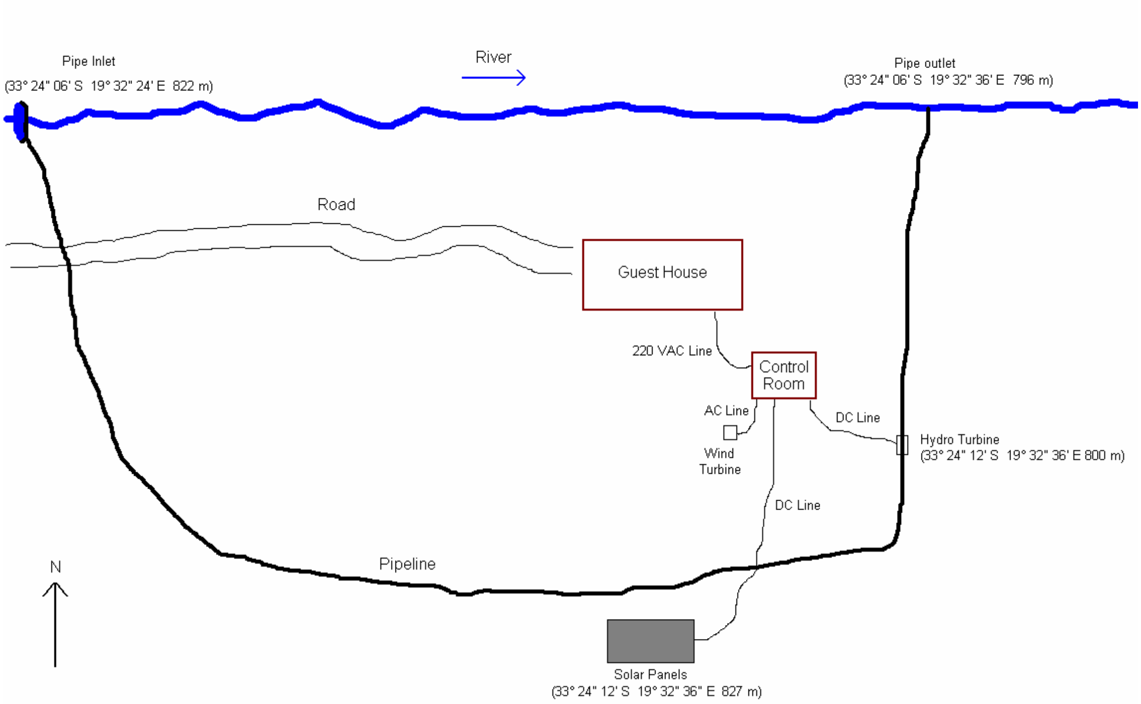

Figure 1: Site Layout

Figure 2: Photo of the guest house taken from solar panels

The electrical layout of the hybrid system is presented in figure 3. The wind turbine, hydro turbine and solar panels are connected to the 36 VDC bus bar. A 3 phase line runs between the wind turbine and the control room and is converted to DC by a diode bridge before it is fed into the 36 VDC bus bar. A 54 VDC line runs between the solar panels and the control room. A MTTP (maximum power point tracking) unit interfaces the solar panels with the 36 VDC bus bar. The alternating current that is produced by the micro-hydro turbine is converted to DC before it runs to the control room.

The batteries are charged from the bus bar. 18 batteries of 2 V each are connected in series. They are rated at 762 Ah @ C_{10} HR or 876 Ah @ C_{100} HR. When the batteries are fully charged, the dump load rejects the excess power into a resistive load. A 6kVA inverter converts the 36 VDC to 220 VAC single phase to be used in the guest house.

