IEA – International Energy Agency

PVPS

PV Injection in Isolated diesel Grids

Feasibility Considerations

October 2007

CONTEXT

In Developing Countries there are many rural villages and towns that rely on inefficient (high energy consumption per kWh produced – less than 3 kWh per litre) and diesel gensets or fuel oil power plants either run by national utilities (state or private) or by individuals or communities. For example, in the Sahelian countries – Mauritania, Burkina Faso, Chad, Niger, Mali, there are several dozen such gensets in each country, of a capacity between 10kW and 5 MW.

Diesel generators, despite being costly, polluting and constraining, particularly with regards to transportation of fuel, oil and spares to remote areas, remain often the easiest power solution in off-grid areas because of its low initial investment cost, its ease of installation and start-up. Besides, the technology is very widely spread and finding mechanics for maintenance is generally not an issue.

As generally, priority is given to maximising access rates, rural electrification project implementers (national authorities – Ministries and utilities, donors, decision makers …) often give priority to minimise initial cost and maximise the number of beneficiaries giving little chance to renewable energy alternatives, though they may be the most sustainable option in the long term.

Isolated thermal power plant (Burkina Faso

However the steady increase of fuel prices and pressure for more environmentally friendly solutions encourage all stakeholders to find new sustainable alternatives.

Individual stand-alone PV systems as Solar Home Systems have been massively promoted in Developing countries over the last 2 decades and have much to offer for small applications and scattered households but they cannot provide enough and flexible electrical power for significant economic development to take place.

Solar home system in Lao PDR

Given the drawbacks of the above options, hybrid systems offer the flexibility of diesel networks and energy savings related to PV systems over the lifetime of the investment.

In this document :

HYBRID SYSTEMS

More recent approaches include hybrid mini-grids combining renewable sources and diesel generators – with or without storage batteries. PV systems can act as fuel saver on a diesel generator powered mini-grid, however just bringing down the load of the diesel generator a bit does not offer very much positive impact, as diesel generators perform poorly at partial load. If the load profile of the mini grid allows a PV system, normally with storage, to stop the diesel generator periodically better overall impact can be obtained:

- Diesel generator time at partial load is minimized improving fuel economy
- Cost of maintenance and repairs/replacements is minimized
- Noise and pollution is periodically stopped

The drawback is mainly a technically more complex electricity generating system requiring competent operation and maintenance staff.

Based on successful experiences in large grid connected PV systems (more than 200kWp) and innovative financing mechanisms put in place to support renewable energy development, Developing Nations could also consider solar PV injection in their mini grid power supply systems – where the cost of alternative generation is high. A good framework would also include incentive institutionnal conditions (clear IPPs status, long-term contracts, tax exoneration for renewable energy equipment import).

INNOVATIVE APPROACH

“PV Injection in Isolated Grids” initiated by I.E.D., aims to study the feasibility of injecting solar PV electricity into existing isolated grids (mini or local) run by diesel gensets. A preliminary assessment of the potential market for such an approach points towards significant potential impact in certain African countries (Chad, Burkina Faso, Mauritania).

Different scenario of load profile shall be considered and cost-effectiveness and sensitivity to fuel prices assessed. The following case study in Mauritania aims to briefly illustrate the possibility of PV injection by comparing specific costs and their evolution in the coming years.

Dissemination of this study shall be undertaken in collaboration with the Club of Rural Electrification Agencies (Africa), www.club-er.org.

POWER DEMAND AND LOAD PROFILE

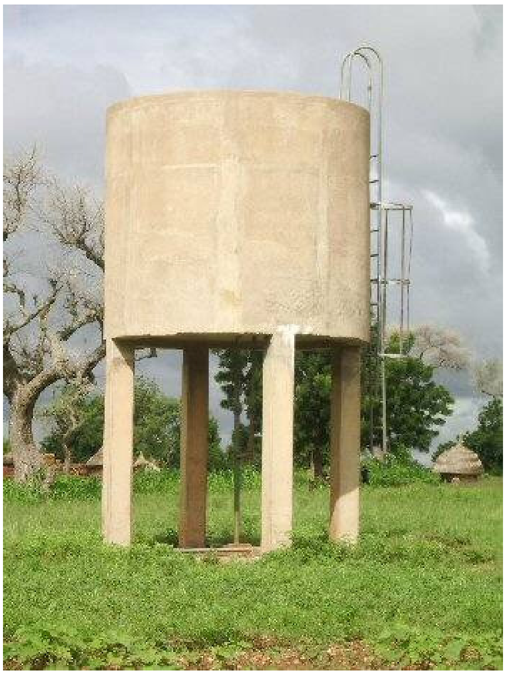
Lessons from African experiences have shown that it is possible to envisage a tariff permitting cost recovery for isolated diesel power plants only for large towns. If tariff is below production cost, then someone has to pay the difference! For this reason most rural towns get "subsidised kWh" to offer 12 to 24 hours services per day suitable for day-time productive activities. If the tariff is full-cost recovery based, the diesel generators generally operate no more than 4 hours per day to meet the evening needs only.

