Rural electrification: economy, efficiency and project planning

Bryan Leyland MSc, FIEE, FIMechE, FIPENZ
Consulting Engineer
Auckland, New Zealand

Abstract

World-wide, 2 billion people do not have an electricity supply and their monthly energy bills for water, charcoal, kerosene or batteries could be as much as 20 - 30% of their earnings.

Rural electrification brings large social and economic benefits. It is no accident that indices of economic growth, health and social development correlate closely with the wide availability of a reliable and economic electricity supply.

In many developing countries, rural electrification is regarded as and extension to urban electrification and the standards developed for supplying a high density load are used without modifications to supply the very low density load typical of rural supply.

The paper discusses what needs to be considered before embarking on rural electrification and then goes on to discuss sources of electricity and the options for the distribution system itself. It discusses the advantages of the Single Wire Earth Return system that provides remote rural communities with a reliable, low cost supply.

This paper shows that by adopting international best practice, countries of Southeast Asia can provide their rural populations with a reliable supply of electricity at a price that they can afford and without the need for large subsidies or the problems and organizational overheads involved in dealing with Development Banks.

This paper follows on from a paper I presented in Thailand in 2006 that concentrated more on the technical aspects of rural distribution[1].

Introduction to rural electrification

Rural electrification brings an economic and reliable supply of electricity and the benefits of modern technology to rural populations. Without it, more and more young people will move into the cities leaving behind older people and children without the benefits of modern technology. This often leads to a steadily declining agricultural output and a degraded environment. With a power supply and modern communications, land can be irrigated, small industries can flourish and farmers can make sure they are getting the best price for their produce. And at schools, children can learn all about modern technology and about societies in other countries.

In my travels around the world over last 45 years, I have noted that in most developing countries, rural electrification is expanding slowly because of its very high cost. In every country I have visited, there was high demand for rural electrification but it was often regarded as being too expensive and hopelessly uneconomic. In many countries, the distribution companies have demanded large subsidies for rural electrification. In the long run, these subsidies have been counter productive because they have eliminated the normal commercial drive to minimize costs by using appropriate technologies.

Rural distribution requires a different approach from the overhead distribution systems used in towns and large villages. The load density is low, and after the initial rapid increase as new consumers purchase appliances, the future load growth may be quite low. In some areas electricity will stimulate local development and load growth may be rapid, with power required for machinery, water pumping, and the like. This is not a problem, because, if large loads emerge, the income from them will fund any new lines that may be needed.

The guiding principle must be: "The lower the cost, the larger the area that can be reticulated with the amount of money available."

The first steps

Any organisation that is considering a major programme of rural electrification needs to have a good understanding of what they want to achieve and the options for achieving it. This will be different for every country because the population density, that the topography, and the existing power system will all be different from most other countries. So simply adopting existing urban practice is seldom the best option.

It must always be remembered that whatever system is adopted, it will probably be in use for more than fifty years. Therefore, if - for example - the system adopted is twice as expensive as it needs to be, a huge amount of money will be wasted. This is likely to have a serious delaying effect on the program because, in most cases, the rate of expansion of rural electrification is limited by money rather than resources. So if the money can be made to go twice as far, it will double the number of people who benefit.

A very important decision needs to be made quite early on: whether to develop local expertise and local resources or to rely overseas consultants and contractors. If the money is being provided by a Development Bank, it usually requires the use of overseas consultants and contractors. But if the government or the electricity organization is able to finance the program from its own resources, then, in my view, the best option is to develop local resources. If this is to be done, I would suggest that an engineer known for his (or her) innovation and ingenuity and with some experience in distribution should be given the responsibility of investigating the best overseas practice and, if necessary, selecting a few overseas experts to help train a specialist team of engineers and linesmen specifically for rural electrification.

In my view, the countries with the most relevant expertise in rural electrification are Australia, Southern Africa and New Zealand[2]. Australia has the world's most extensive system of rural electrification supplying very sparsely settled areas. It has literally hundreds of thousands of kilometers of rural electrification. Australian expertise is particularly valuable for countries with similar topography and climates ranging from very dry to those with a we season and severe lightning storms. For more mountainous countries the expertise developed in New Zealand is also very relevant. In recent years, South Africa has made considerable progress in rural electrification and they have made outstanding progress in providing very low-cost supplies to isolated villages and houses typical of the many developing countries. They have developed some excellent prepayment metering systems and other systems operating on a fixed fee basis with very effective load limiting capabilities[3]. As the cost of rural electrification system depends, to a very large extent, on the maximum demand – which often lasts for only a few hours, management of demand can be very important.

At beginning of the project, it would be very sensible to find young or retired engineers from Australia or New Zealand who are very happy to spend six months or a year in a different country where they will meet many challenges and have many interesting experiences helping local engineers.

