New Designs for Rural Electrification

Private-Sector Experiences in Nepal

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NEW DESIGNS FOR RURAL ELECTRIFICATION

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बुटवल पावर कम्पनी लिमिटेड
Butwal Power Company Limited

USAID

National Rural Electric Cooperative Association

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To villagers in rural Nepal and in countries around the globe who are key to the sustainable development of their nation yet who lead an arduous existence, often without the myriad benefits of electrification taken for granted by urban populations

EXECUTIVE SUMMARY

Pressure for greater access to electricity and to its benefits continues to be felt throughout the world. But extending the national electricity grid into rural areas has generally been a costly exercise. To have a realistic chance of meeting the demand for electric service in these areas requires progress on two fronts:

- reducing the costs associated with electrification and
- increasing the benefits and financial returns from the use of electricity.

But rather than addressing these issues, rural electrification often proceeds in a manner analogous to that pursued in the urban areas. Little effort is focused on assessing whether designs and standards developed for urban centers are the most appropriate to meet the needs of rural populations, whose principal electricity use is for lighting and whose peak demand is, and will realistically remain, very low. One exception to this trend has been the work carried out by a group of companies and development workers under the aegis of the United Mission to Nepal (UMN). These have been involved in the generation and distribution of electricity and have taken this opportunity to investigate alternative approaches to rural electrification. This study summarizes some of their experiences.

The principal issues facing rural electrification which are addressed and documented by this study are summarized below, followed by brief descriptions of the interventions made and conclusions drawn from experiences to date. Definitive conclusions cannot always be drawn from experiences to date. Rather, this study recognizes that efforts in the field are continuing and that lessons learned are being fed back into ongoing efforts.

1. Cost of grid extension: One reason that high costs are commonly associated with extending the grid into rural areas is that conventional designs used to supply densely populated, urban centers are also routinely adopted in remoter areas, without much thought to their appropriateness.

New intermediate distribution voltage: A 1/0.23 kV distribution system was selected to serve several villages with no road access, because an initial analysis showed a 30% savings in cost over that incurred through the use of the conventional 33/0.4 kV system. Although the system continues to operate well, a recent reassessment indicates that no significant cost advantage is associated with the use of the 1 kV voltage at this site. Furthermore, under these circumstances, using this voltage would be costlier if there had been additional consumers to be served at a distance beyond 5 kilometers from the main 33 kV line.

However, the consumer density in the area served is fairly high. In a more typical situation in Nepal, it would appear that the size of the consumer clusters would be smaller and more dispersed. Under these circumstances, the 1 kV distribution voltage could prove less costly. Furthermore, relying on transformers which can be carried by a single porter could prove a significant advantage when bringing electricity to remote communities with no road access. In continuing to pursue the least-cost approach to rural electrification, it is important to remain alert to the cost advantages of alternative distribution system configurations and voltages for different consumer patterns and to be receptive to using non-conventional designs if these contribute to increasing the affordability of rural electrification.

2. Utility poles for off-road application: Cast concrete poles are commonly used for roadside electrification in Nepal. However, if there is to be any chance of extending the electricity supply into remote areas, an alternative to these unduly heavy concrete poles must be found.

Fabricated steel poles: A standardized set of tapered galvanized steel poles has been designed of telescoping sections which readily can be carried by porters to remote locations and assembled on-site. Furthermore, the need for expensive poles is reduced by using insulated bundled cable for secondary lines that can be supported by locally cut poles, live trees, or sides of buildings. While rudimentary and less costly lines can be built, the use of fabricated poles and bundled cable ensures a system which is safe and reduces maintenance, repair, and replacement cost to a minimum.

3. Cost and complications of housewiring: Conventional housewiring poses two problems: high cost for small consumers and the difficulty in installing in homes of less than "permanent" construction.

Wiring harnesses: Designs for wiring harnesses have been developed which can be assembled under controlled conditions and installed with minimal expertise. Because of the flexibility they offer, these harnesses are also popular in some homes where conventional wiring could be installed. By using a harness, costs as low as $5 per home are possible, while the cost for conventional wiring begins at $20 to $30.

4. Cost of meter: Besides the cost of electricity itself, the cost of an energy (kWh) meter is an additional expense which dissuades poorer villagers with minimal disposal income from accessing electricity:

Current cutouts: Various approaches have been developed using thermistors, miniature circuit breakers, or electronic current cutouts to replace more expensive, conventional energy meters ($3 to $10 vs. at least $20 for the latter).

5. Meter-reading and billing costs: These electric utility expenses can add significantly to the cost of electricity supply for small consumers.

Power-based tariff: A power-based (kW) tariff was implemented which eliminates the need for, and costs associated with, meter-reading and billing consumers. For small, rural consumers who may spend $0.40/month for electricity, the costs of meter-reading and billing alone can equal this sum.

Although the power-based tariff structure also encourages use of non-peak power, no significant additional benefits have yet been associated with this increased load factor.

6. Limited benefits from electrification: Because of the costs incurred in electrification and the need to reduce subsidies, benefits attributable to electrification must be maximized. But experiences around the world have shown that initial benefits of rural electrification often have been restricted to lighting.

Development of end-uses: Recognizing the need to increase the socio-economic impact of electrification on rural communities, significant thought has been focused on developing benefit- and income-generating end-uses. But experience has further confirmed the fact that numerous complementary inputs are necessary for this to occur. Increasing end-use of electricity is further complicated by the fact that many consumers have access to only small amounts of power and have little disposable income for purchasing appliances or equipment to put this electricity to other uses.

It must be emphasized, however, that electricity is generally highly valued and that consumers are willing to pay considerably for this resource and for the benefits they associate with it, whether or not those are quantifiable by researchers. In this respect, these rural consumers do not differ from typical residential consumers in industrialized nations.

7. Electric cooking: This represents a major use of energy in Nepal, but the high power demand and coincident nature of cooking loads make it necessary for a generating and distribution system with significantly greater capacity and cost than would otherwise be the case.

Low-wattage cookers: Several interesting designs have been developed which have made cooking possible with a power consumption as low as 200 W. But social and/or financial obstacles still remain: The *bijuli dekchi* requires a change in cooking style and still costs about $30 per pot, while the forced-air cooker more recently developed minimizes changes in cooking style but is costlier (more than $60). Furthermore, until the real cost of extracting fuelwood from Nepal's dwindling forests is reflected in the cost of that resource, the higher cost of electrical energy will continue to act as another deterrent to its use. In the meanwhile, an increased subsidy for cookers that use hydropower-based electricity might prove a net advantage to the nation.

8. Management: Electric utilities hesitate to serve the more remote areas because of the logistical difficulties and costs they incur in constructing these systems and in maintaining staff to oversee operations. The low financial return for their efforts is a further deterrent.

Users' organizations: The concept of users' organizations, already in use in other sectors, has been adopted to provide coordination between the villagers and the electric utility during project design and construction, to collect monthly fees from all consumers and deposit them in the utility's local bank account, and to maintain liaison between consumers and the utility to resolve technical problems that may arise. The burden on the utility from operating rural systems is thereby minimized.

9. Lack of awareness of electricity: Most villagers have seen electric lights; nevertheless, a general lack of awareness of electricity and its uses tends to prevent potential consumers from maximizing the benefits they might derive from it.

Motivators: The utility hired and trained individuals on a full-time basis to familiarize villagers with all aspects of electrification—housewiring, safety, tariffs, and end-uses. Consequently, unlike "electrified" villages throughout the world which actually may have only a few domestic connections, a very high percentage of villagers in the service area have opted for access to electricity in spite of very small disposable incomes.

By adopting designs that reduce costs while retaining safety and reliability standards, the private sector has illustrated that project implementation costs considerably below those commonly assumed for such projects are possible.

The area described in this study includes six villages, with about 500 consumers distributed in an area 2 kilometers wide and extending 5 kilometers from the 33 kV line. Constructing a distribution system to supply this area with a 33 kV substation transformer and either a backbone 1 or 11 kV ACSR line and a low-voltage network would cost about $60,000 at today's prices, exclusive of service drops and housewiring, or about **$120 per connection**. Furthermore the total cost of materials and labor for a three-phase (three-wire) 25 mm^2 ACSR line with 70 m spans supported by galvanized steel poles is **$3,700 per kilometer** (about equally divided between conductor and pole costs) in an area without immediate road access. These costs are significantly below those commonly encountered worldwide—**$600 per consumer** and **$5,000 to $15,000 per kilometer**, respectively.

If the objective is to provide electricity to rural households in the most cost-effective, sustainable, and environmentally benign manner, one should be equally receptive to all options, considering new technologies and designs as well as new institutional approaches to implement and manage these systems. This study reinforces the proposition that the option of grid extension should not automatically be dismissed as unaffordable on the basis of poorly designed rural electrification projects found around the world. Rather, there is a need to reassess the commonly assumed costs of grid extension and to be receptive to new designs that more cost-effectively meet rural needs. Experiences in the Andhi Khola area illustrate that grid extension promises the potential to provide electricity at a quality, quantity, and cost that are much more competitive with alternatives than is commonly thought.

CONTENTS

8

a

ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

ACSR	aluminum-conductor, steel-reinforced*
AHREP	Andhi Khola Hydel and Rural Electrification Project (p. 2)
AKP	Andhi Khola Project (p. 2)
bijuli dekchi	low-wattage cooker developed in Nepal (p. 32)
BPC	Butwal Power Company Ltd. (p. 2)
DCS	Development and Consulting Services
ECC	electronic current cutout (p. 26)
HH	Himal Hydro and General Construction Co. Ltd. (p. 2)
HMG	His Majesty's Government (of Nepal)
ITDG	Intermediate Technology Development Group (headquartered in England)
kV	kilovolt (1,000 volts)
kW	kilowatt (measure of power equivalent to 1,000 watts)
kWh	kilowatt-hour (measure of energy)
LCC	life-cycle cost
MCB	miniature circuit breaker (p. 25)
MJ	megajoule, a measure of energy equivalent to about 0.28 kWh
MW	megawatt (1 million watts)
NEA	Nepal Electricity Authority, the national electric utility
NHE	Nepal Hydro and Electric Co. Pvt. Ltd. (p. 3)
primary distribution voltage	11 kV or higher (as used in this study)
PTC	positive temperature coefficient thermistors (p. 26)
PV	photovoltaic
Rs	Nepali rupees**
rural households	households in project area at some distance from main road (Aserdi)
secondary distribution voltage	1 kV or lower (as used in this study)
semi-urban households	households in the project area which are located on or near the main road (Upper and Lower Galyang, Falang, Bhati, and Amila Kharka)
tayari wiring	"ready-made" wiring harness (p. 27)
UMN	United Mission to Nepal (p. 2)
UO	users' organization (p. 39)
VDC	Village Development Committee (p. 40)

* As used by BPC, ACSR conductor is measured in square millimeters of copper equivalent. In this publication, these figures have been multiplied by 1.6 to get the aluminum equivalent, which is the unit of measure commonly used worldwide.

** All rupee costs have been converted to 1994 US$. Conversion factors are noted in Annex A. All dollar costs included in this report are in 1994 U.S. dollar equivalents. In 1994, US$ 1.00 = Rs 50.

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The material that forms the basis of this study was gleaned from the experiences of numerous people, each of whom has devoted at least several years striving to develop approaches to bring the benefits of electrification to Nepal's rural population.

Foremost, I wish to thank Dale Nafziger, BPC Rural Electrification Planner, who spurred me to actually embark on this project and who served as a critical link to events and players in the field by coordinating inputs. He promptly responded to, and appeared undaunted by, the constant stream of faxed inquiries from Washington and critiqued this document to ensure an accurate portrayal of the experiences described. Furthermore, through his extensive field studies over the years, which resulted in several publications including the dissertation, "Impacts and Implications of Rural Electrification Ideology in Nepal's Domestic Sector", Dale has contributed information toward this study which would otherwise have been difficult to obtain.

Vinay Bhandari, Assistant Electrical Engineer with BPC in Galyang and AHREP Planning In-Charge, generously gave of his time to accompany me on field visits and provided detailed responses based on extensive involvement in the field. He conscientiously applied himself to undertaking the challenging and demanding task of reassessing a variety of distribution configurations and voltages to determine the least-cost approach to serving rural loads, an analysis which should contribute further to finding a more cost-effective solution to electrifying rural Nepal.

Suman Basnet, AHREP Manager, coordinated site visits, provided a personal glimpse into the work at the project site, and shared access to documentation in the field. Bhola Shrestha, Project Engineer with ITDG Nepal, provided prompt and detailed responses to numerous inquiries for information on the forced-air heat-storage cooker. And Bikash Pandey, micro-hydropower consultant and Office Manager of ITDG Nepal continues to be a knowledgeable, informed, and reliable source of information on the micro-hydropower and rural energy sector in Nepal.

This study could not have been undertaken were it not for the efforts of Odd Hoftun who had the original vision to harness Nepal's indigenous hydropower resources to bring electricity and its benefits to those in remote rural portions of the country and whose commitment over the past nearly 40 years has been translating this vision into reality. He also originated a number of the ideas with the view of making electricity more accessible to rural communities, such as the use of the 1 kV intermediate distribution voltage and other innovations included in this study. The author is also indebted to a number of UMN staff who over the years have unknowingly contributed to this effort by leaving an abundant paper trail documenting their activities and experiences.

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PREFACE

Around the world, from the steep, terraced hillside slopes of Nepal and the dense, luxuriant jungles of Papua New Guinea to the stark, expansive desert regions of Tunisia and the forlorn, wind-swept plateaus of the Bolivian altiplano, rural populations are increasingly demanding electricity and the benefits commonly associated with it.

Many seem willing to pay considerably for access to small amounts of electricity to perform tasks they value. Consumers in the industrialized nations commonly pay **US$ 0.10** per kilowatt-hour (kWh) and consumers in many developing countries pay considerably lower subsidized rates. But Nepalis, living in communities a week's walk from the nearest road and eking out a living in an austere environment, are willing to pay up to **$0.30** per kWh ($1.50 per month) for basic service. In Indonesia and elsewhere, people purchase small diesel/generator sets and sell electricity to neighbors, with the real cost of **at least $0.40** per kWh. In Panama, campesinos carry their automotive batteries to the nearest town to charge them for the equivalent of **$1.00** per kWh plus the costs of their transportation and periodic replacement. In the Dominican Republic, rural farmers willingly spend $5 to $10 per month or the equivalent of **more than $2** per kWh for household photovoltaic (solar) systems providing very limited energy for some lighting, radio, and TV use. And people throughout the world who rely on dry cells for radios and cassette players are purchasing these at an equivalent cost on the order of a surprising **$50** per kWh.