The load profile varies considerably from one country to another but the general trend is:

- In secondary and major towns, due to ever increasing air conditioning and refrigerating units, peak is observed around noon time, even with active Demand Side Management to reduce consumption.
- In rural settings and small towns, peak demand is from domestic consumption during the evening and with sometimes a smaller dawn peak.

The minimum demand can be either during day-time if little commercial or administrative activities occur or during night-time mainly for security and public lighting and refrigerators.

Home in a village in Lao PDR
Most of the demand in rural settlements is due to domestic consumption : lighting, TV, mobile phone recharge...



Water storage tank (Burkina Faso)

Pumping applications for water supply can be in some cases an important energy consumption that, thanks to storage tanks, can be shifted during the day to better match the energy production profile.

PV OPTIONS

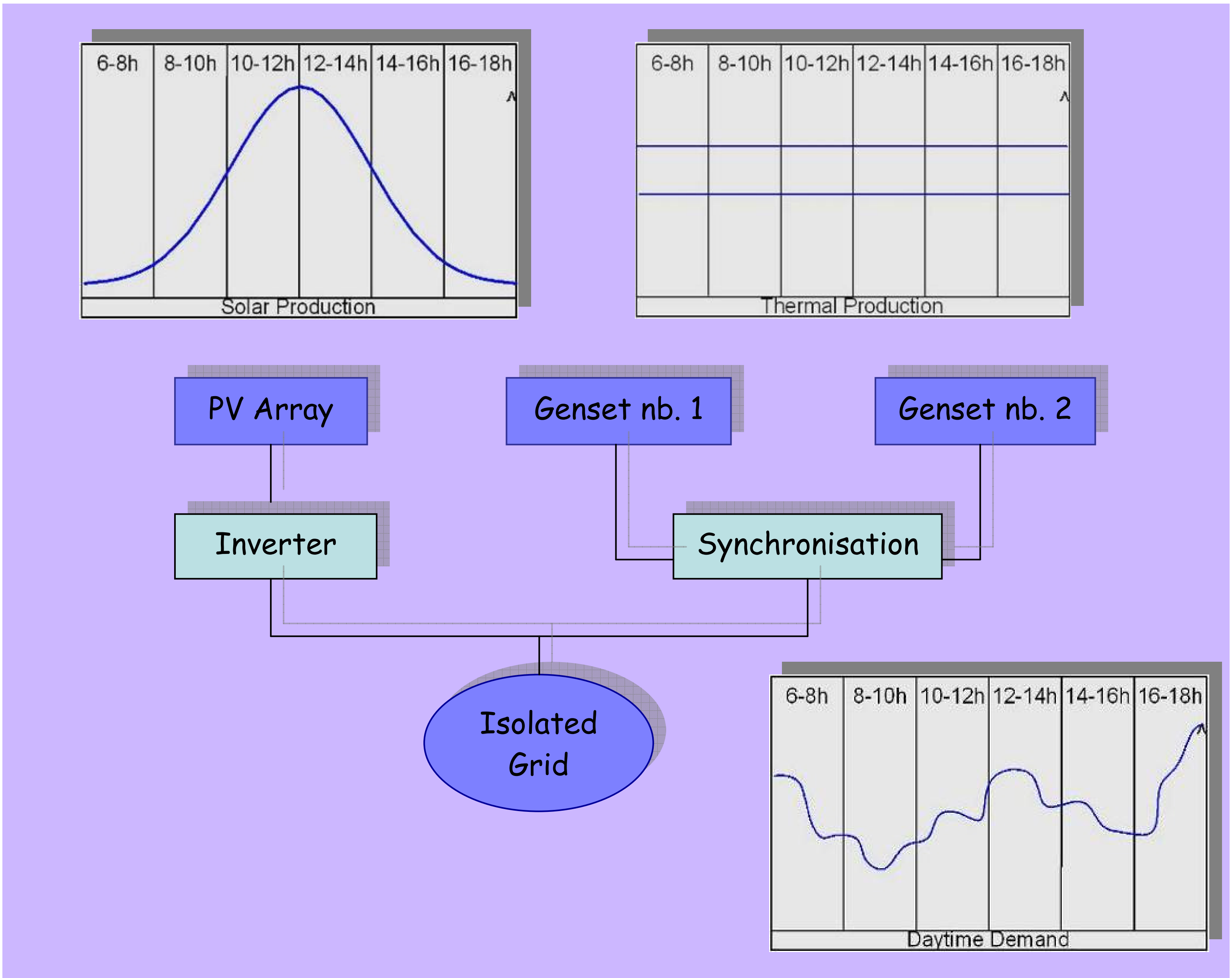
Historically the first solar power plants implemented in Developing Countries were 100% PV. Both investment and recurrent costs (battery replacement!) were very high due to the need to oversized PV arrays and required battery storage to ensure all-year-round electrical service.

