GRID CONNECTION

Introduction

It was in London in 1882 that the Edison Company first produced electricity centrally that could be delivered to customers via a distribution network or 'grid'. Since then electricity has become one of the commonest energy sources for domestic use in the West. Electricity is extremely versatile, clean, easy to use, and can be turned on or off at the flick of a switch. Electricity has brought enormous social benefits in all areas of life. It is the preferred method of supplying power for many household applications, especially lighting. However, some 1.6 billion people still do not have electricity globally, with connection to the national electrical grid is a rare occurrence in rural areas of the developing and under developed world. In the majority of the worlds' poorer countries it is estimated that significantly less than 5% of the rural population are connected to the national grid. There are many reasons, both technical and economic, which make grid connection unfeasible and these will be looked at briefly in this fact sheet. In urban areas of the developing world grid connection is more commonplace, though not always in 'slums' or informal communities.

There are other possibilities for providing electricity in rural areas. In many areas where electricity is required and there is no grid within easy reach then a localised grid (or micro-grid) can be established using a local power source such as a diesel generator set or small-scale hydro power scheme. Alternatively, individual households can be connected to stand-alone systems which can be powered by any of a wide variety of energy sources.

Technical

The grid

The national grid is a network of power lines which allows distribution of electricity throughout all or part of a country. The grid can be connected to a single power source or electricity generating plant but is usually linked with other plants to provide a more flexible and reliable network. The electricity is usually transmitted at very high voltage, typically several hundred thousand volts (depending on power transmitted, national guidelines, etc.) as this reduces losses and means that smaller cables can be used, reducing the overall cost of the network. Bulk electricity is generated and transmitted in 3 phase, alternating current (a.c. - 50 or 60 cycles per second) form and distributed to the consumer as three phase or single phase depending on the end use requirements. Transmission by direct current (d.c.) is also used, losses associated with d.c. electricity being lower than a.c., but other costs are incurred as heavy duty rectification equipment is then needed to supply a.c. electricity to the consumer.

Electricity standards in selected countries

COUNTRY	VOLTAGE	FREQUENCY
Brazil	110/220 V	60 Hz
Cambodia	230 V	50 Hz
China	220 V	50 Hz
Ethiopia	220 V	50 Hz
India	230 V	50 Hz
Kenya	240 V	50 Hz
Philippines	220 V	60 Hz
South Africa	220/230 V	50 Hz
Thailand	220 V	50 Hz
Uganda	240 V	50 Hz
United Kingdom	230 V	50 Hz
USA	120 V	60 Hz

After generation, the voltage has to be stepped up (to a high voltage) for transmission and distribution using a transformer and then stepped down (to a lower voltage) for end use, again requiring a transformer. The step down process is usually done in several stages as the network is reduced in capacity. Typical consumer voltage is 210V or 415 V for three-phase and 120 V or 220 V for single phase depending on national standards. Three-phase electricity is used for higher power equipment such as factory or workshop machinery whereas all domestic electricity supply is single phase.

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Electricity production

Electricity is most commonly produced by converting an energy source into mechanical shaft power, which in turn drives a generator which produces electricity. The energy source can vary depending on the available resources. Typical sources include fossil fuels, nuclear fuels (rarely in the developing world), hydro power (a selection of countries producing a significant proportion of total electricity from hydro power; Kenya 55%, Nepal 90%, Peru 48%), solar power, wind power, geothermal, etc.

- Traditional **thermal** power generation uses oil, coal or gas to produce heat which in turn is used to create steam which drives a steam turbine. The turbine provides the mechanical power for the generator.
- **Nuclear** power generation uses nuclear fuels such as uranium, which undergo a process known as nuclear fission in a reactor, to provide heat to drive the turbine.
- **Hydropower** (which is a very popular source of power in regions where the hydrological and site conditions permit and /or fossil fuels are scarce) uses the stored or potential energy of water which has a 'head' or height above a certain point. The water is dropped through a turbine which provides shaft power for directly driving a generator.
- **Windpower** uses a similar principle but the energy is extracted from the wind to drive the turbine.
- **Geothermal** energy is heat energy stored in the earth's crust which can be tapped to heat water for driving a turbine (Kenya currently has 127MW installed geothermal power).
- **Solar** energy for providing electricity can be derived using one of two methods. Heat from the sun can be concentrated to drive a steam turbine, or the more popular method uses the photovoltaic principle to convert sunlight directly into electricity.