But low electricity consumption, little disposable income, high construction and staffing costs, and logistical difficulties encountered in serving rural consumers are all factors that have prevented a large segment of the rural population from accessing grid electricity. Furthermore, while those in industrialized nations make extensive use of electricity in all their daily activities and take it for granted, some question the merits of supplying electricity to rural populations. They feel that financial resources used for electrification should rather be used to support other, more critical infrastructure development efforts. Providing electricity to rural areas is seen by some as too costly an exercise. From their perspective, it vies for funds with the construction of roads, which facilitate access to markets; with water and sewage systems, which reduce the incidence of disease; or with education, which offers rural populations the opportunity to better themselves and their nation.

Clearly, there is a widespread desire for electricity in rural areas, and some villagers are willing to pay considerably for this commodity. Furthermore, few will dispute the fact that electricity is an intervention that plays a critical role in development. However, to increase its attractiveness to governments and financial institutions, which are usually responsible for initial capital investments in electrification; to encourage its broader replication; to permit a larger portion of the population to avail itself of the benefits customarily attributed to this form of energy; and to contribute to other rural development activities, reductions in the costs associated with distributing and using electricity are needed.

In order to reduce the costs of electrification, several points seem clear. First, because of economies of scale, centralized power generation usually rep-

In a village north of Vientiane, Laos, batteries are being charged for villagers beyond reach of the national grid.

resents the lowest-cost source of electricity. Furthermore, if one relies on fossil-fuel-based electricity, as is commonly the case, centralized generation permits the potential for more efficient use of this resource and greater facility in mitigating any adverse environmental impacts.

Second, while centrally generated power may be the least expensive, significant costs are incurred in transmitting and distributing this power from the powerplant to the rural consumer.

Third, covering these costs through subsidies is becoming more difficult as governments are faced with revenues inadequate to cover an increasingly broad range of needs.

One promising option for harnessing the advantages of centrally generated power and for making electrical energy for development more accessible to rural population is to reduce the technical and institutional costs of transmitting and distributing electricity from centralized powerplants to rural areas. The United Mission to Nepal (UMN), a broad-based, church-related development organization with four decades of commitment to the people of Nepal, has been attempting to address this challenge.

Making mechanical or electrical energy for development activities available to rural populations has been of interest to UMN since its establishment. Construction of the 5 MW Andhi Khola hydropower plant and irrigation scheme in a formerly unelectrified portion of the country has enabled UMN to research approaches to enhance accessibility to, and to increase the benefits from, rural electrification. This effort has extended over most of the past decade. Institutions and individuals working in the field, however, frequently are too preoccupied with their daily activities to document their experiences and lessons learned to assist others in parallel efforts to reduce the costs of rural electrification and increase the benefits attendant to the introduction of electricity.

Also involved in rural electrification internationally has been the National Rural Electric Cooperative Association (NRECA), whose initial objective when it was founded in the 1940s was to encourage and facilitate the electrification of rural America. Success in the United States has been achieved by acknowledging the need for, and implementing, new approaches to rural electrification. The North American distribution system (four-wire grounded-wye primary lines, with single-phase extensions) and a reliance on the cooperative form of ownership and management have been two major innovations. With the formation of its International Program Division in 1962, NRECA has strived to share its experiences with less economically developed nations around the world.

As we approach the end of the 20th century, NRECA recognizes a need to reach out once again for new, creative ideas to broaden access to electricity by the world's still unserved rural population. It also recognizes the innovative and dedicated efforts of UMN in striving to bring the benefits of electrification to the people of Nepal as one step toward achieving this end. UMN's efforts are far from complete, and lessons continue to be learned. But rather than wait several years until each innovation's success in increasing accessibility to electricity can be more definitively assessed, NRECA and UMN have prepared this publication to share UMN's initial experiences with others interested in promoting sustainable rural electrification. It is hoped that this may encourage others both to delve into unconventional approaches to rural electrification and to document their experiences to the benefit of others.

This publication is a result of a survey of available literature, supplemented by information gleaned from extensive field visits and consumer interviews. It begins with a descriptive overview of the project and summarizes the innovations associated with it. The two subsequent chapters present detailed narratives of these innovations. These are followed by observations and an assessment of the impacts of the various interventions. The report ends by drawing tentative conclusions from these interventions, tentative because a study of both electrified and non-electrified rural populations over a period of time would have been required to evaluate more definitively the impact of electrification on rural populations. It also recognizes that these impacts do not take place overnight and that work at the project site continues. Additional changes may therefore follow.

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14

INTRODUCTION

BACKGROUND

Rationale for involvement in rural electrification

Although Nepal is a small country, the paucity of roads and the ruggedness of the terrain hamper communication and transportation among the numerous villages scattered throughout this land-locked nation. Electricity, water supplies and sewage facilities, hospitals, and other amenities are largely unavailable outside the densely populated areas.

Electricity, an important ingredient for development, is transmitted along the country's southern border with India, but access to it is limited largely to those within easy reach of the national grid. Much of the country finds itself in the dark, its burgeoning population leading an arduous existence, eking out a livelihood from overexploited lands and quickly depleting its principal source of energy—its forests.

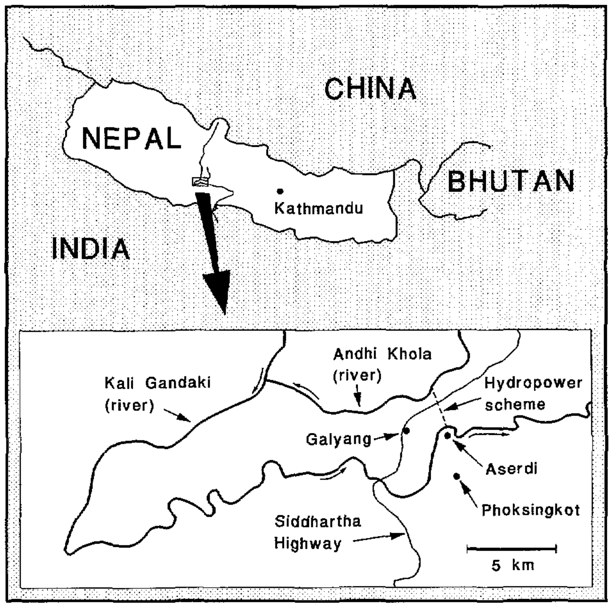

Fig. 1. Map locating the Andhi Khola hydropower scheme and the communities of Galyang, Aserdi, and Phoksingkot.

However, the innumerable rivers that traverse the country, fed by melting snows from the Himalayas and monsoon rains, suggest a locally available resource that could be harnessed to meet the energy needs for development activities in its towns and isolated communities—hydroelectricity.

The Andhi Khola, one of many rivers crisscrossing the country, presents unique characteristics. From just north of the small town of Galyang, its waters flow westward into the Kali Gandaki, eventually changing direction, and finally flowing eastward, covering a distance of 65 kilometers before returning to a point just south of the same town but at an elevation of 250 meters lower (Fig. 1). This represents an ideal hydropower site—a significant drop in elevation from one river to the other, over a short distance—where 5 MW of electric power could be generated and distributed up and down the valley to areas largely lacking electricity, between the large towns of Pokhara, 80 kilometers to the north, and Butwal, 80 kilometers to the south.

But the United Mission to Nepal (UMN), which eventually assumed responsibility for developing this site, was as equally interested in developing the nation's human resources as in the constructing infrastructure. This potential project was not seen simply as a means of generating electricity to feed the national grid. Rather, the UMN envisioned it as a major component of an integrated rural development project that could begin to address some of the pressing development issues facing rural communities in Nepal.

UMN hypothesized that (1) substituting electricity for fuelwood could reduce pressure on the forests, (2) using electricity for lift irrigation, the operation of ropeways, and agro-processing could increase yield from existing land, and (3) harnessing electricity could generate new employment opportunities. By constructing the Andhi Khola powerplant, which could serve as a large reliable source of electricity, UMN foresaw the project as a unique opportunity to test new ideas and approaches to rural electrification that might reduce the significant costs incurred in implementing such projects. UMN also saw the opportunity to assess whether the introduction of electricity into the rural milieu, where households have limited financial resources at their disposal, could benefit small isolated communities. It was also interested in assessing whether electrification could reduce growing environmental degradation, apparent in the form of decreasing forest cover, and provide alternative employment opportunities to agriculture, which is being practiced on increasingly marginal lands.

Andhi Khola Hydel and Rural Electrification Project (AHREP)

The prime mover of these development activities has been UMN, a Christian Protestant organization formed in 1954 and now comprising nearly forty member bodies representing the mission boards of churches and independent mission societies from about twenty countries. UMN has been involved in health, education, engineering, industry, and rural development.

In fulfilling its mission over the years, UMN has developed institutions and infrastructure that utilize Nepal's natural and human resources and promote a policy of import substitution: the Butwal Technical Institute, followed by Butwal Engineering Works, Development and Consulting Services, Butwal Wood Industries, Bio-gas and Agricultural Equipment Development Company, Butwal Plywood Factory, Butwal Power Company, Himal Hydro and General Construction, and Nepal Hydro and Electric. UMN's effectiveness has largely been a result of the skills of its workers, their recognition of the long-term commitment required to bring about effective change, and their dedication to serving the people of Nepal.

During UMN's search for a site for its technical institute in the early 1960s, a proposal was formulated that it be located in the area near Galyang, where it could take advantage of the hydropower potential of the Andhi Khola. The institute was eventually located at Butwal, and UMN subsequently undertook the construction of the 1 MW Tinau Khola hydropower project to generate electricity for that area. At that time, UMN formed the Butwal Power Company (BPC) to construct the powerplant.

By the late 1970s, the Tinau Khola project was completed. Experiences gained through this effort led to the conclusion that hydropower development was a sector worthy of further UMN involvement. Also during this decade, UMN embarked on the design of turbines and associated hardware and the implementation of micro-hydropower plants (5 to 15 kW) for providing motive power in remote areas for hulling rice, milling grain, and extracting oil from seed. Subsequently, other projects were sought in which the hydropower expertise and experiences gained could be applied. UMN and BPC agreed that the Andhi Khola site seemed the logical follow-up site to develop.

But the 1970s was also a period of growing interest in development involving popular participation, appropriate technologies, and integrated rural development. As the Andhi Khola power project evolved, UMN directors on the BPC board used their influence to steer the Andhi Khola Hydel[1] and Rural Electrification Project (AHREP) away from focusing solely on a hydroelectric project to assuming a key role in an integrated rural development project. In response to expressed local needs, UMN became involved in irrigation, resource conservation, drinking water and sanitation, adult literacy, and nonformal education, in what is known as the Andhi Khola Project (AKP). These two projects operate side by side in the same geographical area. AHREP's focus is on rural electrification, while AKP's is to provide supporting activities that contribute to the broad development of the region in a complementary fashion.

Furthermore, UMN felt that developing indigenous capability to supply the engineering and industrial services, rather than relying on a continuing stream of overseas consultants, would be the most efficient and economical way for Nepal to exploit its considerable hydropower resources and to contribute more broadly to the nation's development. Consequently, in partnership with His Majesty's Government in Nepal (HMG), UMN established several local companies beginning in the 1970s, including:

- Butwal Power Company Limited, a public utility operating and managing hydroelectric power projects and associated electricity distribution systems, currently the owner of AHREP;

- Himal Hydro and General Construction Company Limited (HH), a contractor specializ-

[1] Hydel is an expression commonly used in the Asian subcontinent as a synonym for <u>hyd</u>ro<u>el</u>ectric.

16

ing in tunneling and in civil construction for hydropower plants and irrigation projects; and

- Nepal Hydro and Electric Company Private Limited (NHE), a manufacturing and service industry based in Butwal which, with some foreign collaboration, manufactures and repairs various electro-mechanical equipment for the generation, transmission, and distribution of electric power.

In June 1982, an agreement for the implementation of AHREP was signed between HMG and UMN. Among other terms, it stipulated that UMN was to be responsible for the "development of appropriate technology and suitable methods and tariffs for rural electrification."

While the hydropower plant could be developed economically, the viability of the electrification component of the project was less easy to establish. It was decided that the electrification scheme would be non-profit. A major objective was then to reduce costs sufficiently to be able to set a tariff that would be affordable to the consumers, yet one that could generate sufficient income to cover direct operating and maintenance expenses, with some remaining for reinvestment.

Construction of the hydropower plant commenced in the early 1980s. It included the construction of a concrete diversion weir and intake structure on the Andhi Khola, a 1.3 kilometer-long horizontal tunnel approximately 2 meters high cutting through the mountain, and a vertical shaft 4 meters in diameter and 230 meters down to the underground powerhouse.[2] This shaft contains the penstock and provides access to the powerhouse. Another horizontal tunnel 1.1 kilometers long conveys the spent water back to the downstream portion of the river (Fig. 2). Three secondhand 1.7 MW Pelton turbines and generators from Norway were refurbished by NHE and installed at the site. A 33 kV transmission line connecting the project site with the existing Nepal Electricity Authority (NEA) line to the south was completed in mid-1988, and the local distribution system for electrification of the pilot project was completed and energized in mid-1989. Commercial electricity generation formally commenced in July 1991. Initially, 90% of all households in the project area subscribed to electricity.