Isolated PV installation in the Philippines

More recently hybrid systems (where the main source is a PV-battery system with a backup diesel genset) have been introduced and experimented in various countries (Indonesia, India, China, Mongolia …). Despite the cost reduction compared to previous full-PV design, the cost of electricity produced by hybrid systems is still high compared to kWh cost from small fuel oil power plants except in particularly remote island cases where access is a tremendous problem. Furthermore a significant percentage of the solar energy is lost through the battery storage, and one needs a battery inverter plus a grid-tie inverter (compared to only the battery inverter in the previous option). In addition, the grid-tie inverter must be capable of being shut down by the battery inverter in case the battery is full.

One positive point of the intensive investigation on hybrid systems is the significant progresses in inverter technology that allow today to inject electricity from PV or other power sources in an isolated grid – grid connected wind has tremendously contributed to this. Still specific care should be taken to check suitability of existing inverters with unstable isolated grids (wide voltage and frequency fluctuations; poor power quality) and islanding risks. Some specific research facilities (ISET, GENEC) exist for testing new designs & products for isolated grids.

The proposed approach to be studied is to inject a certain but limited amount of PV power - so as not foster any disturbances in grid stability due to intermittent generation - in an isolated mini-grid (or local grid) continuously supplied by a thermal power plant (one or more gensets) as schematically represented in the drawing. Depending on the load profile considered, the PV system will act as a peak load shaving solution or as a contribution to the base power production (reduction of the load factor). The major benefit is to reduce the fuel consumption but the genset size required to meet the peak demand is not expected to be reduced as solar radiation and power demand are unpredictable – except to some extent in the peak shaving option.