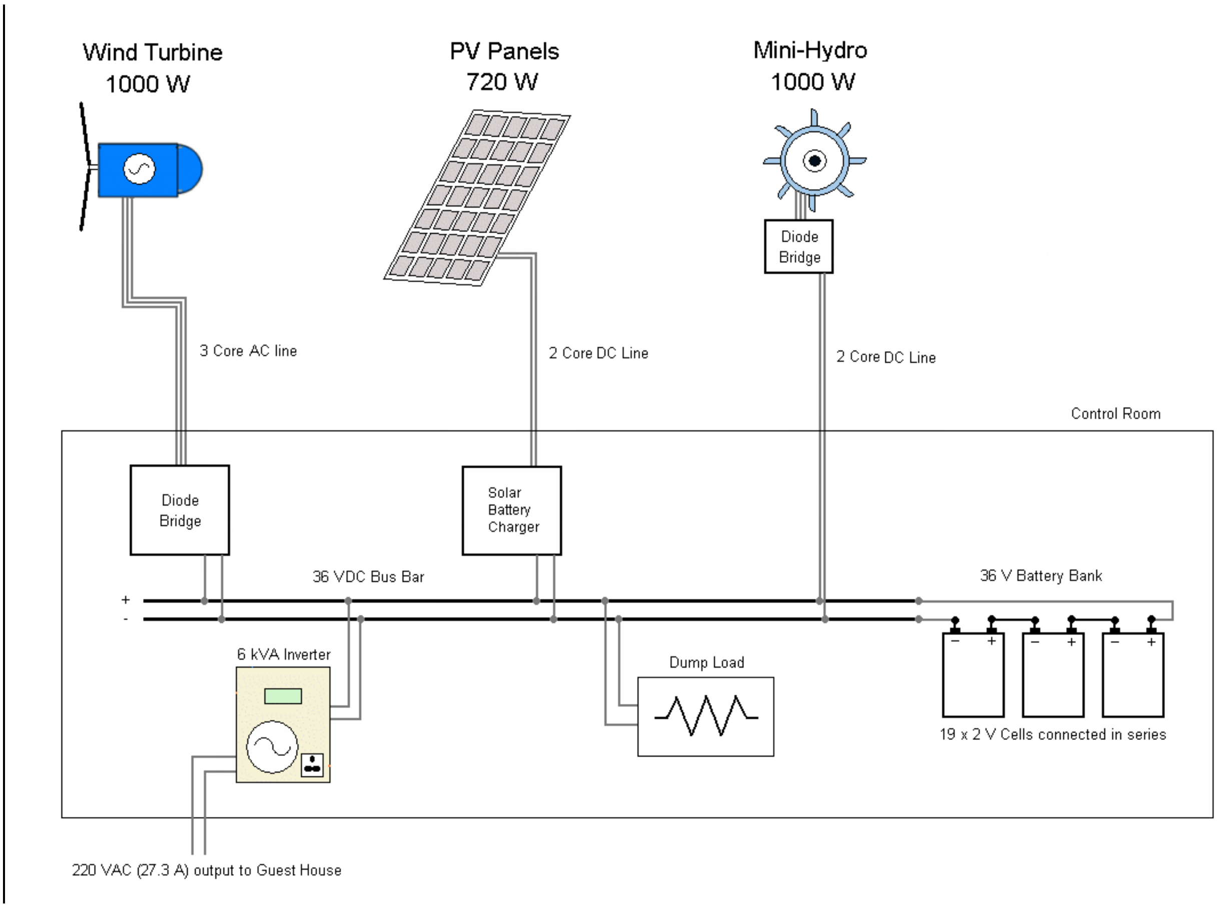

Figure 3: Hybrid System Electric Layout

The project relied on data which was collected during a once-off site visit. Further information was supplied by the owner prior, during and after the visit through email and fax communication. Each component on the system will be discussed. Refer to Appendix B for the power production guidelines for each installation.

Solar

Crystalline solar PV panels are a mature technology. These panels were installed due to the general abundance of this renewable energy source in South Africa.

The guest house is at the bottom of a gorge near the river. In winter months, the mountain on the Northern side of the guest house casts a shadow in the gorge and on the guest house (figure A.1 and A.2). To increase the amount of sunlight hours on the solar panels, they were installed about 120 m up the slope directly South of the guest house.