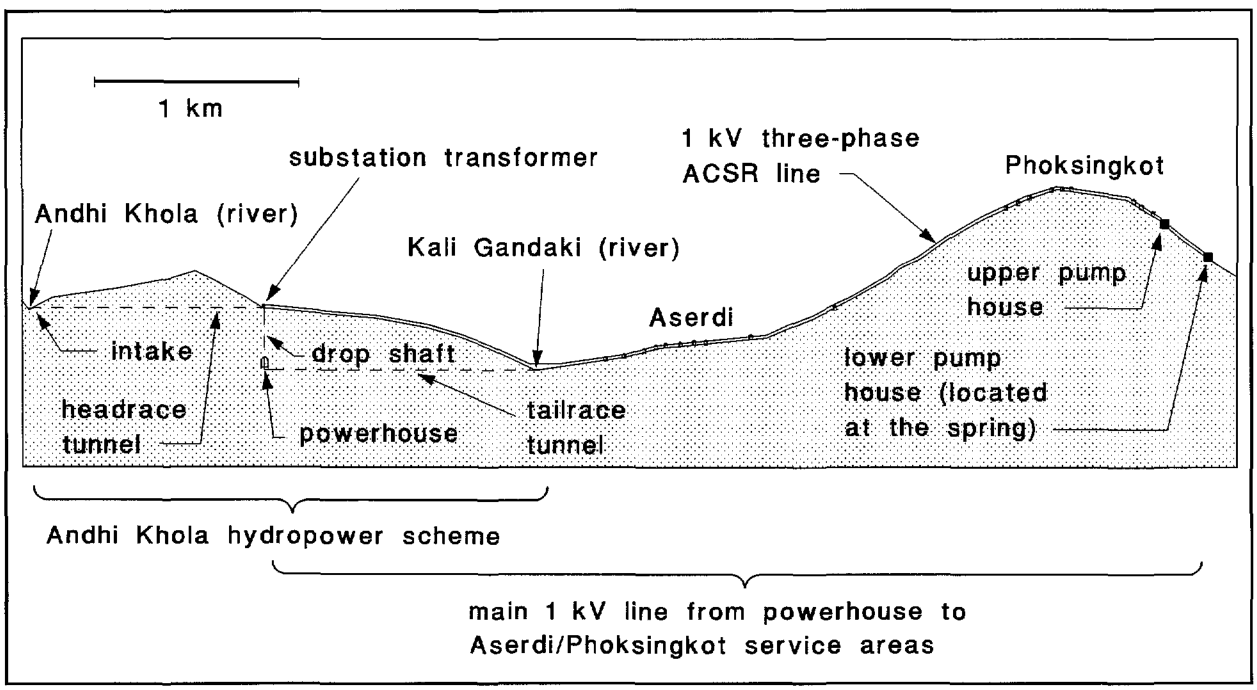

Fig. 2. Cross-sectional view of the hydropower and rural electrification projects in the AHREP area.

[2] Just before the water descends the vertical penstock, a portion can be diverted into the irrigation system which has been included as another component of the overall infrastructure development in the area.

Coinciding with the construction of the hydropower plant, detailed planning for the rural electrification pilot project began in May 1986 with the formation of the AHREP Rural Electrification Committee. Committee members were representatives from BPC, AKP, the Rural Electrification Section of Development and Consulting Services (Butwal), and the Rural Development Center (Pokhara), all UMN-related organizations. This committee continues to meet twice a year. A Technical Sub-Committee was set up to deal with technical aspects of the pilot project installation.

The area for the pilot rural electrification project initially included "semi-urban" consumers in Galyang and three other villages located on or near the main road close to the Andhi Khola powerplant and "rural" consumers in the somewhat remote village of Aserdi. Electrification of Galyang and the several neighboring villages was achieved using a conventional three-phase 400/230 V distribution system with several unconventional aspects: some use of bundled rather than uninsulated ACSR cable, steel rather than concrete poles, and two-tier rather than conventional (single-tier) metering. Approximately 270 consumers were initially connected. The principal objective of this project component was to research a new tariff structure as well as various methods of construction. Electrification of Aserdi was achieved with the use of a three-phase, three-wire line and single-phase spurs at an intermediate voltage of 1 kV. Almost all of the approximately 170 households in the rural component of the pilot project were initially connected to the system. One of the objectives of this project component was to assess the suitability of this infrequently used voltage.

Some of the electricity not consumed in the vicinity of the Andhi Khola powerplant is distributed by BPC in the larger town of Walling, on the road to Pokhara, which has since been electrified using the same approaches used in the semi-urban areas

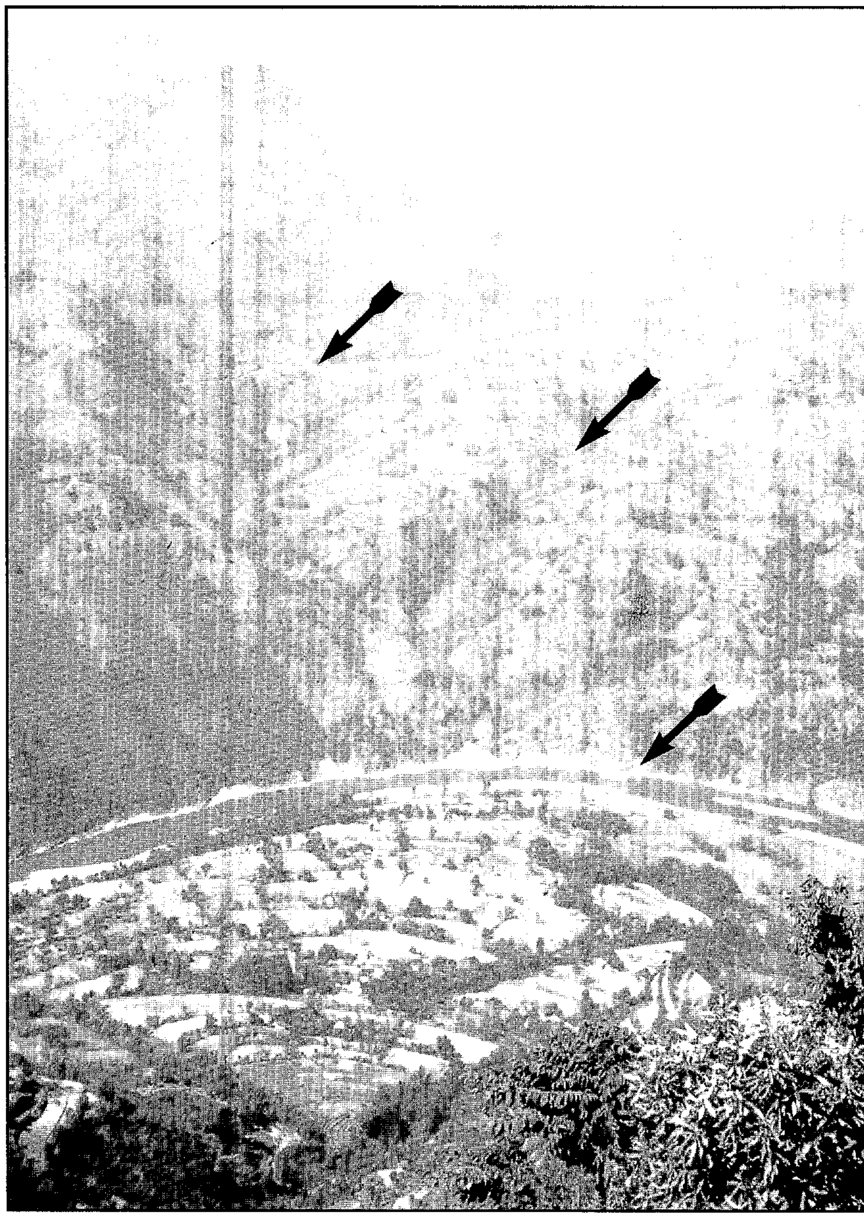

Fig. 3. A view from the area around Phoksingkot down to Aserdi, the Kali Gandaki river, and back up to Galyang, situated on the saddle (upper arrow). The Andhi Khola river is located in the valley behind Galyang. The lower arrows indicate the entrance to the shaft leading down to the powerhouse (which is at approximately the same elevation as the Andhi Khola) and the water exiting from the tailrace tunnel.

near the powerplant. A portion of the electricity was also used by BPC in constructing the 12 MW Jimruk Hydel and Rural Electrification Project located 70 km to the west along another transmission line constructed by HH. The bulk of the energy is exported via Butwal and fed into NEA's national grid (at the current rate of about US$ 0.025/kWh).

Profile of the pilot project area[3]

A profile of the villages in the AHREP area appears below and serves as a point of reference as to the conditions under which electrification was undertaken. The factors of greatest relevance in this profile, from the viewpoint of rural electrification, are the economic status of the villagers, the sources of energy now used for which electricity could be a substitute and expenses they incur for this energy, and the receptivity of villagers to new ideas.

The population within the project area falls into two fairly clear categories. The "semi-urban" component resides in Galyang Bhanjyang (referred to below simply as "Galyang") and several neighboring villages located on or near the two-lane Siddhartha Highway (the main north-south road between Pokhara and Butwal). The "rural" component resides in Aserdi, a village located about an hour's walk from Galyang, across the Kali Gandaki river and with no road access (Fig. 3).

The major village, Galyang, is a bazaar town and a busy bus stop along the road. It is located at 10 minutes' walk from the Andhi Khola powerplant and has hotels, banks, several private health clinics, a government high school and two private boarding schools, and a large number of shops bordering the road (Fig. 4). Approximately 70% of the consumers live in substantial structures constructed of permanent materials. A gravity-fed water system provides water through a network of public taps.

Aserdi is a village with approximately 170 households, one government middle school that goes through to eighth grade, and an agro-processing mill. A majority of the inhabitants of Aserdi are involved in agriculture, from which they derive

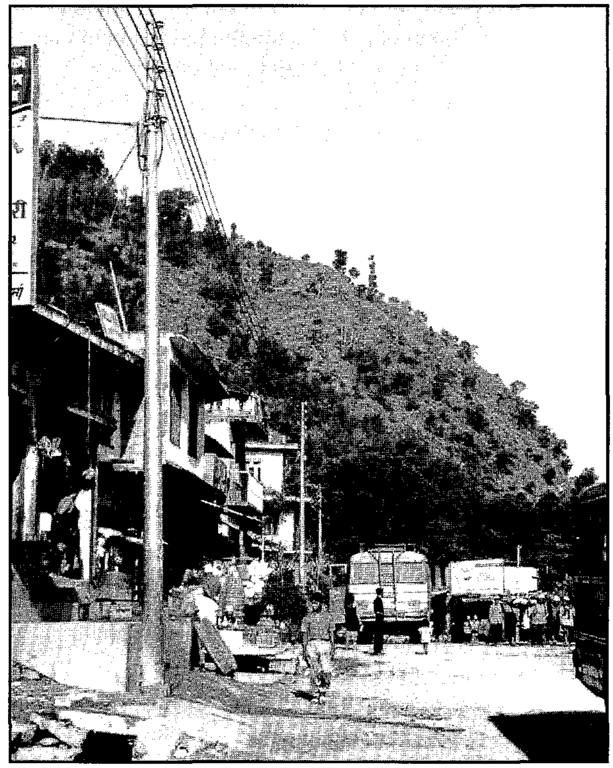

Fig. 4. Main street in the center of Galyang. Galvanized steel poles manufactured by NHE are also used in the town.

some of their disposable income. The village is also served by a gravity-fed water system feeding a number of public water taps. A precondition for the installation of a water system was that each household construct a pit latrine. Most of these are now still being used. Traditionally, sanitary facilities are not used in rural areas of Nepal.

The area around the project site has a fairly large population density, approaching 1,400 inhabitants/km^2 of <u>cultivated</u> land or 500 inhabitants/km^2 of total land. With a population growth of about 2.7%, pressures on the land continue to increase. A survey several years ago noted that agricultural yield in the area is sufficient to cover domestic needs only 7 to 9 months of the year, implying a need for some households to divert income to cover their food deficit.

[3] The information in this section is derived from several studies undertaken over the last decade in a number of villages in the general vicinity of the Andhi Khola powerplant. Some of the data were obtained from household responses to a house-to-house survey, with no formal verification of these estimates by independent measurement, observation, etc. The following information, therefore, is not meant to be a precise statement of the facts, but rather is presented to provide a general idea of conditions found in the area.

Most households have a source of cash income, through casual labor, sale of agricultural produce, or commercial activities. The median annual income is very roughly $500/household. Almost all rural households also own several water buffalo, half own one or two cows, many also own smaller animals such as goats, and some have chickens.

An average household in the project area has five resident members. In both the rural and semi-urban areas, there are significantly fewer men than women in their productive years (from 15 to 45 years old). A number of men, especially young men, have migrated either permanently or temporarily outside the community, primarily in search of employment. In this process, they have been exposed to new ideas, which should filter back to the community. It is not clear, however, to what extent this contributes to increased use of electricity, because the area continues to be a food deficit area, with a portion of the annual income diverted to purchase food to make up for this deficiency. There is conservatism on the part of the villagers as far as adopting new ideas, because they are hesitant to take risks when their livelihood is at stake.

The largest source of energy consumed in the area is fuelwood, which is used primarily for cooking of household meals. Some fuelwood is also used for cooking animal feed each day. A smaller portion is also used for space heating. It is difficult to get a reliable estimate of fuelwood consumption. Studies in the area have indicated a median monthly fuelwood consumption varying from 100 kg/month to 500 kg/month.[4] Perhaps a more realistic figure might be obtained not by villager interviews but instead by computing the energy requirements for cooking typical Nepali meals and converting that back to fuelwood requirements to supply that energy. Separate derivations concluded that the annual energy requirements for cooking for a typical Nepali family of 5 to 6 members are 1,800 and 2,400 MJ. If one were to assume an energy requirement of 3,000 MJ to include some space heating, fuelwood requirements for such a family would be computed to be on the order of 150 kg/month.[5]

Except for some homes, tea shops, and other establishments on or near the main road, families collect fuelwood from the surrounding countryside or from their own land holdings rather than purchase it. Between 200 to 600 hours per household are spent on this task each year, mostly by female members.

Kerosene for lighting is used by most non-electrified households in the early morning hours (from 04:00 until daybreak) and by all in the evening hours (from about 18:00 to 21:00). Households typically use one or two kerosene wick lamps and occasionally a hurricane lantern. The median expenditure for kerosene is on the order of $9 per year. The cost of kerosene is about $0.20 per liter near the road. Farther away, transportation charges can more than double this cost. Households in rural areas consume on the order of 1.0 to 1.5 liters per month, while those in semi-urban areas consume 4 to 8 liters per month.

Batteries, a third energy source, are used in both flashlights and radios by most households. The number of batteries used for flashlights ranges from about one to three per month while the monthly use for radios ranges from one to four batteries. The median expenditure for batteries is about $10 per year. Batteries (D cells) cost approximately $0.40 per pair.