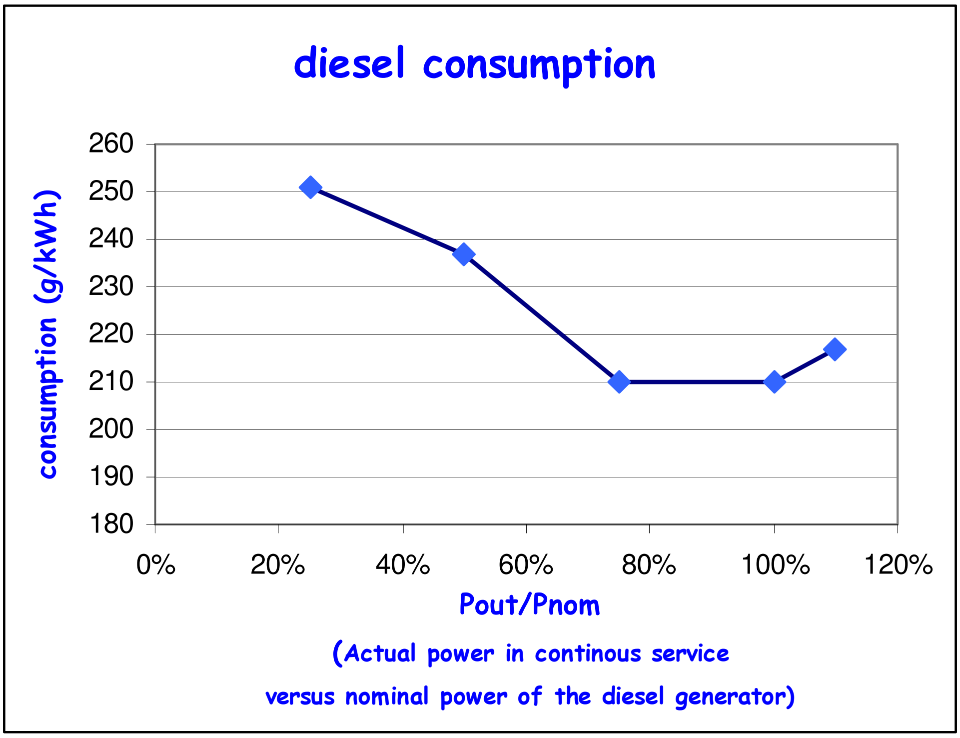


The PV injection can be done at different levels:

High injection rate when the solar peak power of the PV array is higher than the daytime minimum power. Battery is needed to store the excess solar energy produced during minimum demand, to smooth solar transient variations and also to simplify the power production management (switching mode between generators). This configuration is similar to conventional hybrid systems with battery-inverters and not considered. However, it can be economically viable in some circumstances to meet peak demand.

Medium injection rate when the solar peak power of the PV array is just higher than 50% of the minimum power during daytime. The random character of the solar radiation can affect the quality and stability of the overall production. Conventional grid-tie inverter needs to be adapted and a small buffer battery (e.g. autonomy of 1 hour or more) can simplify the power production management in case of unexpected abrupt solar or demand variation.

Low injection rate when the solar peak power of the PV array is lower than 50% of the minimum power during daytime. All the solar production is directly injected in the distribution network without intermediate storage: the load factor of the generator is reduced and the specific consumption of fuel slightly increased (cf. next curve). The fuel savings are modest but not negligible; furthermore such battery-free system is cost-attractive and local grid stability problems minimised. More details in next Case studies.



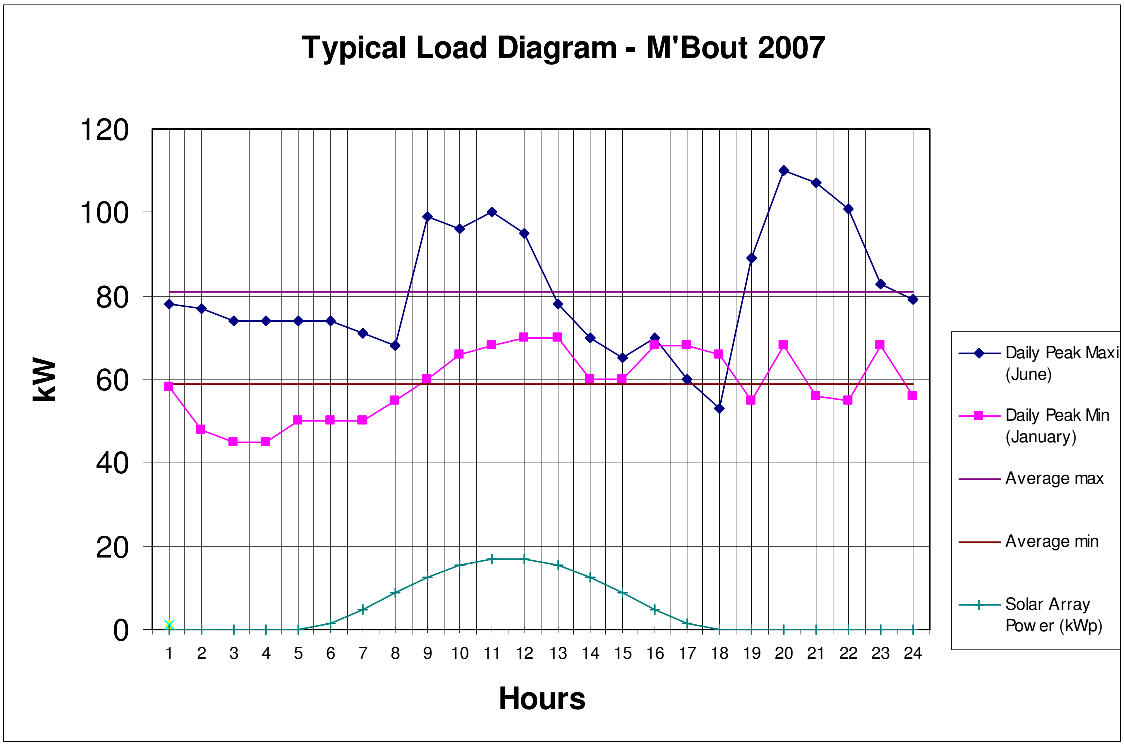
CASE STUDY - MAURITANIA

In Mauritania, the national utility SOMELEC is operating 14 isolated grids supplied by thermal power plants (2 or 3 diesel generators). A preliminary study has been conducted to inject solar electricity in the power network supplying the remote town of Mbout in Gorgol province.