Solar and wind technologies are increasingly being used for grid power. Wind farms, both on-shore and off-shore are becomingly increasing common, India has an installed wind power capacity of 7,114 MW (2007). Roof top solar photovoltaic systems are increasingly being used to supply the grid in some developed countries, with Germany leading the way 40% of the world's PV installations.

The grid can be owned privately or by the state and is not necessarily owned by the electricity producer.

Figure 1: National Grid pylon and transmission lines which do not serve the local village where it is situated, on the Pokhara road, Nepal. Photo: Steve Fisher / Practical Action.

The type of fuel source which will be used to provide electricity is dependent upon several factors.

These include the following:

- a country's fossil fuel resources
- cost of importing fossil fuels
- government energy policy
- availability of sites for exploitation of renewable energy sources e.g. large rivers, dams or lakes for hydro power; wind regime for wind power or geothermal resources
- technical expertise available in country

Cost of grid connection

There are many constraints to rural grid based electrification. Firstly there is the question of cost. The cost of grid connection is influenced by the voltage and proximity of the grid and whether there is a step down transformer already serving the area in question. Capital cost of the distribution system is very high and demand in rural areas is very low. A 2000 World Bank/UNDP study on rural electrification programmes placed the average cost of grid extension per km at between $8000–10,000, rising to around

$22,000 in difficult terrains. Households can be widely dispersed and often rural consumers will want to use only a few light bulbs and a radio in the evening. The cost-benefit relationship shows that there is little incentive for an electricity producing utility to extend the grid into remote rural areas. Often rural regional centres will be electrified but the network will usually stop there or bypass the remoter villagers as high voltage cables passing overhead. The figure below shows the cost of grid connections in relation to load density in rural and urban areas. In poorer communities the cost of house wiring, appliance purchase and electricity prices can also be prohibitive.

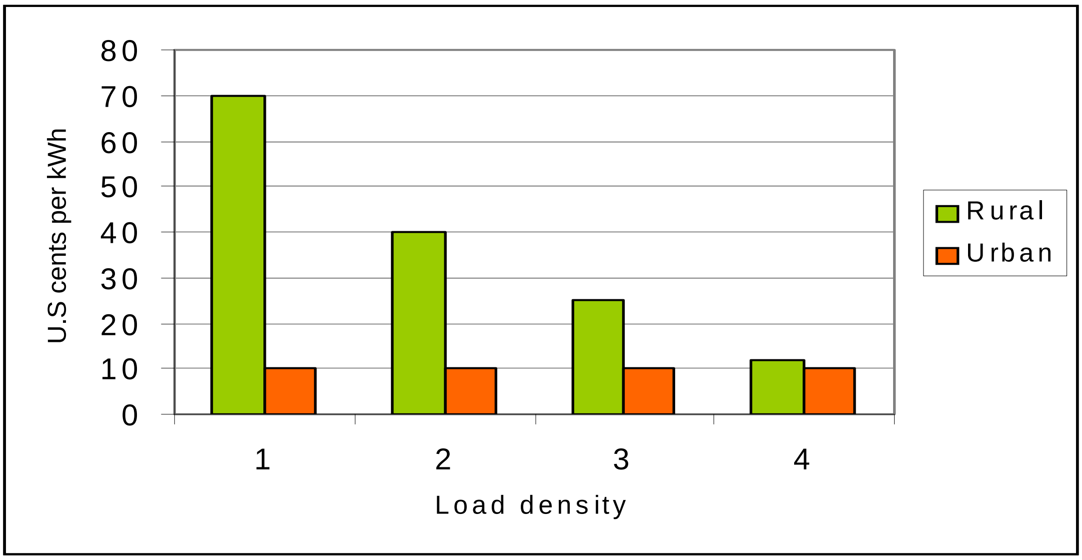

Figure 2: Cost of grid electrification in relation to load density*
(*Note: Costs in Figure 2 are indicative and may vary with location)

Rural electrification schemes often require subsidies to make them financially viable.