SUMMARY OF INNOVATIONS AND THEIR RATIONALE

Below are summary descriptions of the major technical and organizational innovations introduced into the AHREP project area and the rationale behind each of these innovations. More detailed descriptions of these innovations, as well as an assessment of their success in decreasing the cost of rural electrification and in increasing the benefits it provides to rural communities, are included in subsequent chapters.

[4] After researching fuelwood consumption in various studies, Donovan (1981) noted that, even after eliminating several extreme points in the data, minimum and maximum estimates of per capita fuelwood consumption differed by a factor of 26. This may highlight natural differences in fuelwood consumption in disparate geographical areas, differences arising from such factors as climate, availability of wood, and cooking patterns. In any case, this finding underscores the need to be careful about the credence given to particular survey findings, no matter how precise they may appear.

[5] This assumes a cooking efficiency of 11% and an energy content for wood of 15 MJ/kg.

Intermediate 1 kV distribution voltage

Rationale: The cost of a distribution system is heavily influenced by the size of the conductor necessary to supply the service area; therefore, the minimum acceptable conductor size is usually selected. For most rural systems, this is the size which keeps the voltage drop (which affects the consumers' quality of service) within acceptable limits. Too small a conductor increases its resistance and, therefore, the voltage drop along that line. By increasing system voltage, however, it is possible to reduce line current required to serve the same load, permitting use of a smaller conductor without increasing the voltage drop. The constraints to increasing distribution voltage yet higher to further reduce conductor size and cost are such factors as ensuring sufficient conductor strength during fault conditions, increased costs of the added insulation at higher voltages, and higher poles to maintain adequate clearance between the line and the ground for safety reasons.

Determining the optimum operating voltage under specific load conditions is therefore important in minimizing the costs of electrification.

Innovation: To reduce distribution costs, a study undertaken for BPC concluded that an intermediate distribution voltage of 1 kV would be the least-cost approach for supplying the AHREP service area. The rationale was that, by using this higher voltage rather than 0.4 kV, line loading (as measured in kW·km) could be increased by a factor of $(1.1/0.4)^2$ or approximately 6. In other words, 6 times more load could be imposed on the same line without increasing the percentage voltage drop. Furthermore, this voltage permits the use of insulated conductor and components commonly used for low-voltage (400/230 V) applications at its maximum voltage rating, thereby exploiting the advantages of higher voltage without the need for additional, costlier insulation.

Transmission and distribution line poles

Rationale: In Nepal, solid cast-concrete poles are manufactured in-country and are commonly used for electrification. Concrete poles, however, are heavy. The widely used 8-meter pole weighs 500 kg, and the lack of roads in rural areas makes it impossible to transport poles for rural electrification projects even a small distance from a motorable road. Their weight also complicates setting them in the ground.

Innovation: The NHE has designed tubular steel poles, used predominately to support primary and secondary distribution lines, and steel lattice towers, used as transmission structures; both are fabricated and galvanized locally. These can be carried by porters to the site (Fig. 5) and assembled with simple tools. To reduce the costs of distribution within a rural area even further, maximum use is made of wooden poles contributed by the villagers (Fig. 6) and existing trees and buildings.

Low-wattage cookers

Rationale: One of the largest energy needs in rural areas is for cooking (Fig. 7). Current heavy reliance on fuelwood is contributing to environmental degradation, especially in marginal areas already cleared for agriculture. In many countries, it has also been placing a growing burden on women and children, who are spending an increasing number of daylight hours gathering fuelwood. Finally, smoke for indoor fires frequently contributes to

DALE NAFZIGER

Fig. 5. A portion of a pole being carried to the work site.

Fig. 6. Both wooden and fabricated steel poles are used in the electrification of less accessible villages.

respiratory problems. Shifting from fuelwood to electricity would relieve the burden on both the environment and rural families. The major problem in using electricity for cooking, however, is that a significant amount of power is usually required (typically at least 1,000 W per consumer). This is further compounded by the fact that most families cook at the same time. To handle this peak demand, the distribution system requires a more robust and costly design. Furthermore, the number of consumers capable of being served is severely restricted in cases where the powerplant has limited capacity.

Innovation: To reduce the peak electricity demand attributable to cooking and to make use of the underutilized capacity commonly found in rural systems (manifest ultimately as a low load factor), DCS has researched several designs of cooking appliances. It has developed and is promoting a low-wattage cooker (beginning at about 200 W per consumer) for heating water, cooking rice, and preparing stews.

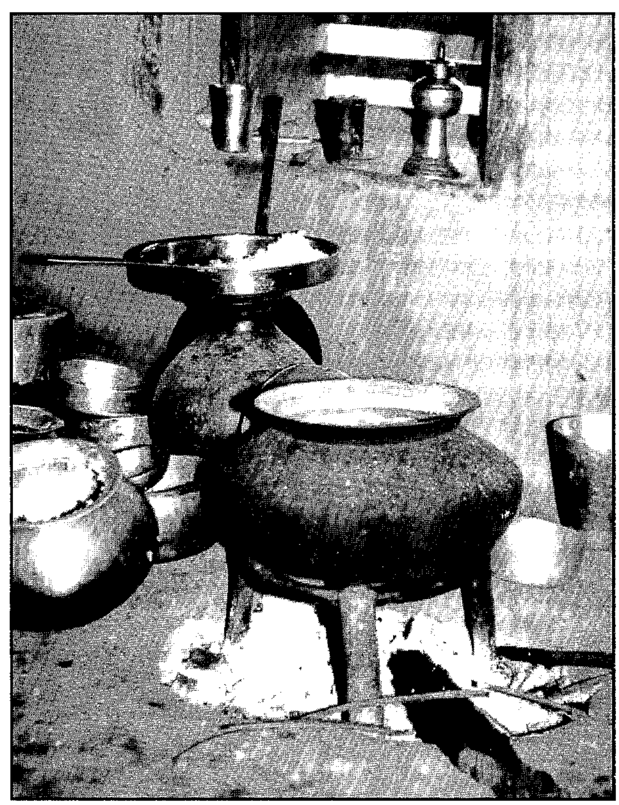

Fig. 7. The traditional approach to cooking contributes to inefficient use of fuelwood resources.

Power-based tariff and metering

Rationale: In conventional electrification, energy use is measured by means of an energy (kilowatt-hour) meter. This approach dictates the need for meters, meter readers, and more sophisticated collection and accounting procedures, each of which implies an additional cost.

Innovation: The availability of hydropower-based electricity at a low marginal cost and the desire to use energy for low-wattage cooking prompted the project designers to implement a power-based (kilowatt) tariff to avoid the equipment and operations costs associated with an energy-based (kilowatt-hour) tariff. Any of several types of current limiting devices can be used to limit the maximum consumption at each home. These include older electro-mechanical devices, thermistors, miniature circuit breakers, and electronic current cutouts. These are less costly than meters. Furthermore, because the tariff is based on the installed capacity of these devices, periodic meter readings are not required. Bill collection and accounting are thereby simplified.

Wiring harness

Rationale: Conventional electrical wiring of individual homes is expensive because of the need to custom-design each installation and the need for skilled electricians. This task is further complicated by the varied home construction styles encountered in rural areas.

Innovation: A wiring harness for housewiring has been developed which can be prefabricated in a controlled setting where it is easier to ensure high-quality workmanship. The harness can be installed with minimum training and at minimum cost. It also results in a product less likely to pose a fire or safety hazard. Several standard configurations are available.

Users' organization (UO)

Rationale: Logistical difficulties and associated costs encountered in serving remote and dispersed rural areas are important factors discouraging the spread of electrification into these areas. Furthermore, national utilities are generally too preoccupied with the demands and urgencies of the more vocal and influential urban consumers to channel limited resources into the rural areas.

Innovation: While wishing to provide electricity to outlying areas, BPC did not wish to increase significantly the burden that such an effort would place on itself, nor was it willing to compromise on enforcement of its regulations. AHREP therefore gave BPC an opportunity to test the effectiveness of relying on electricity users' organizations to assist it in its task of rural electrification. The users' organizations would maximize local manpower and material inputs in the construction, maintenance, and management of village-wide systems. They would further stimulate self-reliance and local initiative and ensure villager commitment to the project. They would also reduce the cost of implementation and operation for small village systems and place responsibility for the financial success of the project on the villagers (by having them reduce operational costs, follow up with delinquent consumers, and ensure that theft of energy was minimized). Such an approach allows the utility to focus on the generation and transmission of electricity—more centralized functions which it is better qualified to undertake.

Motivators

Rationale: In rural electrification project around the world, electric utilities usually see their responsibility as restricted to bringing electricity to new areas. Furthermore, while there is much less awareness among rural populations than among their urban counterparts about end-uses for electricity, most utilities show little interest in ensuring that potential consumers maximize the benefits of this new energy source. Moreover, they frequently seem to display little interest in ensuring that they generate adequate revenues to cover the costs they incur in the process. In other words, although they make large investments in developing the infrastructure, they tend to make little commensurate effort to ensure that their investments benefit either themselves or their consumers.

Innovation: In an attempt to ensure that most households in its service area have access to electricity in their homes and safely use it to their benefit, BPC has hired and trained a team of extension agents commonly referred to as "motivators". Through drama presentations, committee meetings, and household visits, they carry out the following activities:

- increase awareness among villagers who will have access to electricity of potential uses to which this resource can be put;

- assist in deciding to what level of consumption consumers should subscribe;
- share ideas about how best to electrify their homes; and
- respond to other questions potential consumers may have concerning this new commodity.

24

TECHNICAL INNOVATIONS

This chapter contains descriptions of the various technical innovations that have been introduced into AHREP's service area in an attempt to reduce costs and increase the rural population's access to electricity. The rationale for each of these innovations is included in the preceding chapter. The last chapter attempts to evaluate the impact of each innovation on the costs of, and accessibility to, electrification.

INTERMEDIATE 1 KV DISTRIBUTION VOLTAGE

Analysis

For many national electric utilities, rural electrification involves gradually extending the urban network into areas farther and farther removed from cities and towns. Often, this approach implicitly assumes that consumers in rural areas have demand patterns and needs similar to those in urban areas. But in 1987, before initiating construction of the distribution and transmission systems, BPC also took a step commonly overlooked by national utilities when electrifying rural areas: selecting an appropriate system voltage (Hagen, 1987). This is a critical step if the cost of rural electrification is to be reduced.

Based on field experiences, Hagen first projected what design load BPC would be expected to meet and what design criteria it should adopt. He then set out to determine which primary distribution voltage would most economically meet the projected load and quality of service. This was followed by a similar exercise to determine the most appropriate lower voltage(s) to use. In all cases, the voltages considered were restricted to standard voltages[6] (i.e., 66, 33, 22, and 11 kV for the higher distribution voltages and 6.6, 3.3, 1.0, and 0.4 kV for the lower distribution voltages) so that less costly, standardized distribution hardware could be used.

The voltage level of 22 kV had never been used in Nepal and therefore was not considered; 66 kV was clearly too high for the loads and distances that were planned in the area. Of the two remaining possible voltages, Hagen concluded that 33 kV would be the most economic to transmit power to areas served by the Andhi Khola powerplant. This does not mark a departure from common practice and will not be described further.

Concerning the choice for the lower distribution voltage(s), a number of countries around the world have adopted the European approach to distribution, in which a primary distribution voltage is transformed to the secondary voltage of 400/230 V. This commonly permits economical coverage over a radius of about 1 kilometer before voltage drops become excessive.

However, at Andhi Khola, this voltage would restrict service to too narrow a strip straddling the 33 kV line, and because of the dispersed settlement patterns in the rural areas, service would reach few consumers. Because the objective was to serve an area 5 kilometers on either side of the 33 kV line, it was felt that relying solely on 400 V as the secondary voltage might be difficult in spite of the relatively low consumer demand. Consequently, an intermediate voltage was then considered.

Considering the alternatives, 3.3 and 6.6 kV are not widely used, and procurement of the necessary hardware therefore would be more difficult and costly. Furthermore, if hardware costs were comparable with those associated with 11 kV hardware, little would be gained in using these lower voltages. Consequently, these two options were eliminated. Hagen then focused on the one remaining option: 1.0 kV. One rationale for selecting this voltage is that line hardware and insulated conductor already used with 400 V systems are actually rated at 1.1 kV, so no additional cost would be incurred in moving to this somewhat higher voltage.

Hagen then proceeded to analyze the costs of several basic supply alternatives to determine the most economic option for the type of service area in rural areas around the project site. These included the following, depicted in Fig. 8:

[6] These are voltages included in the International Electrotechnical Commission (IEC) standards.

25

A. Placing 33/0.4 kV transformers along the 33 kV transmission line and extending radial, three-phase (four-wire) 400 V lines to serve the areas on either side of the line.

B. Extending a three-phase 33 kV line laterally into the service area (to shorten the 400 V lines then required) and including several 33/0.4 kV transformers to supply shorter three-phase 400 V lines.

C. Extending a single-phase 33 kV line laterally into the service area and including 33/0.23 kV transformers to supply single-phase 230 V lines.

D. Placing 33/1 kV transformers along the transmission line, extending radial, three-phase (three-wire) 1 kV lines to serve the areas on either side of the transmission line, and using a larger number of small 1/0.23 kV single-phase transformers to serve load clusters.