Four Sanyo 54 Vp and 180 Wp panels are connected in parallel (figure A.4). The panels are stationary and do not track the sun. They face due North and have a rated module efficiency of 15.3 %. The altitude angle (angle of tilt from the horizon) can, however, be adjusted (figure A.4). Currently the altitude angle is about 50° and the panels are not tilted or adjusted through the year.

A MTTP (maximum power point tracking) unit from Blue Sky is used as an interface between the solar panels and batteries. This unit ensures the batteries are charges at the correct voltage and converts addition voltage (difference between PV output and battery charge voltage) to current in order to maximise the power output from the panel.

A 120 m long DC cable runs between the solar panels and control room. This cable has four cores (each 10 mm^2) of which only two is utilised. The resistive losses in this cable could not be accurately established during the site visit.

Solar panels are generally considered to be maintenance free. The only maintenance is an occasional cleaning of the panels with water. Solar panel efficiencies decrease when the panel temperature rises.

Hydro

A nearby water stream has been harnessed using a small hydro turbine (Stream Engine – 1000W). The advantage of this turbine is that is operates continuously while there is sufficient flow. The flow rate of the river is unknown and according the owner this perennial stream has its lowest flow in February each year.

The turbine uses a permanent magnet brushless alternator. This alternator can produce voltages at 12, 24 or 48 VAC. The AC output is converted to DC before it is fed to the control room. This turbine has the additional option of a 110 VAC or 220 VAC output if the distance between the turbine and batteries is long.

Since the hydro turbine was installed when the 36 V system was already in place, a Stream Engine with 36 V output was especially reconfigured for this installation.

The vertical height between the turbine inlet and outlet was determined to be approximately 26 m (provided by the owner (using a dumpy level) and confirmed during the site visit by using a GPS). The water flow rate through the turbine could be varied by a valve upstream of the turbine (figure A.8).

Two different flow rates were investigated.
-At a flow rate of 5.2 L/s the output of the turbine was 180 W.
-At a flow rate of 6.8 L/s the turbine output was 360 W.
In both these cases the turbine is only producing about 30% and 45% respectively of the expected output suggested by the suppliers. During the site visit the Stream Engine was not run at its peak capacity. During installation an output of 540 W was achieved.

The Stream Engine has sealed bearings. A set of three similar Stream Engines has been running on a guest lodge at De Vlugt (located on the Prince Alfred Pass between Uniondale and Knysna). These turbines have been running for about seven years without replacing the bearings or any other major maintenance. According to the owner, Ingo Vennemann, he weekly cleans the impeller of any dry leaves and monthly cleans the pipes from any algae or blockages.

Wind

The wind turbine (Whisper 200, figure A.6) is designed to operate at low to moderate wind speeds of 3.6 m/s and greater. It can produce up to 1000 W (at wind speeds of 11.6 m/s) and the blade diameter is 3.1 m. The permanent magnet brushless alternator can produce a 3 phase current at 12, 24, 36 or 48 V. This turbine is rated by the suppliers as a 6.8 kWh per day (equivalent to 283 W for 24 hours) turbine at a rated wind speed of 5.3 m/s.

During a test, an average wind speed of 3.5 m/s was measured using a cup-anemometer at a height of 2 m above the ground. The corresponding output from the turbine was 4.5 A at 36 V (162 W). This power output is higher than given by the supplier and should only be produced by winds of 6.8 m/s. The reason for this difference in actual and predicted wind speeds could be attributed to the wind speed being higher at the turbine hub level. The turbine hub is located on a pole 7 m above the ground. Wind speeds are commonly lower closer to ground level due to surface drag. The wind regime at higher elevations is also smoother and therefore more productive.

A wind measurement at 2m above ground level therefore proved to be not very useful for assessing the performance of the wind turbine.

According the manufacturers, the side-furling Angle-Governor, exclusive to the range of Whisper turbines, protects the turbine in high winds by turning the alternator and blades out of the wind, reducing turbine exposure (figure 4). Unlike other wind turbines that lose as much as 80% of their output when furled, the Angle-Governor allows the Whisper to achieve maximum output during wind speeds above the furling speed.