Other barriers to grid connection

- Lack of productive end-uses: Although introduction of electricity to a community often stimulates income generating activities and hence a gradual increase in the uptake of electricity use, the conditions for introducing electricity do not normally exist in rural areas. Most commercial and industrial activities are concentrated at the regional centres. Electrification projects alongside rural development programmes will often make electrification more viable.

- Lack of power supply capacity: In many developing countries the existing generating capacity is unable to cope with demand. Black outs are a common occurrence in many major cities, especially as the process of rapid urbanisation continues. The utilities often find it difficult to cope with the existing demand, let alone think about catering for an increased demand from rural areas.

- Political will: Positive political will and subsidies or loan schemes for rural electrification can remove some of these obstacles but often neither are forthcoming.

It seems, therefore, in many countries of the developing world, that little progress will be made if rural communities are to wait for the grid to reach them.

Alternatives to grid connection
It is now widely accepted that for many rural locations an alternative to grid connected power is required. Many rural power programmes will combine grid supply to the most accessible areas with off-grid alternatives to more remote locations or disperse communities. One alternative, which is used widely, is to utilise small diesel generating sets to provide electricity for local networks. Another alternative can be found in the form of decentralised power generation using renewable energy technologies, including solar photovoltaic, micro hydro and wind power.

Renewable options are becoming more popular due to climate change concerns and the availability of carbon financing.

A cost/benefit analysis of the alternatives (grid/diesel/renewable) will be required to decide which option is appropriate for each location, to include economic analysis, fuel availability, ownership and management of the scheme and operation and maintenance issues.

Develop markets for off-grid energy services in Brazil

Aggressive market development efforts for decentralized off-grid solutions will be needed to achieve Brazil's universal access targets at a reasonable cost. Off- grid electricity includes electricity for village mini- grids (powered by hydro-, solar, wind, diesel-battery, or hybrid solutions) and standalone systems (AC or DC power from pico-hydro, wind, diesel and/or PV generators for multifunctional productivity platforms, home systems, or battery charging stations), as well as non-electrical energy solutions for domestic, public, and productive uses (such as process heat, cooling chain, efficient cooking). The potential for off- grid solutions in Brazil is huge, but largely untapped. Existing isolated diesel systems are often inefficient, unreliable, expensive to run, and a continuous drain on government funds. Grid extension is not an economically viable option for many remote and dispersed users (for example, users in Amazonia). Costs per household can easily rise beyond US$2,000 (see table 1) —while many rural households use far less than 50kWh per month even after connection. For such dispersed settings, off-grid solutions can provide more flexible energy services, fitting the varying demand patterns of rural users and uses.

Table 1: Costs of New Grid Connections in Bahia, Brazil

Bahia	Grid extension costs per consumer in US$ (broken down by distance form existing grid in km)					
Utility poles per consumer	0-1	>1-5	>5-10	>10-20	>20-50	>50
=0.5	105	145	202			
>0.5 - 1	322	324	357	373		
>1.1 - 2	632	642	646	711		
>2.1 - 4	1179	1184	1208	1325		
>4	4166	4343	4763	6530	6818	28219

Sources: Brazil: Background Study for a National Rural Electrification Strategy: Aiming for Universal Access March 2005.