To determine the most economical conductor and voltage combination, it was first necessary to project a maximum consumer demand into the foreseeable future. For this purpose, it was assumed that maximum demand would be 250 W per consumer (permitting most or all consumers to make simultaneous use of 200 W low-wattage cookers described in detail beginning on p. 30).[7] With a potential consumer density estimated at 45 households/km^2 (based on population figures for the area), each service area measuring 2 km by 5 km would require about 110 kW. With expected use of cookers throughout the day, load factors were expected to be fairly large (estimated at about 0.84), as were relative line losses.[8]

To establish the design criteria, Hagen examined both existing national and international standards as well as the voltage and frequency tolerances of the various electric end-uses that might be supplied by the proposed system and concluded the following:

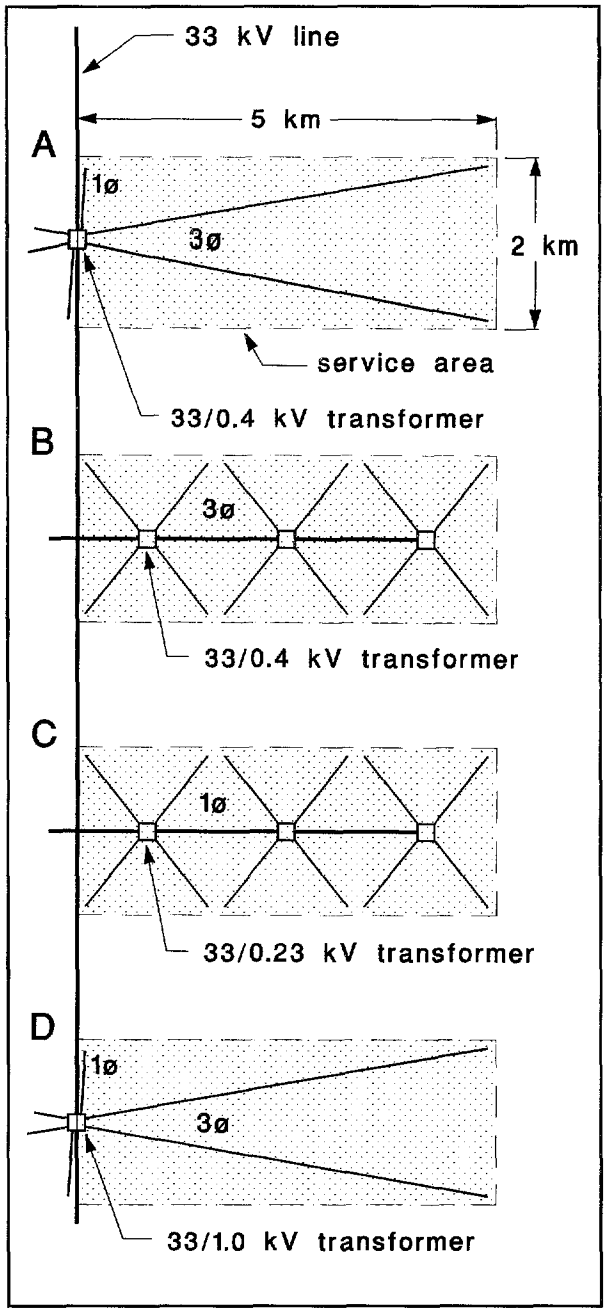

Fig. 8. A representation of four alternatives analyzed to supply a 10 km² service area on either side of a 33 kV (transmission) line. Table 1 presents the annual costs for each of these alternatives.

[7] In reality, the actual average peak demand has turned out to be about 90 W (including line and transformer losses), because there has been little use of electricity for cooking. As is shown later in this section, this reduced consumer demand has no impact on the conductor size selected for the optimum system in this case.

[8] The analysis also assumed a coincidence factor of 0.7 and a "load location factor" of 0.6 (implying a load fairly well distributed along the line).

- Incandescent bulbs, fluorescent lights, and low-wattage cookers would be the principal demand in the rural Andhi Khola service area. On the basis of a design voltage of 230 V at the source, these could accept a variation of +10% to –20%, corresponding to a total voltage drop of about 30%.[9] Based on practice elsewhere, it was assumed that 70% of this drop could occur on the secondary system. A maximum voltage drop of 21% was therefore deemed permissible on the intermediate- and/or low-voltage (1.0 and/or 0.4 kV) systems.

- From the point of view of strength, the minimum conductor size for a 1 kV ACSR line would be 16 mm^2 (and 25 mm^2 for a 33 kV line).

Using these design constraints, transformer costs, and the linear cost of single- and three-phase lines using steel tubular poles (p. 19), the total annual cost (annual investment cost plus annual cost of losses) of the various supply alternatives was determined. Derivation of the annual investment cost assumed an annual fixed-charge rate of 19% (which includes cost of capital and operations and maintenance) and that of the annual cost of losses assumed a cost of energy of about $0.06/kWh. The costs of the single-phase 230 V branch lines as well as the service drops, service entrances, and housewiring were not included as these were assumed to be similar in all cases. The breakdowns and totals of these calculations are found in Table 1. The 1987 Nepali rupee costs in the original report were converted to 1994 U.S. dollar equivalents (see Annex A).

An additional analysis was undertaken on yet another alternative which took a 33 kV line to a single transformer at the center of the service area and used a combination of single-phase 230 V and three-phase 400 V lines to serve the consumers (a combination of Alternatives B and C). While this illustrated that it would be possible to minimize costs somewhat by optimizing the design, Alternative D, using the 1 kV intermediate voltage, still appeared to present a fairly significant savings in investment costs of about 30% over the next most favorable option.

In costing each of the proposed alternatives, it became apparent that cost of line and transformer losses was generally a small portion of the total annual cost. The controlling parameters in design are voltage drop and conductor strength, rather than minimization of total annual costs, including losses. Use of the latter criterion would have led to voltage drops larger than what was felt permissible.

Although Alternative D appeared the most economical, a sensitivity analysis was undertaken to determine whether any foreseeable changes in load, annual fixed-charge rate, price of components, load factor, or cost of energy would alter this assessment. The following conclusions were drawn:

- The previous analysis was performed after halving the consumer demand over each rectangular service area. This reduced demand could be caused by initially overestimating consumer demand or by a lower than expected connection rate. Under this condition, Alternative D still clearly remained the least-cost option. (The more conventional approach, Alternative A, now became the next most attractive option, as might be expected with the reduced load.)

- The annual fixed interest rate and price of components are two parameters that affect the annual investment cost. However, because this cost is significantly above the annual cost of losses, foreseeable decreases in these two parameters would not reduce the annual investment cost so much as to make annual cost of losses the determining factor for the least-cost alternative and therefore change the relative costing.

- The load factor and cost of energy are two parameters that affect the annual cost of losses. However, any foreseeable reductions in the load factor (due to less than expected use of the low-wattage cookers) would only further decrease the value of the already small annual cost of losses and not affect the relative costing. For the same reason, any foreseeable changes in the cost of energy would also have

[9] The life of incandescent bulbs decreases very quickly with higher voltages; their expected life decreases to half with only a 5% increase in voltage. To address this issue, Hagen suggested that those consumers who have a constantly high voltage level should use bulbs with a higher voltage rating. The practicality of this approach, however, is unclear. More advanced equipment such as televisions and other electronic appliances must then be equipped with voltage stabilizers and/or high-voltage disconnects, but this is standard practice in Nepal today as voltage variations are not unusual.

Table 1. Breakdown of total annual costs (in 1994 US$ equivalent) for the principal distribution alternatives considered. Numbers in parentheses represent maximum percentage voltage drop in the line described.

Description	Quantity and unit cost	Cost breakdown	Totals
A. 400 V DISTRIBUTION SYSTEM			
Investment costs			
Line			
230 V, 1ø, 40 mm^2 (18%)	1.0 km @ $5,280	$5,300	
400 V, 3ø, 190 mm^2 (21%)	10.2 km @ $14,700	$150,000	
Transformer			
33/0.4 kV, 3ø, 168 kVA (shared)	½ @ $5,040	$2,500	$158,000
Annual investment cost		$30,000	
Annual cost of losses		$5,300	$35,300
B. 33 KV AND 400 V, THREE-PHASE DISTRIBUTION SYSTEM			
Investment costs			
Line			
33 kV, 3ø, 25 mm^2 (0%)	4.2 km @ $12,900	$54,200	
400 V, 3ø, 16 mm^2 (8%)	15.4 km @ $6,040	$93,000	
Transformers			
33/0.4 kV, 3ø, 28 kVA	3 @ $1,820	$5,500	$153,000
Annual investment cost		$29,000	
Annual cost of losses		$2,600	$31,600
C. 33 KV AND 400 V, SINGLE-PHASE DISTRIBUTION SYSTEM			
Investment costs			
Line			
33 kV, 1ø, 25 mm^2 (0%)	4.2 km @ $11,600	$48,700	
230 V, 1ø, 40 mm^2 (20%)	15.4 km @ $5,230	$80,500	
Transformers			
33/0.23 kV, 1ø, 28 kVA	3 @ $1,820	$5,500	$135,000
Annual investment cost		$25,600	
Annual cost of losses		$4,300	$29,900
D. 1.0 KV DISTRIBUTION SYSTEM			
Investment costs			
Line			
1 kV, 1ø, 16 mm^2 (2%)	1.0 km @ $4,920	$4,900	
1 kV, 3ø, 25 mm^2 (18%)	10.2 km @ $6,740	$68,700	
Transformers			
33/1 kV, 3ø, 178 kVA (shared)	½ @ $5,740	$2,900	
1/0.23 kV, 1ø, 5 kVA	21 @ $590	$12,400	$88,900
Annual investment cost		$16,900	
Annual cost of losses		$7,100	$24,000

insignificant impact on the conclusions drawn by the initial analysis.

In conclusion, for any foreseeable demand scenario for the rural areas being considered, Alternative D, relying on a 1 kV intermediate distribution system with relatively short 230 V service drops, appears to be the most economic means of serving the area.

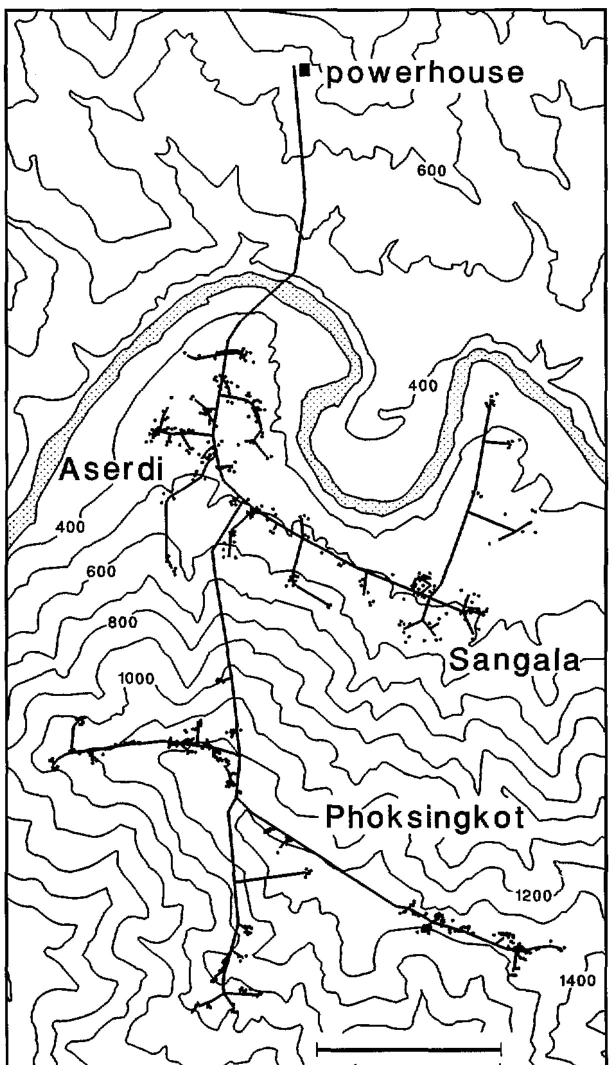

Fig. 9. Map of the area currently served by the 1 kV distribution system from the Andhi Khola powerplant. This study focuses on the village of Aserdi, the first community to be served by this system. Contours at 100 m intervals are shown.

There are several other advantages associated with the use of 1 kV as the secondary voltage. One is that it eliminates the theft of electricity because, while the line might be tapped, this voltage is not usable by the consumer. This is not the case where a 400/230 V system is used and the lines are within easy reach of many consumers.

Another practical advantage of a 1 kV system is the feasibility of carrying a number of 1 kV transformers with 1 or 2 kVA capacity by porter over narrow mountain trails into remote service areas. On the other hand, carrying the smallest commonly used three-phase 33 kV transformer (30 kVA) weighing at least 600 kg to serve a rural load center becomes unrealistic.

Construction details

Aserdi, situated above the banks of the Kali Gandaki river about 2 km from the hydropower plant, started receiving electricity over a 1 kV line in 1989 (Fig. 9). The individual communities in an area collectively referred to as Phoksingkot, which is located farther along the same 1 kV line but 800 meters higher in elevation on a mountain ridge, are in the process of being electrified.

Electricity to Aserdi is supplied from the powerplant by means of a 2.5 km, three-phase 1 kV ACSR bare conductor line, with 150 mm^2 conductor down to the river crossing (Fig. 10) and 40 mm^2 on to Aserdi.[10] All branch lines from the main line to clusters of homes within the service area use bundled cable—2.4 km of single-phase (2 x 16 mm^2 Al) and 0.4 km of three-phase (3 x 25 mm^2 Al) cable. These clusters are served by 39 1/0.23 V transformers (34 1-kVA and 5 2-kVA transformers) using service drops (2 x 2.5 mm^2) up to about 50 meters long. One three-phase transformer has since been installed in the only mill in the village to provide power to a 10 hp motor. The entire system is ungrounded.

More recently, the three-phase 1 kV line from the river crossing to Aserdi was reconductored with 80 mm^2 ACSR and extended up to the mountain ridge to serve the communities of Phoksingkot, about 2.5 km south of Aserdi. A principal end-use for the electricity in Phoksingkot will be to pump

[10] The line from the powerhouse down to the river was used during the excavation of the tailrace canal and was sized to meet the demand during construction. When the line was extended to Aserdi, this first portion of that line was not reconductored.

29

water for domestic use, in two stages, from a spring on the southern side of the mountain up 360 meters to a reservoir from where it will be distributed to four villages (see Fig. 2).

For protection, fusible disconnects are located at the 1 kV transformer near the powerhouse, wire fuses are placed on the low side of the 1/0.23 kV service transformers, and similar fuses are also placed at the service entrance before the cutout in the home. Wire fuses have also recently been installed in metal boxes at the beginning of branch lines, not so much for protection as to permit disconnecting these lines when repair work is necessary.

The 1/0.23 kV transformers used in Aserdi—both 1 and 2 kVA single-phase and 10 kVA three-phase—were assembled by NHE with cores imported from overseas. These are dry-type, epoxy-dipped. The 1 and 2 kVA transformers weigh 18 and 25 kg, respectively, and are each mounted in a box fabricated of steel sheet (Fig. 11).