Figure 4: Whisper Wind Turbine during high wind speeds

No wind rose for the site could be sourced. According to the owner the months of April to August are considered relatively windy. The South-Easter also blows in the months of September to November. The months of December to March (and especially November and January) has less wind.

The wind turbine is “a 1000 W turbine that can operate at low wind speeds”. It is important to note that the maximum output of the turbine is 1000 W and that this output is only achieved during relatively high wind speeds. It is further important to note that, when the wind speed doubles, the turbine output increases eight fold (refer to Appendix B.1)

Financial resources and partners

The installation was privately funded by the owner.

The initial costs are roughly:

Equipment cost :

Wind turbine	R 18500
PV Panels	R 21600
Micro Hydro Turbine	R 15000
Battery Bank	R 27000
Inverter	R 17000
Other Electrical equipment	R 8000
Sub Total	R107100

Installation and infrastructure cost

Wind turbine	R 1000
PV Panel including cable	R 2500
Infrastructure for hydro including pipe	R 8000
Other installation cost	R 3000
Sub Total	R 14500
Total	R121600

The owner received the following quote from Eskom during 2005 for an electric line to the location of the guest house:

25 kVA 380 V 3 phase line:
Option 1 – Once-off
-Connection fee: R4900
-Once off payment: R147,000 + R2100 deposit

Option 2 – 25 year Contract
-Connection fee: R4900
-Deposit: R7300
-Monthly instalment: R1730

16 kVA 220 V single phase line:
Option 1 – Once-off
-Connection fee: R3250
-Once off payment: R64,600 + R2100 deposit

Option 2 – 25 year Contract
-Connection fee: R3250
-Deposit: R4400
-Monthly instalment: R760

In all cases a monthly cost of R372.00 is due. Electricity cost is R0.286/kWh

Finding / Outcomes

The installed renewable energy solution provides the following estimated average daily output (for more accurate figures a data logger should be installed for at least one year):

Wind : Average of 280 W for 12 hours per day = 3.36 kWh
(Note that this is purely a prediction)
Solar : Summer day : 4.18 kWh
Winter day : 3.34 kWh
Average day : 3.76 kWh
This was predicted form table B.1 minus 10% for cloudy periods.
Hydro : 360 W for 24 hours per day = 8.6 kWh

Total of 15.72 kWh per day = 5.74 MWh per year

A detailed cost of electricity for this installation is beyond the scope of this report. An estimated electricity cost is R1.32/kWh calculated with the following assumptions:
-Total installation cost was R121,600
-Calculation over a period of 20 years

-Inflation rate of 0%
-No maintenance cost
-No replacement of batteries or other equipment during 20 years. This could be achieved if the batteries are operated within the recommended 10 – 20 % of the discharge rate. If this recommended discharge rate is exceeded, battery life could come down to 8 years.
-80% of the generated electricity is used

The current municipal electricity cost is around R 0.45/kWh while farmers pay R 0.286/kWh.

Except for the labour during the installation, no significant job creation can be linked to this installation.

Lessons learned and repeatability

The following observations were made and recommendations are made accordingly:

General

It is crucial to avoid unnecessary shadows on solar panels from trees, buildings and mountains (for the obvious reason that solar panels functions on solar radiation), especially during the winter months when the sunshine hours are less than in summer.

If the system was to be re-installed, a single water turbine operating at higher capacity (655 W) would be adequate to match the current (predicted) supply of 15.72 kWh. A battery bank would only be necessary to supply peak demands above 655 W (assuming there are times e.g. during the night when there are excess energy to charge the batteries. To size the battery bank, an analysis of the load profile and generation profile of the site is required.

A micro hydro system without solar and wind installations (with the same output as the current system) would bring down the total installation cost to R61,000. This would be for a system consisting of a micro-hydro turbine, an inverter, dump load and a smaller battery bank (approximately half the capacity of the current battery bank based on the sizing and costs listed above).

Should a hydro-only system be installed, a second hydro turbine or diesel generator should be considered during backup/maintenance situations.