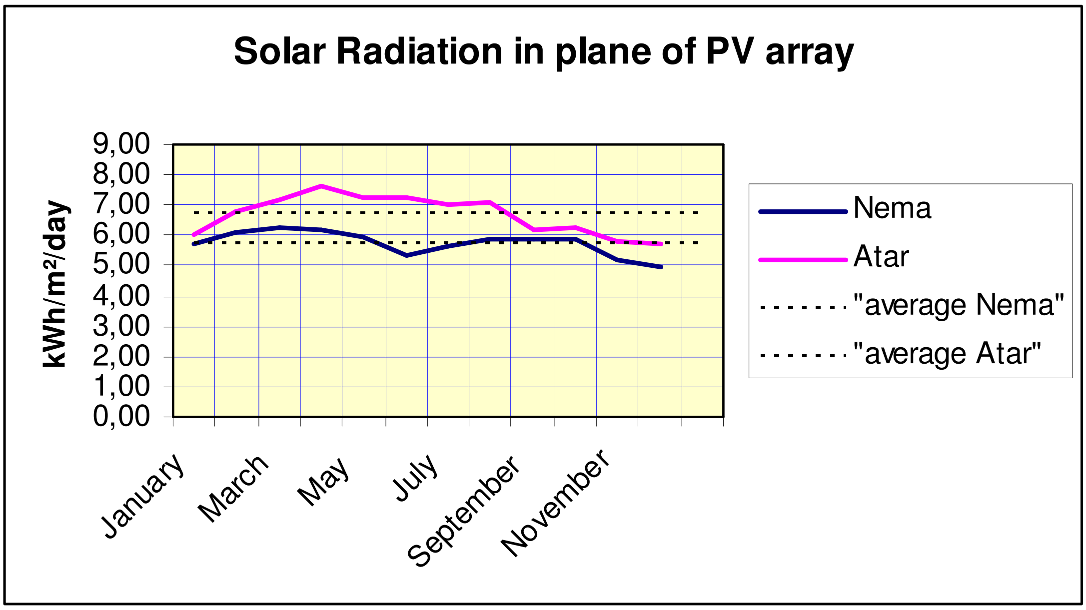
The power plant includes 2 generators of respectively 200 and 80 kW after the planned rehabilitation. In 2006 the thermal power plant has produced 550,000 kWh with an average specific consumption of fuel of 296 gr/kWh which is expected to be reduced to 250 after rehabilitation.

The electricity demand from Mbout town (including technical and non-technical losses but not included the 4% used for the plant auxiliaries) reached 528,000 kWh in 2006, i.e. **1447 kWh per day** for a population below 10,000 in 2006. There are very little economical activities except an undefined number of mills working during day time, and air conditioning or refrigerating units are certainly not common yet.

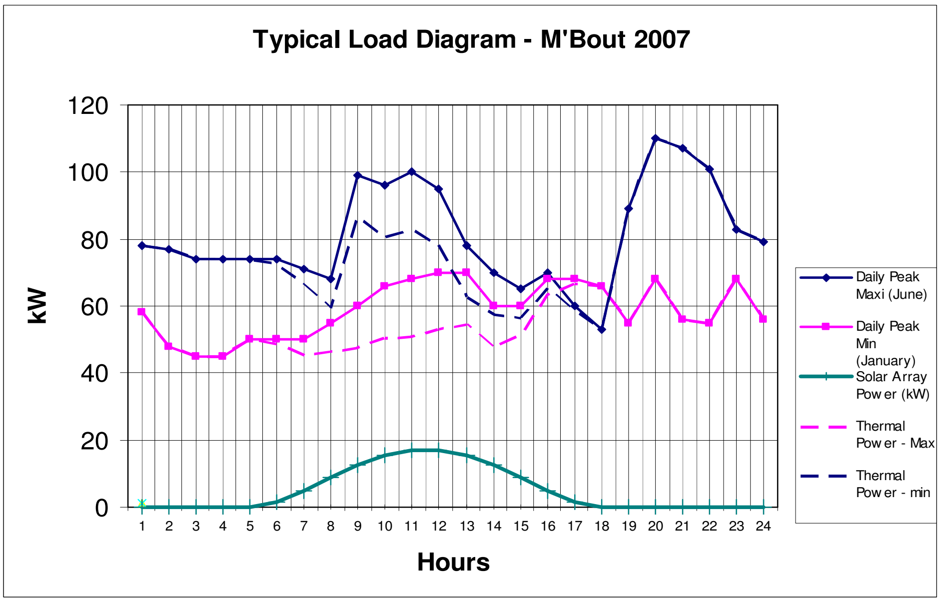
The load curves for typical days in summer and winter time are given in the next figure showing 2 peaks in summer time. Whatever the season is, it seems that the minimum demand during day time is always higher than 50 kW with a peak between 9:00 and 13:00, rather appropriate for direct solar PV injection.