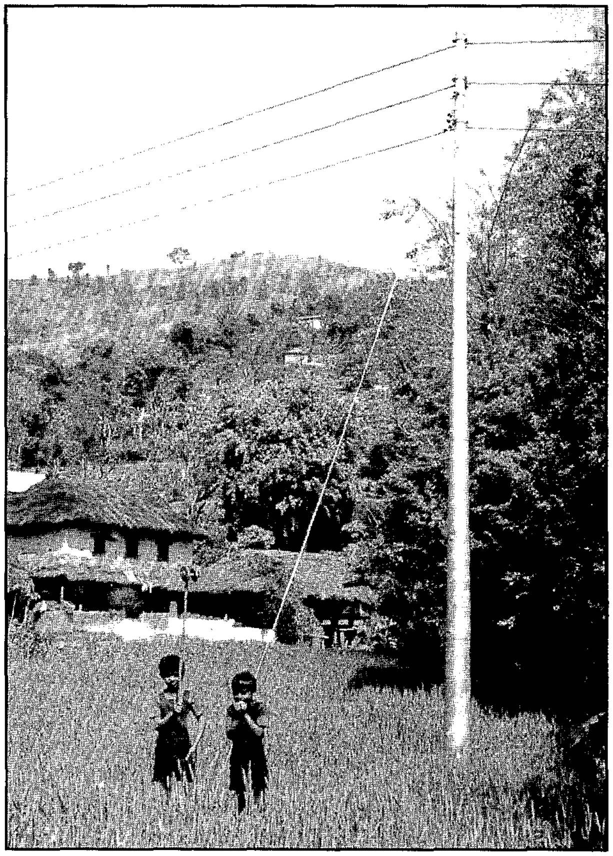

Fig. 10. The three-phase 1 kV line bringing power from the Andhi Khola powerhouse to Aserdi.

Because BPC had access to Norwegian cutouts (see p. 25), these were originally installed in Aserdi. However, with the supply depleted, both thermistors (PTCs, see p. 26) and miniature circuit breakers (MCBs, see p.25) will be used for residential consumers in Phoksingkot. PTCs will be used for 25 and 50 W peak-demand consumers while MCBs will be used for 250 W consumers. MCBs would also be used for the 100 W and 350 W consumer categories being proposed.

Typically, secondary distribution systems incorporate 400 V, three-phase, four-wire lines strung as individual uninsulated conductors. However, in the system at Aserdi, self-supporting, plastic-insulated bundled aluminum cables are used. Although the cable itself is considerably more expensive than conventional ACSR cable, it offers several advantages, some of which reduce the overall cost of the

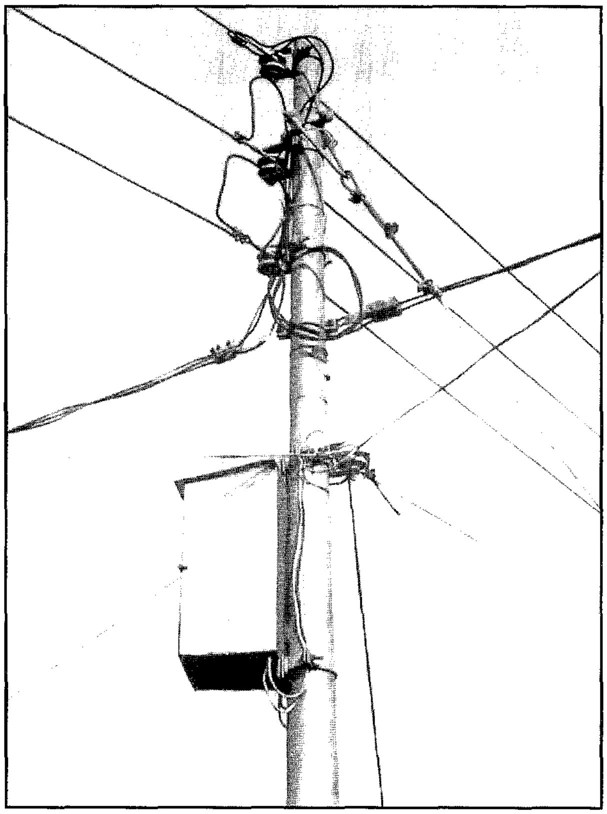

Fig. 11. Along the main 1 kV line, a 1/0.23 kV pole-mounted transformer housed in a shelter fabricated of galvanized steel sheet supplies five homes. In addition, a three-phase 1 kV tap provides power to the mill in Aserdi, and a single-phase 1 kV tap supplies residential consumers.

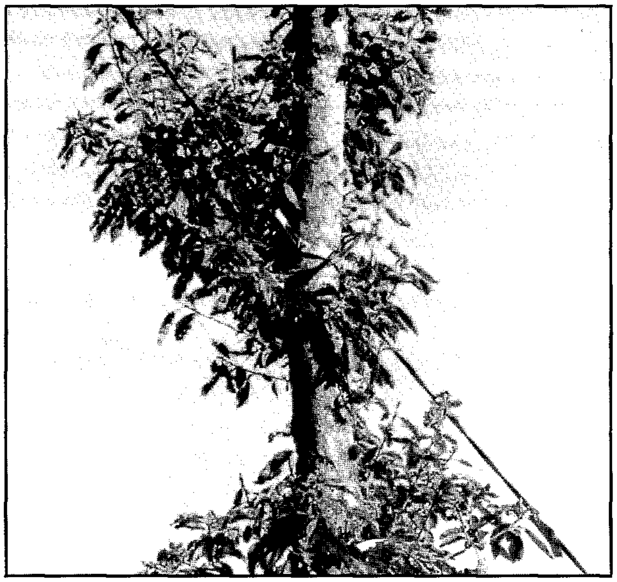

Fig. 12. A single-phase 1 kV branch serving Phoksingkot is occasionally secured to well-established trees.

installed system.[11] It requires less time to install, and installation costs are therefore reduced; the variety of line accessories required in stock is reduced; less clearance is required so that poles can be shorter and smaller; and because the insulation minimizes any potential safety hazard, the line can be fixed to trees (Fig. 12) or on the sides of homes, reducing the need for expensive poles.[12]

A disadvantage of bundled cable is the cost of piercing connectors. Currently, an alternative approach is used. To make a connection, a short length of insulation is removed, parallel groove clamps are secured to the conductor at this point, and the clamp is taped once the connection has been made. Another disadvantage is that, because of the high cost of dead-end clamps, locally available clamps are used. However, these tend to strip the insulation and cause shorts between the conductors; several times this has caused fuses to blow. Yet another potential disadvantage is that, because the cables are bundled, there is less dissipation of any heat generated by high currents. However, because of the very low consumer loads, this is not a problem in the rural areas being served.

Line hardware such as supporting clamps, dead-end clamps, fuse boards, and clamps have been designed for local manufacture.

While locally manufactured steel tubular poles (see p. 19) are used along the main three-phase line (Fig. 13) and at strategic locations where strength is required (such as for supporting the 1/0.23 kV transformers), costs have also been reduced by using wooden poles cut and donated by the villagers to support 1 kV branch lines and service drops (Fig. 14). Lines are also supported by trees when available. These options are possible because of the use of insulated, self-supporting, bundled cable. As is the case with steel poles, the buried portions of wooden poles are painted with bitumen paint.

Actual costs

The Aserdi component of the rural electrification project cost a total of $55,000. However, because a portion of the system was built with future expansion in mind, the sum required to electrify Aserdi alone totaled $31,000. This includes the costs for

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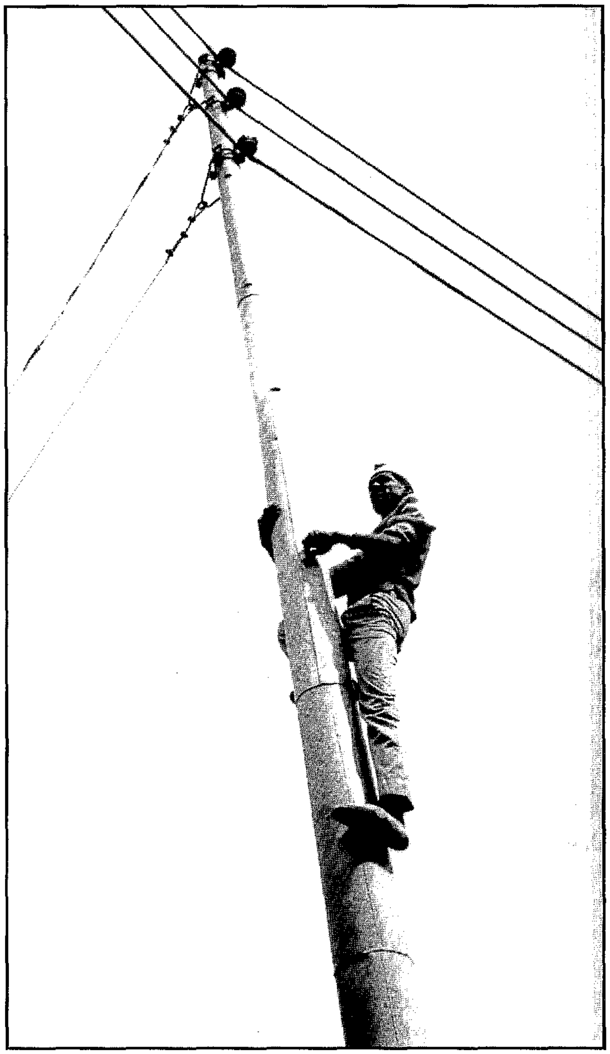
11 Bundled cable is roughly twice the cost of ACSR conductor. However, because of the significant cost of poles and the fact that higher poles are required to maintain adequate ground clearance for ACSR conductor, the wide disparity in costs disappears once the conductor has been installed. A comparative costing was undertaken for a portion of 25 mm^2 secondary (400/230 V) distribution line in a village of Aserdi. Pole locations were determined by physical features on the ground and were the same for all configurations costed. Per-kilometer costs of materials for the various line designs are as follows:

	Single-phase, two-wire		Three-phase, four-wire	
	ACSR	Bundled	ACSR	Bundled
Poles	$2380	$1530	$2430	$1530
Conductor	$580	$1160	$1150	$2330
Pole hardware	$350	$220	$470	$240
Total	$3310	$2910	$4050	$4100

12 Because of the insulation, reduced likelihood of electricity theft is generally another advantage of using bundled conductor. However, this is of little consequence in this case because of the use of 1 kV, a voltage which is not usable by the consumer.



DALE NAFZIGER

Fig. 13. Climbing a pole carrying the main 1 kV line to Aserdi.

the entire distribution system, from the 33 kV line up to and including the service drops and ready-made wiring harnesses in the homes (see p. 27). The system consists of a 3.5 km-long main line of ACSR conductor from the powerhouse up through Aserdi and 2.8 km of mostly single-phase branch lines of bundled cable supplying 39 transformers. Each transformer serves a group of homes. With about 170 households or consumers served by this system, the cost per consumer was about $180.

In this pilot project, an effort was made to provide electricity to everyone applying for it. However, if a cost analysis had been performed before installation, with the goal of optimizing the economics of the project, some areas would not have been electrified. These include areas served by long branch

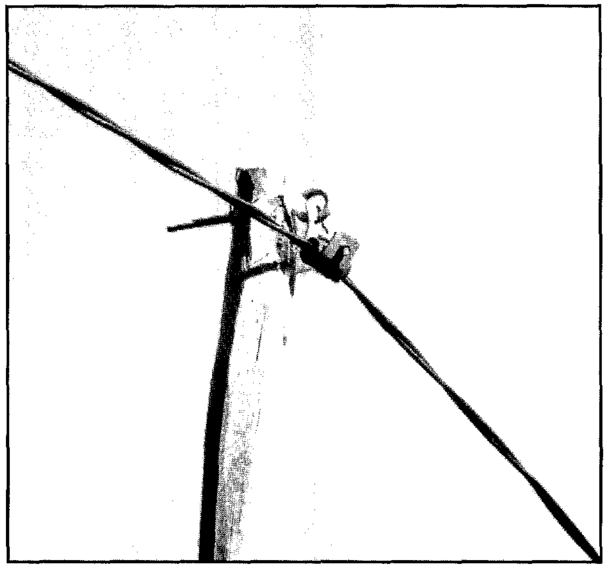


Fig. 14. A wooden pole donated by the community serves to support a single-phase branch from the main 1 kV line.

lines and/or by single 1 kVA transformers supplying only two to four homes.

Approximately 15% of overall costs for Aserdi were for labor; the remainder were for materials. Of this total cost, about 30% was for the main ACSR line, another 30% was for the branch lines of bundled cable, 20% was for the 1 kV service transformers, 5% was for the share of the high-voltage transformer that serves Aserdi, and the remainder was primarily for the service connections and ready-made housewiring.

Operational aspects

Twice a year, load measurements are taken on the lines to the project area to observe trends in electricity consumption over time. These are made by recording voltage and current on each phase every hour (or every half-hour during peak times) for an entire day. Using this information, the peak load in Aserdi with its approximately 170 residential consumers was measured as 18 kW. But the fact that the connected load in Aserdi totaled 13 kW implied that the current cutouts were set too high. After recent recalibration of the cutouts in the village, peak load was measured at 14 kW, still slightly more than would have been expected. This represents an average coincident peak demand of 90 W per household (including line losses). The peak voltage drop along the main line is about 2.5%, and the corresponding energy loss is about 0.5 kW.

By comparison, the semi-urban consumers, who number approximately 270, impose a peak demand of 114 kW (excluding 35 kW peak demand at the milk chilling center). This represents an average coincident peak demand of slightly more than 400 W per household.

Current revenues generated by sales of electricity to Aserdi currently total about $1,700 annually, or approximately 5% of the capital investment in the distribution system. Of this sum, about 10% is returned to the users' organization (see p. 39). The balance covers the cost of energy production and, if any remains, the original capital investment.