Their job will be to set up preliminary design standards and then help with the training of line crews who will face many new challenges in installing poles and stringing lines in remote areas - often over very rough country. At the end of this first stage, the design standards will need to be revisited and modified if necessary. Once this is done, it is relatively easy to develop a large scale rural electrification programme, confident that the system selected will provide an economic and reliable supply.

As an example, let us consider a country with a relatively low population density and electricity supply restricted to towns and large villages that has decided to supply small villages and isolated settlements and farms. This is as near as one can get to a "green field" situation, so there are a wide range of options to be considered.

The first decision is the distribution voltage. In many countries, for historical reasons, the distribution voltage (MV) is 11 kV with 33 kV as a sub transmission voltage. In others, the distribution voltage is often 20 kV. Experience has shown that 11 kV is not an ideal voltage for rural distribution and 33 kV is, in most cases, too high for distribution[4] but not sufficiently high for sub transmission. The "ideal" voltages are 20 or 22 kV for distribution and between 66 and 110 kV for sub-transmission. So, for this case, the first choice is 20 or 22 kV.

The next decision is the system to be used. Where European practice has been adopted, three phase distribution at 11 kV or 20 or 22 kV in a three phase star configuration with an earthed neutral. Low voltage distribution is three phase four wire. Where American practice has been followed, there are a wide range of voltages: 7.2 kV, 12 kV, and 23 kV. Some are star connected and some are delta connected. There is a wide variety of low voltage supplies – 110/220 volt (using a centre tap) with 220 V used for large loads is quite common. Unlike

European practice, American residential and rural distribution is primarily a single phase supply that supplys quite large single phase motors in air conditioners and other large appliances.

Neutral earthing practices also differ. The European/UK systems usually keeps the MV earthing separate from the LV neutral and do not string a neutral/earth wire for the high voltage system.

Rural distribution in America is based on a single phase wire with a neutral/earth wire running beneath it. As result, virtually all rural electricity supplies are single phase. Rural electrification in Europe is similar to their residential distribution systems except that lighter lines and conductors are used and, in some cases, a single phase supply is provided by running only two phase conductors to supply small loads on spur lines. In my view, both of these systems are more expensive than they need to be for supplying sparsely settled areas.

For sparsely settled areas, the Single Wire Earth Return system invented in New Zealand80 years ago still offers the lowest-cost and the highest reliability. A brief description of this system and its early history is given below.

From the 1920s to the 1970s, rural electrification expanded very rapidly in New Zealand. The engineers were faced with a limited amount of money and many isolated communities clamouring for a supply. These rural communities saw electrification as the key to productivity, prosperity and a much higher standard of living. So they challenged the engineers to expand the system at minimum cost. The engineers soon realized that they could not afford to build a three phase line with "standard" conductors (e.g. 25mm^2) to supply an isolated farm. So they built low cost lines for a two or three phase supply using ordinary fencing wire as a conductor and poles cut from the nearest forest. In many cases, the rural community provided the poles, the horses needed to pull out the conductor and the labour - apart from a single linesman to make sure it was all done properly. To further reduce costs, they made the most of any opportunity to put poles on the top of hills with long spans from hilltop to hilltop.

In the early 1920s, Lloyd Mandeno, a very enterprising New Zealand engineer decided that he could save even more money by using a single live conductor and connecting the other end of the distribution transformer high voltage winding to earth so that the current returned to the high voltage neutral point of the transformer at the zone substation using the earth as a conductor. His invention is called the "Single Wire Earth Return" (SWER) system. It was widely used in New Zealand and it has been adopted in many other countries. It is still in very wide use in Australia where there are in excess of 200,000 km of SWER distribution in service. Many of these lines use steel conductors or small high strength steel and aluminium conductors.

Compared with a conventional three phase system to SWER, roughly three times as many consumers can be supplied for the same cost.