It is suggested that the 2200 W electric water kettle in the kitchen of the guest house be replaced by a gas kettle (to be used on the existing gas stove). This is a low cast method to reduce the peak demand on the electric system (which is limited by the inverter).

It is suggested that the gas-geysers be complemented by solar hot water systems. The installed gas geysers could be used as backup or during above-average high loads on the warm water supply.

It is possible to change the altitude angle of the solar panels (figure A.4). This is not currently adjusted and should be done at least once a month to optimise the output from these panels. The panels should be perpendicular to the sun at 12:45, i.e. solar noon for this latitude. This would be an altitude angle of 10 ° during mid summer and 57 ° during mid winter for a 33.5 °S latitude.

Electrical

The 120 m long DC cable that runs between the solar panels and control room has four cores (each 10 mm^2). Only two of these cores are utilised for no apparent reason. If all four these cores are used, the current line losses will drop by 50%. (Line losses are directly proportional to the resistance of the line which in turn is directly proportional to the cable core diameter)

According to the data sheets of the MPPT unit, the output of the controller is either 12 VDC or 24 VDC. This controller, however, is connected to a 36 V battery bank. The manufacturer in the US was contacted about this matter. The manufacturer supplies units to South Africa that are specifically modified to have a 36 VDC output.

The input voltage of the MPPT unit is either 36 or 48 VDC. The maximum voltage output of the solar panels is, however, 54 VDC. A local solar electric company, Solardome, was contacted. Solardome installs Sanyo PV panels and also stocks the Blue Sky Solar Boost (MPPT) similar to this installation. According to Solardome it is possible to run the MPPT on a 54 VDC input voltage.

The micro-hydro turbine output is rated to be either 12, 24 or 48 VDC. It is, however, connected to the 36 VDC bus bar. The installer was contacted regarding this matter. Since the hydro turbine was installed when the 36 V system was already in place, a Stream Engine with 36 V output was especially reconfigured for this installation.

It is further suggested that:
-A small data logger be installed to measure the annual energy output of each unit
-Six analogue ammeters to be installed as suggested in figure D.1 to monitor the system

Conclusion

In conclusion, this is a very neat hybrid system but the technical optimisation of the system needs attention. The upgrade of the installation when the micro-hydro was added did bring some technical challenges (as mentioned above) which should be investigated.

Hydro power, when available, is a very viable and attractive option, technically and economically, for off grid installations. This is due to the continuous power supply, low maintenance and lower installation cost compared to wind and solar installations producing the same output.

Contact for more information:

Project Web Site: www.sun.ac.za/crses
Organisation / Agency: Centre for Renewable and Sustainable Energy Studies
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Appendix A