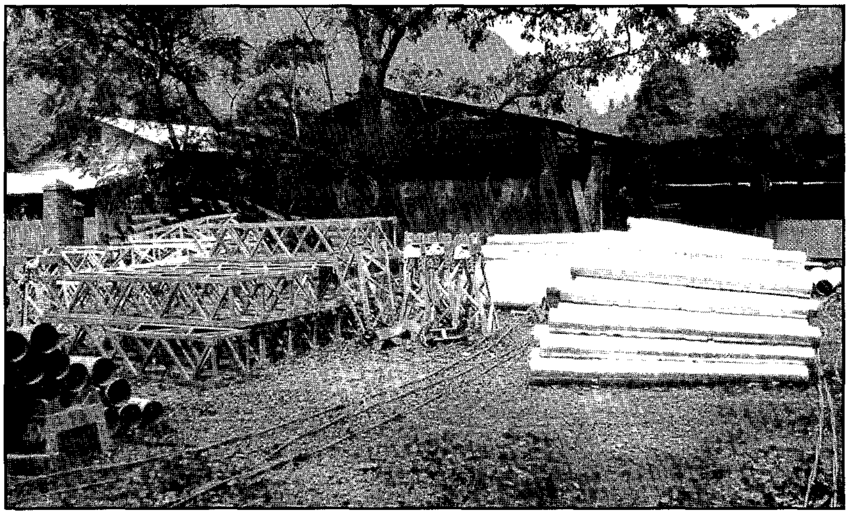
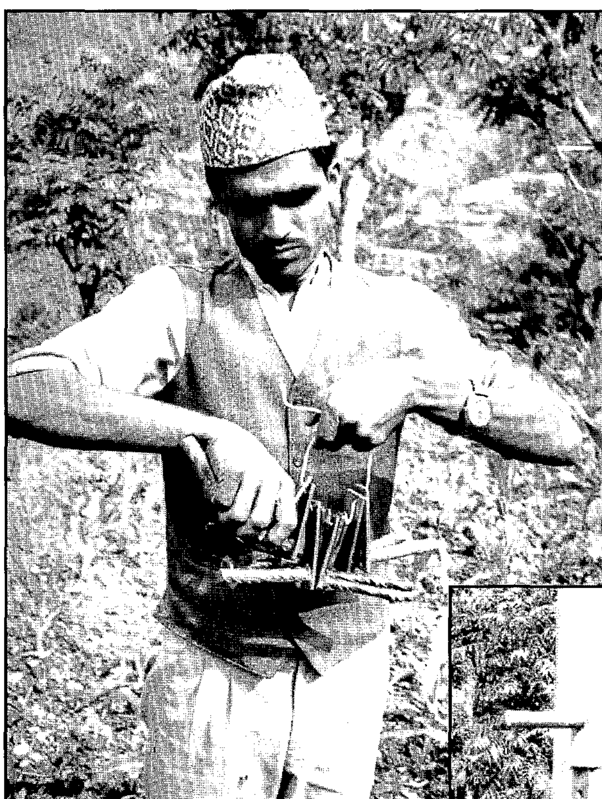


Fig. 15. Poles in storage outside the NHE workshop. Sections for steel lattice towers can be seen to the left.



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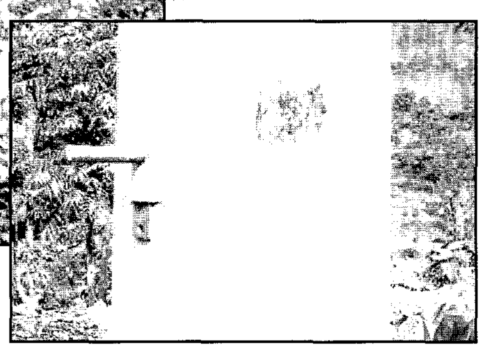


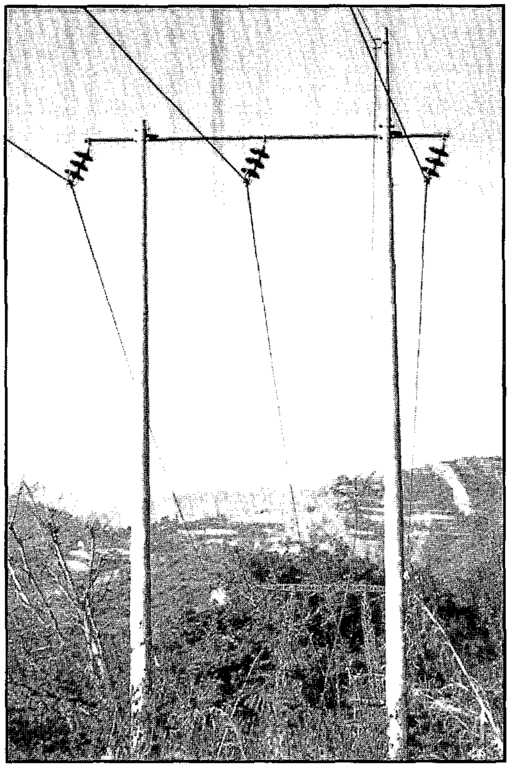
Fig. 16. Pole steps are inserted into brackets (see insert) for climbing galvanized steel poles.

TRANSMISSION AND DISTRIBUTION LINE POLES

While they are relatively low-cost, concrete poles commonly used for urban electrification installations in Nepal are heavy, relatively delicate to transport, and difficult to set by hand. Furthermore, they can be installed only at locations with road access. With an 8-meter concrete pole weighing 500 kg, they cannot easily be transported to villages accessible only on foot.

Needing an alternative pole design of sufficient strength to support both primary and secondary lines as well as distribution transformers, NHE developed a slightly tapered, tubular galvanized steel pole which can be assembled from 2.5-meter-long sections (Fig. 15). The heaviest section for the larger poles weighs about 40 kg. Because the sections are tapered, they can be nested within each other to reduce volume during shipment or portering.

To install these poles, a hole is excavated and a base plate is dropped in. The lowest section of the pole, which has been painted with bitumen, is inserted, and the hole is backfilled. The ends of the remaining sections are inserted within each other on the ground and compressed. Originally, a



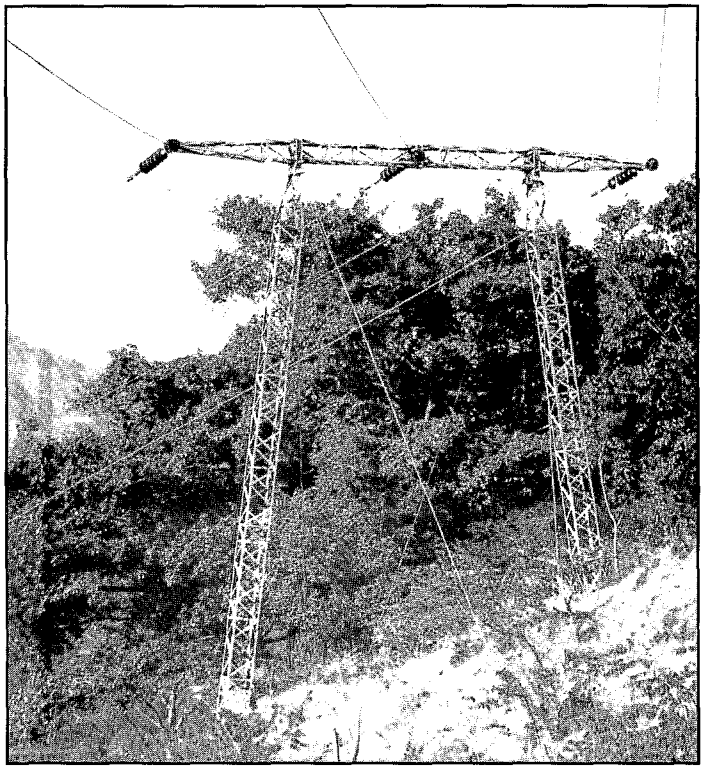


Fig. 17. A 33 kV transmission line carrying power from the Andhi Khola powerhouse to the south is supported by both lattice and pole towers assembled from sections which can be portered to areas far from motorable roads.

temporary hinging device was used to lift the assembled pole over the lowest section already set in the ground. This was found to complicate the procedure. Now, the base of the assembled pole is cupped over the top of the base section. It is then lifted up by ropes until it reaches a vertical position and slips down over the base section.

To climb the poles, the linesman inserts pole steps into brackets welded at regular intervals on the pole (Fig. 16) as he ascends and then withdraws them as he descends.

While a small pole of lattice construction would also have been lighter than a concrete pole, its base would have to be set in a concrete foundation block, leading to increased transportation requirements for materials, installation time, and effort. The larger surface area of the lower (partly buried) pole section of the tapered cylindrical poles reduces the pressure exerted on the surrounding ground, permitting these poles to handle greater lateral forces caused by small changes in direction of the distribution line without the need for guy wires.

To meet a similar need for structures to support its transmission lines—with the maximum span approaching 1 kilometer—NHE has also developed a steel lattice tower design (Fig. 17) which is constructed of standard sections. These can easily be carried by porter to areas accessible only on foot (Fig. 18). The components are designed to be assembled using only simple handtools; the assem-

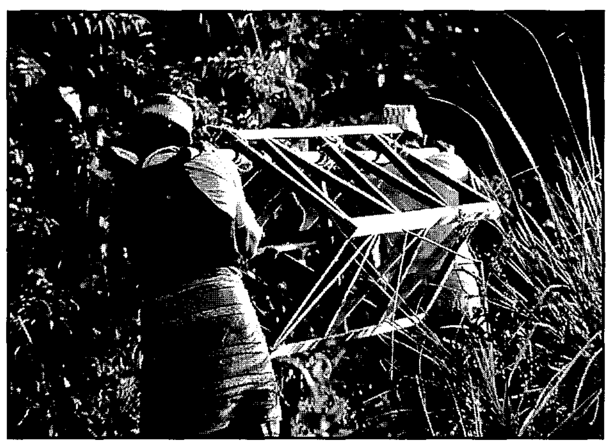


Fig. 18. Porters carrying a modular section of the transmission tower to the field.

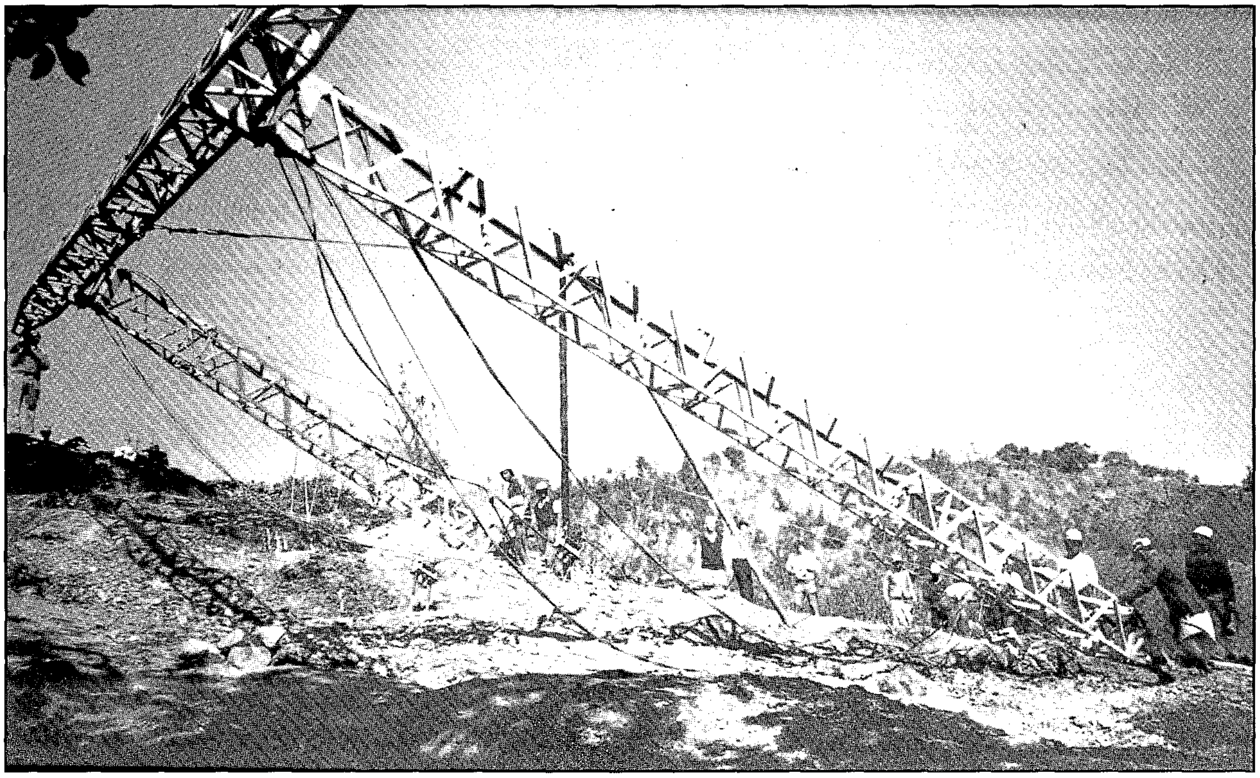


Fig. 19. After portering individual sections of the transmission tower and assembing the tower on-site, it is manually raised using an inverted V structure called a gin pole (in center of photograph).

bled structure is then raised using a hand-powered winch (Fig. 19).

TARIFF SCHEDULE

As with most purchases an individual might make, where cost is determined on the basis of the quantity of goods acquired—be they loaves of bread, kilograms of rice, or liters of water consumed monthly—few seem to question that the cost of electricity should be based on the total electrical energy (kilowatt-hours) used by the consumer each month. Consequently, the conventional approach is to supply each consumer with an energy (kilowatt-hour) meter, which a meter-reader from the electric utility reads periodically in order to prepare the consumer's bill. In addition to being billed for the actual level of electricity consumption recorded by the meter, consumers are billed according to any one of a variety of tariffs, based on such factors as their class (residential, commercial, industrial, etc.), the supply voltage, their peak demand (kilowatt), and the quantity (kilowatt-hours) of energy they consume.

Around the world, electricity tariffs range from 1 cent per kilowatt-hour in countries where the electricity is highly subsidized by the government to $0.20/kWh or more in areas where electricity is supplied by isolated generating plants. In industrialized countries, where electricity is generally priced to cover the costs incurred by the electric utility and where economies of scale exist because of the widespread usage of significant amounts of electricity, the average price of electricity for a domestic consumer is approximately $0.10/kWh.

In designing a tariff schedule, the electric utility must first establish its objectives. Especially for government or parastatal electric utilities, this should include not only the generation of adequate financial returns to the energy producers but also such considerations as the promotion of regional development, the provision of electricity affordable to all consumers, and the substitution of one fuel for another for environmental or national security reasons (such as replacement of expensive imported oil or diminishing fuelwood supplies with electricity). Then, a tariff schedule that attempts to promote appropriate changes in the consumption habits of consumers to achieve these objectives should be devised.