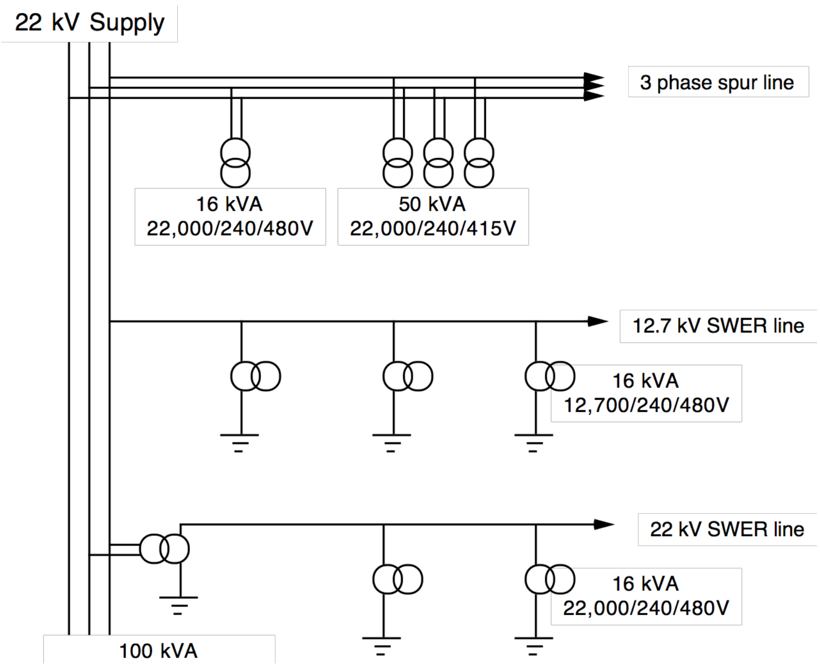
Suggested rural distribution system

The system proposed arises from the author's experience while engaged in mini-hydro studies in Sabah, Sarawak, East Timor, Bhutan and Zambia. In many cases, there was ample hydro potential but the area that could be reticulated - and hence the load - was restricted by the very high cost of rural distribution because they used a system primarily designed for urban supply. Arising from these studies, and my knowledge of the low cost systems used in Australia and New Zealand, I recommend the consideration of the systems described below.

The essential elements of the system are shown in the figure below.

Fig 1 Proposed Low Cost Rural Distribution System using 16 kVA transformers

The distribution lines have light, high strength conductors so that long spans can be used with standard poles. Lines are either three phase or SWER.



One standard size of single phase transformer could be used for three phase and single phase supplies.

LV distribution is either three wire 230/460 V or three phase 230/400 V. A balanced 230/460 V system is twice as effective as a 230 V system.

Power stations for isolated systems

Many small communities are far from the electricity grid so electrification needs to include a power station. In many cases, a small diesel generator will be sufficient but, very often, this is not a practical solution because of the very high cost of transporting diesel fuel and the very high cost of operation and maintenance. Small hydro power is often the optimum solution. Experience has shown that many small hydro power schemes for isolated systems are overly complicated and expensive and suffer from the lack of water during the dry season. Many have intake problems during the wet season and that reduces the availability.

In 1987 I presented a paper at a conference in Kuala Lumpur describing the problems involved in building and operating small isolated hydro power schemes[5]. The final conclusion of this paper was that a very viable option was to have a single hydro turbine and a backup diesel generator in the same powerhouse. Having the two generators at the same location simplifies operations, makes it easier to manage peak demand periods and allows supply to be maintained when intakes have to be cleaned or when the river flow is too low to supply the peak demand. It has the additional advantage that it as possible to install a larger hydropower unit than would normally be the case because, in general, isolated hydro power stations are sized to match the flow available 95% of the time. If diesel backup is available, the hydro generator can be sized to match the flow available for, say, only 60 percent of the time. This could easily be 2-3 times as large as an installation that matches the flow available 95% of the time. Because the cost of a diesel generator is very low compared to the cost of the fuel it burns this is very cost effective because it is needed for a small proportion of the time.

Although still much more expensive and unreliable than hydropower, wind and solar power technologies are improving and becoming cheaper. If there is some hydropower potential available with ample storage but with insufficient capacity to supply the load, then wind and solar power can supply the load when the sun is shining or the wind is blowing while the hydro power station stores water for use in the night time or when the wind is not blowing. Alternatively, the backup to solar and wind can be provided by a diesel generator. In general, systems like this are expensive and are often not suitable for loads greater than 100 kW or so. Nevertheless there are situations where it is a viable option so it should not be ruled out.

Conclusion

Rural electrification is – or should be – a key part if any programme for national development. The economic and social consequences of not supplying electricity to isolated rural communities are quite severe. The rewards can be great.

Rural electrification is inherently expensive so it is very important to make sure that the best available technology is chosen. The best technology is the one that gives the lowest-cost supply without compromising reliability. Experience in many countries shows that the Single Wire Earth Return system developed in New Zealand 80 years ago is substantially lower cost and provides higher reliability than any other system. Many SWER systems have proved themselves all over the world.