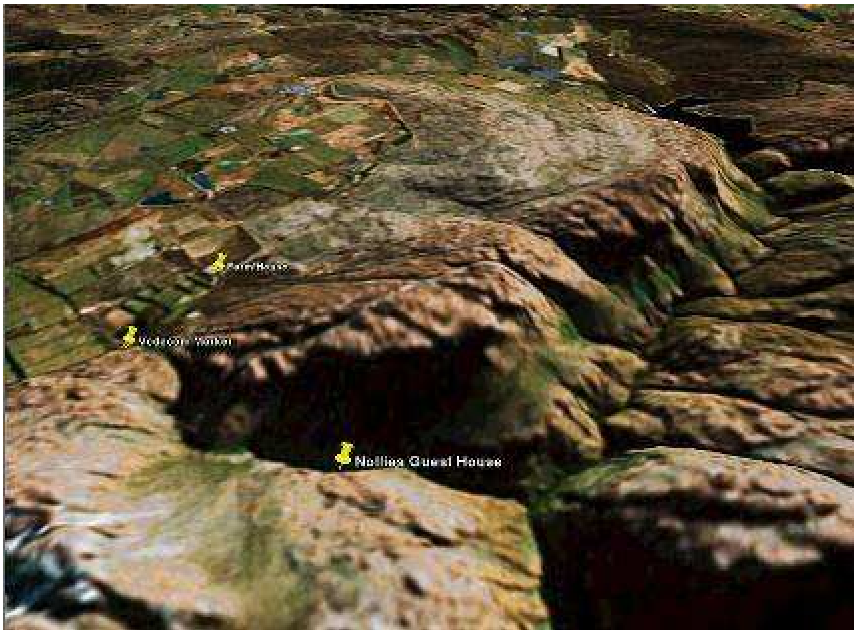


Figure A.1 : Nollies Guest House
The guest house location is : 33 °24”12 ‘ S ; 19 ° 32” 36 ‘ E ; 800 m above sea level. This Google earth image is from an eye-height of 4.27 km. The road to the guest house leads from the Farm House, via the Vodacom Marker and down the gorge. This image was captured in a due North direction.

Figure A.2 : Nollies Guest House
The guest house location is : 33 °24”12 ‘ S ; 19°32 ”36’ E ; 800 m above sea level. This Google earth image is from an eye-height of 2.88 km. The road to the guest house leads from the Farm House, via the Vodacom Marker and down the gorge. This image was captured in a due East direction. The snow capped mountain in the background is known as Matroosberg.

Figure A.3: Solari Meter: Measurement of solar radiation (1152 W/m^2) near guest house.

Figure A.4: PV installation (4 x 180 W @ 54 VDC each)

Figure A.5: The control room consisting of the battery bank (18 x 2V, bottom right), inverter (6 kW, bottom left hand corner) and other electrical equipment

Figure A.6: The Whisper Wind Generator - Model Whisper 200 (1000 W maximum output @ 11.6 m/s wind speeds)

Figure A.7: The guest house (photo taken in a Western direction) with Matroosberg in the background

Figure A.8: The Stream Engine micro hydro turbine (1000 W max output)

Figure A.9: Inside the guest house

Appendix B

B.1 Wind Turbine Power Production Guideline

$$\mathbf{P = 0.5 \times \rho \times A \times V^3 \times C_p \times \eta_g \times \eta_b}$$

where:

P power [W]
(746 W = 1 hp)
ρ air density [kg/m^3]
(about 1.225 kg/m^3 at sea level and about 1.136 kg/m^3 at 800 m altitude, air density vary with temperature and moisture content)
A rotor swept area exposed to the wind [m^2]
V wind speed [m/s]
C_p coefficient of performance [dimensionless]
(0.59 is the maximum theoretically possible {Betz limit}, 0.35 for a good design)
η_g generator efficiency [dimensionless]
(50% for car alternator, 80% or possibly more for a permanent magnet generator or grid-connected induction generator)
η_b gearbox/bearings efficiency [dimensionless]
(could be as high as 95%)

E.g. a 3 .1 m blade diameter turbine (A = 7.54 m^2) in V = 5 m/s wind with C_p = 0.35, η_g = 90% and η_b = 95 % at sea level:

$P = 0.5 \times 1.225 \times 7.54 \times 5^3 \times 0.35 \times 0.9 \times 0.95 = 172$ W

$P = (0.52 \text{ to } 0.64) \times V^3$ (Whisper 200) depending on wind speed

B.2 Micro-hydro Turbine Power Production Guideline

The basic elements required for a potential hydropower development are stream flow and an available drop, or head, through which the stream flow can be used to convert the potential hydraulic energy into electrical energy. The power generated is represented by the equation:

$$\mathbf{P = \eta \times H \times Q \times g}$$

where:

P electric power output [kW]
η overall efficiency range (typically 0.75 to 0.88 for the turbine itself) [%]
(this value could be as low as 0.1 when pipe friction losses are included)
H head [m]
Q water flow rate [m^3/s]
g acceleration of gravity, normally 9.81 [m/s^2]

For small-scale hydroelectric applications, the equation above can be simplified to :
P (kW) = H (m) x Q (m^3/s) (for an overall efficiency = 0.10)
P (kW) = 8 x H (m) x Q (m^3/s) (for an overall efficiency = 0.815)