Areas of application

Uses

Electricity is an extremely versatile, clean and user friendly form of energy. There is an almost limitless range of applications for electricity. Electrical motors provide shaft power that can be used for a multitude of industrial and agricultural activities, as well as for transport. Batteries allow electricity to be stored for periods when it will be required. In a rural context, electricity has many uses. They include some of the following:

Domestic	Other
Lighting - probably the most important from the rural user's viewpoint **Communication**- tv, radio,etc. **water heating** **cooking** **refrigeration** **sewing machines** **water pumping** from rivers, boreholes (community level)	**irrigation pumps** **agro processing** (including milling, oil extraction, threshing, etc.) **small workshops** (carpentry, metal working, automotive,etc.) **hospitals** and health centres **small businesses** - traditional rural industries and many more

The social impact of introducing electricity to a region is enormous. There are the obvious benefits of improved social services; lighting at health centres, hospitals and schools, refrigeration of vaccines, etc. There are other social gains such as street lighting, cinema and television, community services such as milling of grain, sawmills or battery charging (often an alternative to grid connections).

There are also less obvious benefits. The status of a community is raised enormously in the eyes of the rural inhabitants when electricity is introduced. This helps to stem the flow of rural urban migration which is common in many developing countries. Many young people head for the 'lights' of the big cities as soon as they are old enough and introducing electricity has the tendency to stop this exodus which is creating huge problems in many countries. The introduction of electricity often helps to create productive employment in rural areas and there is a positive impact on economic as well as social growth.

Specific issues

Micro-grids

As mentioned earlier, one of the main obstacles to national grid connection in remote rural areas is the prohibitive cost of the distribution network. One way of avoiding these costs are to decentralise the power generating capacity and install local small scale, low voltage grids, otherwise known as micro-grids. This tends to be the main thrust of the work being carried out on rural electrification in the developing world at the present time. Localised grid networks allow local, renewable resources to be exploited. Energy sources such as small-scale hydropower, solar (photovoltaic), windpower and biogas are all being employed successfully in rural electrification projects in the developing world. (More information about these technologies can be found in other fact sheets in this series). Decentralisation of generation also allows control of the system to remain in the hands of the users and removes the dependency on external supplies and market forces.

Environmental issues

Emissions from fossil fuel burning are causing environmental problems worldwide. Governments are now trying to reduce these emissions to bring them into line with projected global emissions guidelines. There are also environmental concerns associated with the extraction and transportation of fossil fuels.

Large dams for large-scale hydropower are also attracting attention due to their negative environmental and social impact. See the Practical Action paper '*Small is Powerful - Appropriate Hydro in Nepal*' and '*Silenced Rivers*' by Patrick McCulley for more information on this topic.

Planning and implementation

Planning for an electrification programme at national level is a complex task. There are many things to be considered: energy policy, generating capacity, priority regions and areas, network design, matching supply and demand, market identification, technology options, load management, pricing, funding, centralised or decentralised generation, fuel options, national development policy, etc. This task alone is daunting for many governments with limited funds and lack of human resources.

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Low cost grid connection

Where grid connection is an option, be it to the national grid or a micro-grid, then one method of making it an affordable option is to keep the connection costs and subsequent bills to a minimum. Often, rural domestic consumers will require only a small quantity of power to light their houses and run a radio or television. There are a number of solutions that can specifically help low-income households to obtain an electricity connection and help utilities meet their required return on investment. These include:

Load limited supply. Load limiters work by limiting the current supplied to the consumer to a prescribed value. If the current exceeds that value then the device automatically disconnects the power supply. The consumer is charged a fixed monthly fee irrespective of the total amount of energy consumed. The device is simple and cheap and does away with the need for an expensive metre and subsequent meter reading.

Reduced service connection costs. Limiting load supply can also help reduce costs on cable, as the maximum power drawn is low and so smaller cable sizes can be used. Also alternative cable poles can sometimes be found to help reduce costs.

Pre-fabricated wiring systems. Wiring looms can be manufactured 'ready to install' which will not only reduce costs but also guarantee safety standards.