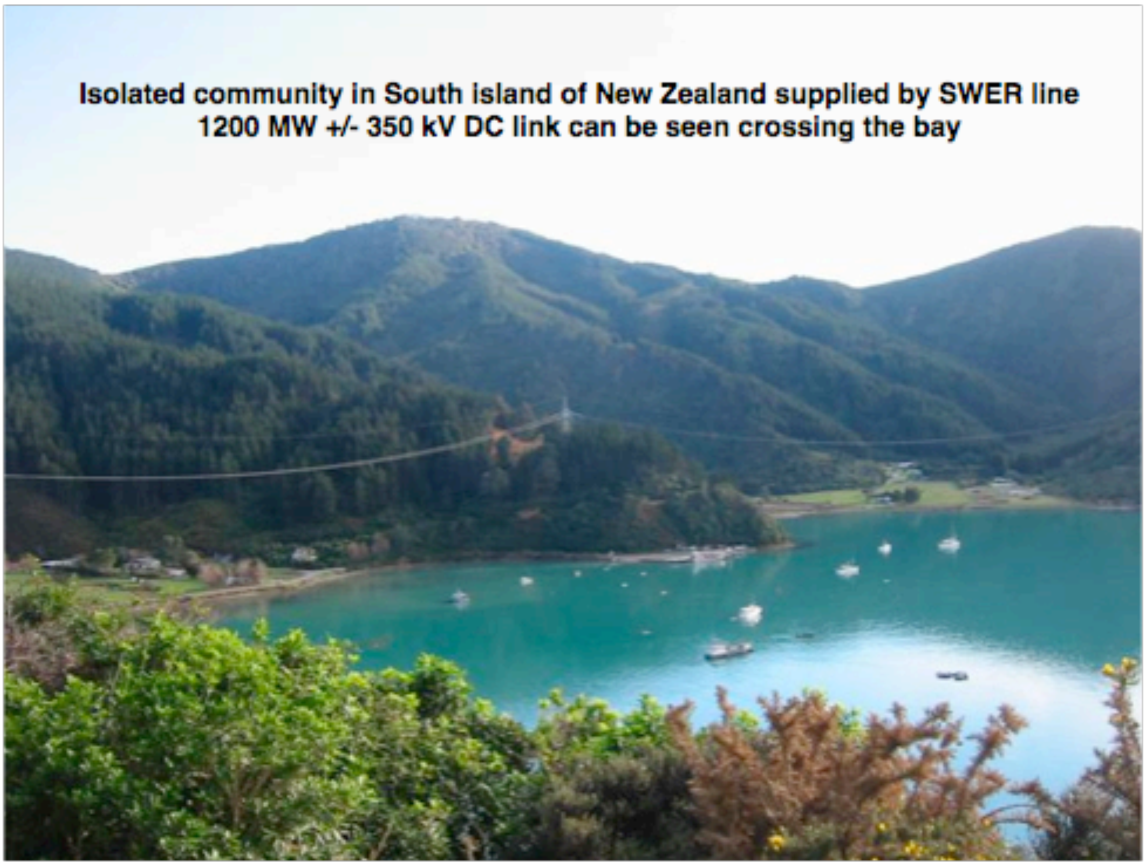
Bryan Leyland MSc, FIEE, FIMechE, FIPENZ, is an Electrical and Mechanical Engineer specializing in power generation and power systems.

He has extensive experience in hydropower generation and rural electrification. He was involved in structuring the electricity industry in Bhutan so that it can maximize its return from exporting large amounts of hydropower to India. He also valued the Bhutanese distribution system and recommended changes that would reduce the cost of rural electrification. He has also advised on rural electrification in East Timor and Malaysia.

He has worked in the UK, Middle East, Africa, SE Asia and the Pacific.

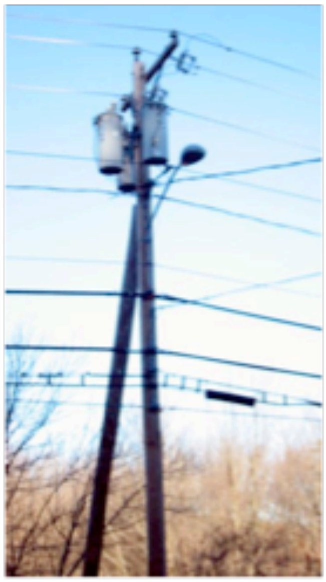
Illustrations:

Rural distribution in New Zealand & USA



16 kVA SWER transformer

25 kVA 2 phase transformer



3 x 100kVA on a single pole in the USA

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[1]"Rural electrification: How to do it better and cheaper" "Water resources and renewable energy" Hydropower and Dams, Bangkok, Nov 2006.

[2]I have been told that South America, too, has extensive rural electrification. But I have no other information about it.

[3] See http://www.cbi.co.za/products_select.php?p=4

[4] 33 kV is widely used in Australia but experience in many countries indicates that small (5 to 15 kVA) distribution transformers are unreliable at 33 kV unless they are very carefully designed and built. Many small transformer manufacturers have failed to make small 33 kV distribution transformers that are reliable.

[5] www.bryanleyland.co.nz hydropower/Hydro Schemes for Remote Areas