B.3 Solar PV Panels Power Production Guideline

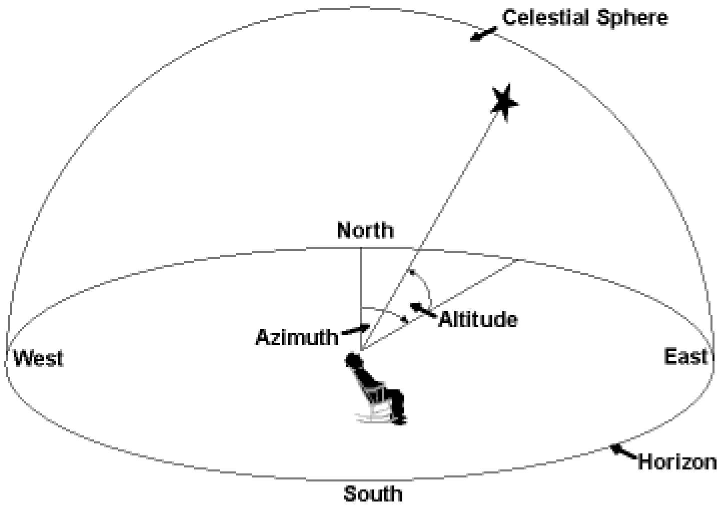
Table B.1: Solar panel power output at different times of the day.

Azimuth [deg]	Portion [%]	Power [W] **720**	Summer [W]	Winter [W]
70	34%	246	0.0	0.0
65	42%	304	0.0	0.0
60	50%	360	0.0	0.0
55	57%	413	137.5	0.0
50	64%	463	154.1	0.0
45	71%	509	169.5	0.0
40	77%	552	183.7	183.7
35	82%	590	196.4	196.4
30	87%	624	207.6	207.6
25	91%	653	217.3	217.3
20	94%	677	225.3	225.3
15	97%	695	231.6	231.6
10	98%	709	236.1	236.1
5	100%	717	238.8	238.8
0	100%	720	239.8	239.8
-5	100%	717	238.8	238.8
-10	98%	709	236.1	236.1
-15	97%	695	231.6	231.6
-20	94%	677	225.3	225.3
-25	91%	653	217.3	217.3
-30	87%	624	207.6	207.6
-35	82%	590	196.4	196.4
-40	77%	552	183.7	183.7
-45	71%	509	169.5	0.0
-50	64%	463	154.1	0.0
-55	57%	413	137.5	0.0
-60	50%	360	0.0	0.0
-65	42%	304	0.0	0.0
-70	34%	246	0.0	0.0
		Summer	**4.64**	kWh
		Winter	**3.71**	kWh
		Average	**4.17**	kWh

The assumptions that were made are listed on the next page.

Assumptions made for Table B.1:
-Panels face due North
-First solar rays on panels in summer : 09:10
-Last solar rays on panel in summer : 16:50
-First solar rays on panels in winter : 10:10
-Last solar rays on panel in winter : 15:50
-Panels altitude angle is adjusted monthly
-Average solar radiation of 1000 W/m^2

Definition on **azimuth** angle and **altitude** angle:



Definition of **Portion**: This is the perpendicular area of the solar panel that can see the sun relative to the total panel area expressed as a percentage.

Appendix C

Data Sheets for electrical equipment

Micro-Hydro Turbine
Stream Engine – 2 Nozzle
www.turbineservices.co.uk/Downloads/May-SEmanual.pdf
www.rpc.com.au/products/hydropower/HYD-060-Manual.pdf

Wind Turbine
Whisper Wind Turbine – Model Whisper 200
www.windenergy.com/documents/downloads/turbine_manuals/whisper/
whisper_200/0212REVB_Whisper200_Owners_Manual_Whisper_Controller.pdf
also see:
www.windenergy.com/whisper_200.htm

Inverter
MLT-Pure Sine Wave
www.solardome.co.za/Pdf/MLT%20drives%20Micro%20inverter.pdf

Solar Charge Controller
Blue Sky Energy – Solar Boost – Model 6024H
www.blueskyenergyinc.com/pdf/SB6024Hdatasheet.swf
also see:
www.blueskyenergyinc.com/pdf/Blue%20Sky_What%20is%20MPPT.pdf