In the following simulation, we have chosen a low injection case with a solar PV array of 20 kWp, i.e. below 50% of the minimum power demand during daytime. The actual maximal electrical power from the solar array shall be around 17 kW due to temperature effect which degrades the PV cell performances above 25℃ (see lower curve in above figure). In Mbout area we can consider an average solar radiation of **5.5 kWh/m²/day** in plane and a minimum of 5.0 in December (in the standard condition of AM 1.5, 1000 W/m² at 25℃) based on data available from Retscreen software in nearby location (Nema town in Mauritania).



Therefore the annual production of solar electricity, given the efficiency of the inverter (which is commonly above 92%), shall reach 31.4 MWh, i.e. **86 kWh/day** in average. It corresponds to only 6% of the Mbout energy demand in 2006 and probably less than 3% in 2020 and hence will not affect grid stability.



This figure gives the Net Thermal Power required if solar PV is injected into the grid (sunny day). This shows that during day time a smaller genset - if available - can be used.

The cost of the "diesel kWh" is **0.18 €/kWh**, when considering the diesel purchase price by SOMELEC of 0.5 €/litre in 2006. The depreciation of the genset is calculated considering an investment cost of 600€/kW and two replacements (life time : 10 years). This "subsidised" fuel price should be compared to international fuel market prices and should include transportation cost in such remote place. Furthermore the calculation assumes a rather conservative specific consumption of 250 gr/kWh (or 0.284 litre/kWh or 3.5 kWh/l @ 1.1765 litre/kg of diesel)

The "solar kWh" cost has been calculated (0.22 €/kWh) based on an estimate of the investment cost to be around 6,620 EUR/kWp including transportation and installation costs in remote african conditions and considering a depreciation of the initial investment over 20 years. The solar kWh cost is thus 38% higher than the diesel kWh cost calculated above. If the inverter is replaced every 8 years, the solar kWh cost is **0.27 €/kWh** and a provision of 1850 € shall be kept every year for further replacement.

Considering the price of diesel at the Nouakchott's pump in november 2008, or in Senegal and Mali in june 2009 (both **0,76€/litre**), the cost of the diesel kWh is already the same as the cost of solar kWh. In addition, if the cost of PV panels decreases by about 10%, solar PV and diesel kWh reach comparable levels.

Whatever the genset size used during daytime, the fuel consumption shall be reduced and the annual savings are estimated to 7.5 tons of fuel, i.e. between 4,400 and 6,600 €/year depending on the diesel price given above.

The 31.4 MWh/year produced by solar generator allow to save 24 tons of CO_2, which can be valued between 180 and 890 EUR per year depending of the market prices (from 7,5 to 37 €/ton of CO_2).

The additional operation and maintenance activities for such PV-diesel power plant are extremely limited as there is no battery and can be managed by the existing operating team without extra cost:

- Synchronise the solar and thermal generators
- Data logging of solar production
- Cleaning of solar modules every 3 months
- Visual and electrical check of wiring and inverters once a year.

In conclusion, the injection of solar electricity in rural isolated grid is not directly cost-effective for SOMELEC in the present conditions, but an increase of the fuel price from 0.5 to 0.7 €/litre and a marginal decrease in the cost of PV investmentsl financially justify the investment.

From the point of view of the government of Mauritania (which supports the fuel subsidy), the direct implementation of such solar PV application is obviously viable if one considers the fuel transportation costs and the environmental benefits.

Isolated grid for remote villages in Mauritania