Credit. Credit schemes can allow householders to overcome the barrier imposed by the initial entry costs of grid connection. Once connected, energy savings on other fuels can enable repayments to be made. Using electricity for lighting, for example, is a fraction of the cost of using kerosene.

Community involvement. Formation of community committees and co-operatives who are pro-active in all stages of the electrification process can help reduce costs as well as provide a better service. For example, community revenue collection can help reduce the cost of collection for the utility and hence the consumer.

Electricity Cooperatives Nepal

Nepal has adopted a new strategy whereby it intends to sell power in bulk to rural electricity consumer groups after putting up the distribution infrastructure. Under this program, consumer associations typically in the form of cooperatives will take the responsibility of managing, maintaining, and expanding the rural distribution of electricity. Communities raise 20% of the investment cost for grid extension to their area and 80% of the funds is provided by the Nepali government. It is expected that this will reduce costs of distribution and also pilferage of electricity. A number of applications from rural communities have been approved for implementation.

Low Cost Distribution networks

There are a number of options for reducing the over all cost of a distribution system for rural electrification. Each option must be considered for the local conditions (distance to be covered by distribution lines, how disperse are the customers, predicted electrical loads). Some options which have been used in a number of countries include:

- Careful balance between use of high voltage transmission lines and low voltage distributions lines. Lower voltage lines are lower cost to install, but incur higher losses of power. (See Tunisia example in box below)
- Low cost distribution poles: one cost-effective way to install overhead distribution poles in off-road locations is to use steel distribution poles (where available) as an alternative to wood poles. Alternatively locally available wood poles can be used.
- Single wire earth return (SWER) or single wire ground return is a single-wire transmission line for supplying single-phase electrical power to remote areas at low cost. It is often used in sparsely populated areas where the cost of building an isolated distribution line cannot be justified. Capital costs are roughly 50% of an equivalent two-wire single-phase line. Maintenance costs are roughly 50% of an equivalent line. This has been widely used in Australian, but has also been applied in parts of Brazil and

Africa. The main disadvantage is that SWER lines tend to be long, with high impedance, so the voltage drop along the line is often a problem, causing poor power quality.

The Box below describes one approach to low-cost rural electrification which worked for Tunisia. Low-cost options must be considered for suitability for each location.

Tunisia's Low Cost Electricity Distribution System

One key reason for cost reductions in Tunisia's successful rural electrification programme was the early adoption, in the mid-1970s, of a low-cost, three-phase/single-phase distribution system, known as MALT.

Unlike most African countries and many other developing countries, Tunisia chose not to adopt the technical standards it had inherited from Europe, which included a three-phase, LV distribution system, suited to densely populated areas and heavy loads. Many developing countries that did adopt this system, ended up with a high-cost-per-km distribution infrastructure that was poorly suited to their scattered settlements and low demand levels.

Tunisia's decision to adapt the lower-cost, three-phase/single-phase distribution technology used in North America and Australia to its unique environment is arguably the single most important reason for the country's later success in rural electrification.

The three-phase/one-phase MALT distribution system adopted in Tunisia consists of major arteries of overhead lines in three-phase, 30-kV, line-to-line voltage, with four conductors (three phases and one neutral wire) and secondary, single-phase, 17.32-kV, line-to-neutral voltage rural distribution overhead lines (two wires: one phase and one neutral). Single-phase transformers give a secondary, phase-to-neutral voltage of 230V (single -phase, LV lines), which is used by most rural customers. The distribution system is composed of robust materials and equipment that are easy to use and maintain.

When Tunisia adopted the MALT system, it made a second key technical decision: opting for a relatively high, single-phase 17.32-kV voltage, rather than the weak 3 or 5 kV of the North American model. The higher voltage was selected for the single-phase rural electrification overhead lines because of the long distances between villages and the nearest three-phase artery and to provide for future demand growth over the 30-year lifetime of the lines.

Source: Low Cost Electricity and Multi-Sector Development in Rural Tunisia: Important Lessons from the Tunisian Success Story, 2004

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