PV Panels
Sanyo – HIT 180B2
www.sanyo.com/industrial/solar/downloads/USA%20Catalogue%202006.pdf

Batteries
Willard
www.willard.co.za

Appendix D

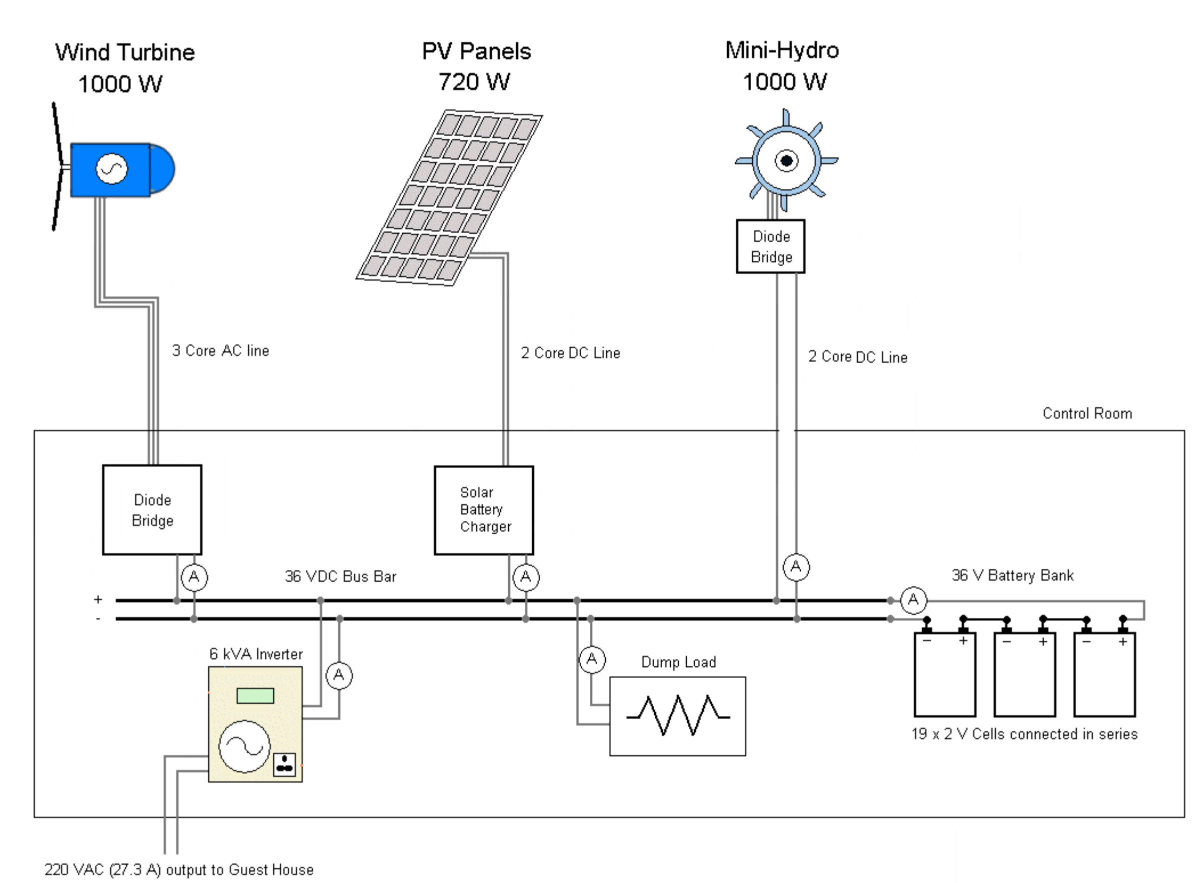


Figure D.1 : Suggested addition of ammeters to the current electric systems. Since all these meters are connected to the 36 VDC bus bar, the 6 different currents can be easily compared to each other (wind turbine output, micro hydro output, solar panel output, battery bank input/output, dump load input, inverter input).