35

Table 2. Tariff schedule for consumers in the AHREP area since project inception. Small consumers have only a demand (/kW) charge; larger (metered) consumers also have an energy (/kWh) charge.

Subscribed demand (W)	Monthly charges, Rs (1994 US$)[a] 1989	1990	1992	1993
SMALL CONSUMERS (WITH CUTOUT DEVICES)				
25	15 (0.60)	16 (0.60)	17 (0.50)	17 (0.40)
50	25 (1.00)	27 (1.00)	32 (0.90)	35 (0.80)
250	60 (2.50)	70 (2.50)	84 (2.30)	95 (2.20)
LARGER CONSUMERS (WITH TWO-TIER METERING)				
500	150[b] (6.20)	75 (2.70)	80 (2.20)	80 (1.80)
700	210[b] (8.60)	105 (3.80)	112 (3.00)	112 (2.60)
1000	300[b] (12.00)	150 (5.40)	160 (4.30)	160 (3.70)
plus a charge per extra kWh . . .				
. . . within subscribed demand:	0.82 (0.033)	0.75 (0.027)	1.00 (0.027)	1.25 (0.029)
. . . above subscribed demand:	2.46 (0.10)	3.00 (0.11)	3.50 (0.095)	3.85 (0.089)

[a] Costs in 1994 US dollar equivalents have been rounded off.

[b] For the initial year, this demand charge included free units totaling 182.5, 255.5, and 365 kWh, respectively, for the three subscribed demands.

In undertaking its electrification efforts, BPC had several objectives:

- to generate sufficient income to cover at least the costs of operating and maintaining the power station and distribution system and possibly to make a margin for investment in further electrification (sustainability objective);
- to bring electricity within the economic reach of the rural population (social equity objective);
- to encourage the substitution of electricity for wood as a source of energy for cooking (environmental improvement objective); and
- to promote development activities to increase disposable income of rural populations (economic development objective).

One step toward achieving these objectives, independent of the tariff itself, has been BPC's efforts to minimize the costs associated with electrification. This need is encountered worldwide and is especially important nowadays when financial resources that can be devoted to electrification are increasingly limited. Most of the activities described in this chapter focus on trying to reduce the cost of electrification and will not be reiterated here.

Once efforts to reduce costs had been initiated, there was then a need to design a tariff schedule which would encourage the most cost-effective use of the project's generating and distribution capacity to meet the utility's objectives.

In the Andhi Khola service area, this design was influenced by two factors:

- First, the source of electricity is a run-of-river hydropower plant. This means that there is no provision for storing energy in the form of water behind a dam. The water is simply diverted to generate power and then redirected back to the river at a point somewhat downstream; unused water simply continues unimpeded. As long as streamflow is sufficient, the marginal cost of generating electricity is minimal—the cost of operating the generating/distri-

Table 3. The number of consumers in each consumer class in mid-1992.

	Consumer class (watts)						
Area	**25**	**50**	**250**	**500**	**700**	**1000**	**Total**
Rural consumers:							
Aserdi	26	116	26	-	-	-	168
Semi-urban consumers:							
Lower Galyang	1	25	50	20	-	1	97
Galyang Bazaar	1	9	81	34	1	4	130
Falang and Bhati	-	8	20	2	-	-	30
Amila Kharka	-	4	18	3	-	-	25

bution system is virtually independent of how much energy is generated. For an isolated plant, any power not used by the consumer represents lost revenues to the utility and/or lost benefits to the consumers. In such a case, the tariff schedule should be designed to encourage maximum use of the plant's capacity and to maximize the load factor.

- Second, during certain times of the year, water in the riverbed is limited, placing a restriction on the maximum power that can be generated. The power capacity of the distribution system is also limited by the conductor size and distribution voltages. Going beyond this limit results in increased energy (and revenue) losses to the utility and reduced quality of power to the consumer. Finally, if each consumer's peak demand is reduced, more consumers can be served. For all these reasons, the tariff schedule should be designed to encourage the reduction of each consumer's peak demand.

Therefore, the tariff schedule should be designed to place a restriction on an individual consumer's peak power demand, either by cutting off power or by imposing a penalty when this prescribed limit is exceeded. It should also encourage him to make maximum use of the power available during non-peak hours. Finally, it should place a higher portion of the burden for covering the cost of the distribution system on consumers with a higher power demand (because this higher demand requires additional line and transformer capacity).

The tariff schedule adopted by BPC is described in Table 2. Charges are shown in rupees as well as in constant dollar equivalents to illustrate the fact that, while the tariff generally has been gradually increasing, it has decreased in real terms.

For small rural consumers, BPC introduced a power-based tariff which is rarely used by electric utilities around the world.[13] Each consumer pays a fixed amount to access up to a certain prescribed level of power, for example, up to 50 W. The monthly bill is determined solely on the basis of this peak demand, independently of how much energy (kWh) is consumed (or, equivalently, for how many hours this power is used each day). Instead of conventional energy meters, each consumer is provided one of several types of cutout devices (see p. 25). These cutout devices limit the current, and therefore the demand (power), to a level to which the consumer has subscribed.

The two lowest categories of peak demand (25 and 50 W) were included in AHREP's tariff in recognition of the fact that a number of rural families would not be able to afford more than the minimal amount of electricity for one to two incandescent bulbs and possibly for powering a radio or cassette recorder. Because of the low levels of subscribed peak demand and disposable income, one also could not expect these consumers to make significant use of the off-peak power which was available.

[13] This tariff has also been adopted in circumstances like those in rural Nepal, where micro-hydropower plants need to serve small communities in remote areas in such a way as to benefit as many people as possible. Reducing peak demands permits the maximum number of consumers to access the electricity supply from plants of limited capacity and encourages maximum use of the available energy.

The highest of the subscribed peak-demand levels currently available to "small consumers" (250 W) was designed to permit households with more income to use excess power for productive purposes, specifically for cooking, thereby reducing their need for fuelwood. DCS developed a low-wattage cooker (see p. 30) specifically to permit 200 W of electric power to be used throughout the day and night for cooking, while still permitting the simultaneous operation of several 25 W light bulbs during the evening and early morning hours. Due to popular demand, 100 W and 350 W peak-demand options were incorporated into the tariff as of July 1994.

For the more affluent consumers in the bazaar and towns along or near the main road, a second type of tariff was designed. This tariff is in part also determined by the subscribed peak demand, but it penalizes the consumer for excess power consumption by imposing a larger monthly fee rather than by temporarily cutting off service, as is done with the smaller consumers when they exceed the limit.

These larger consumers pay a fixed monthly demand fee.[14] They also have a variable monthly energy charge, depending on how much energy they consume and whether or not consumption occurs at the same time that they exceed their subscribed peak demand. If it does occur when they exceed their subscribed demand, they are penalized at a rate about three times the rate they incur if the consumption occurs during a period when the subscribed demand is not exceeded. Each consumer is furnished a meter that separately records the energy consumed when the demand is under and over the subscribed level.

Table 3 summarizes the numbers of consumers in each consumer class in mid-1992. In Aserdi, a significant majority of the consumers subscribe to 50 W, with a small number subscribing to the level immediately above and below it. One can hypothesize that this reflects the limited financial means of these consumers and the lack of income-generating end-uses to which the power can be put. Of semi-urban consumers located on or near the main road, a majority subscribe to the 250 W level, with the next larger group subscribing to the 500 W level.

METERING

The most common form of metering used around the world is to measure the number of kilowatt-hours consumed. Each household's consumption is then recorded by a meter reader from the electric utility, usually on a monthly basis, and billed accordingly. This is also the approach used to meter the larger consumers in the AHREP area. However, because the tariff structure adopted tries to encourage the consumer to reduce his peak demand, two-tier meters are used. These were imported from Norway.

Motivated by the desire to reduce the relatively high costs associated with the purchase of meters and meter reading, another approach was employed: placing a cutout device at the service entrance to each home. Various types of such devices have been used: electro-mechanical cutouts, miniature circuit breakers (MCBs), positive temperature coefficient (PTC) thermistors, and electronic current cutouts (ECC). Each of these devices cuts off the electricity supply to the home when the consumer demand exceeds his pre-established subscribed level. The consumer is then charged a fixed fee on a monthly basis for the connection but pays nothing extra for the actual energy consumed.

Two-tier meter

Relatively few semi-urban consumers in the AHREP area have subscribed to tariff classes that require use of a meter, but these are widely used in the areas served by BPC outside the original pilot project area, such as in the town of Walling. A metered consumer is charged either of two tariffs, one if he consumes energy while his power consumption does not exceed his subscribed demand level and another considerably higher tariff for the energy consumed while exceeding this level. The tariff schedule is identical to that used for the larger consumers in the AHREP pilot project area (Table 2).

Use of two-tier meters and a tariff schedule that penalizes high peak consumption was instituted to try to increase the traditionally low load factors associated with load centers where most consumers

[14] In the initial year of the project, this fixed demand fee included a certain number of free units of energy, such as about 180 kWh/month for the 500 W metered consumers, for the period they did not exceed their subscribed peak demand. In Table 2, the drop in the demand charge after the first year occurred because free units were no longer included as they had been during the first year. All the energy consumed since then has had to be purchased.

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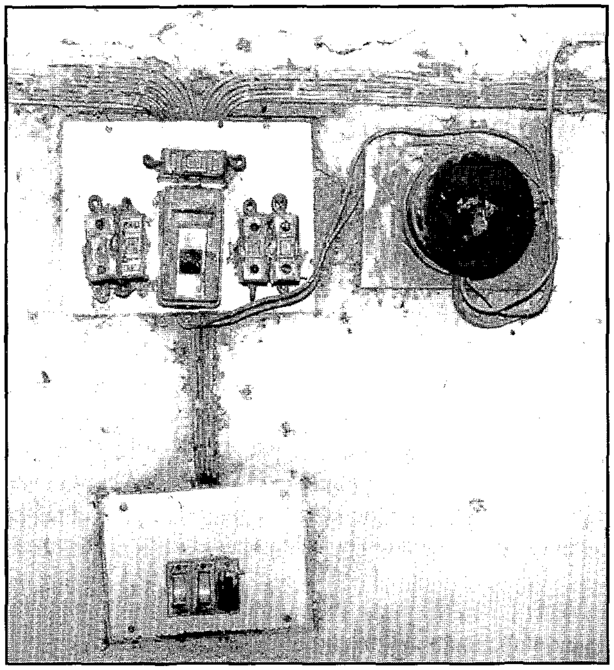

Fig. 20. A service entrance to a home using conventional wiring (wires mounted on wooden lists). The service drop to the home is the single cable entering from the right which leads to a Norwegian cutout.

are residential. This approach seems to have succeeded; while load factors are typically on the order of 20% in areas where conventional energy-based metering has been instituted, the load factor at Walling is currently about 40%. Unfortunately, two-tier meters are expensive, and those now being used are meters that are being replaced in Norway and donated to BPC. New single- and two-tier mechanical meters are available from Norway for $80 and $240, respectively. As a point of reference, single-phase meters commonly used in Nepal are available for about $20.

Norwegian cutout

These electro-mechanical devices had been previously used in Norway and initially used with all peak-demand consumers in the AHREP area (Fig. 20). Consumers claimed one problem with these cutouts is that their "fluttering" response during overload causes bulb filaments to burn out prematurely. In addition to the accumulation of carbon black from indoor cooking fires entering and affecting the operation of these cutouts, they are inherently susceptible to mechanical vibration, magnetic fields, welding of contacts with short-circuit currents, mechanical wear and tear, and loss of calibration over time. (Some consumers apparently intentionally shorted the output leads so that the ensuing short-circuit current welded the contacts closed, rendering the cutoff ineffective.) Because of these problems, combined with a limited supply of cutouts still remaining in stock, BPC began investigating some of the alternatives described below.

Miniature circuit breakers (MCB)

These are also electro-mechanical devices which open the circuit when current exceeds a prespecified level. They can be triggered either thermally and/or magnetically. Thermal MCBs monitor continuous current and are triggered by the heat generated by any excess currents. Magnetic MCBs sense sudden large changes in current and react quickly by magnetically opening a switch.

The temperature dependence of thermal MCBs (as well as of the PTCs mentioned below) may cause some operational problems because the device cannot distinguish the source of the temperature rise—whether it is from excess current or from high ambient temperatures in the home. For example, if the device is located at a point in the home where high temperatures are attained during the hot season or from the cooking fire, it may trip at lower currents. Thermal MCBs have been used in the AHREP area because they are less costly than magnetic MCBs and are apparently not as sensitive to surge currents (such as those created when a small motor is plugged into the circuit).

Magnetic MCBs are not affected by ambient temperatures, but they have not been widely used in the AHREP pilot project area because of their cost. Furthermore, available units demonstrate a lack of reliability. As are fuses, MCBs are designed specifically to protect circuits from shorts and therefore do not have clearly defined cutout points. However, the MCBs imported from overseas and now being introduced into the AHREP service area are adjustable and can be set to open at a current slightly above that corresponding to the consumer's subscribed demand level. Once an MCB has opened, it can be reset manually by the occupant himself (Fig. 21).

MCBs with 100 W ratings or above are available at a cost in the range of $4 to $7.

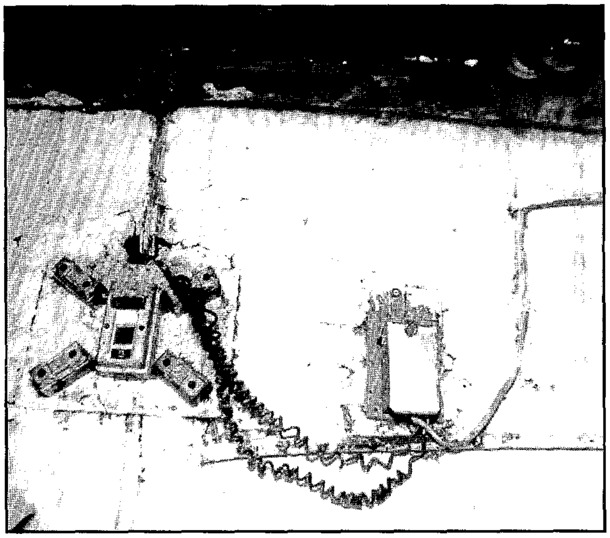

Fig. 21. A service entrance to a home in Aserdi, with the service drop (wires from the right) leading to a box containing an MCB. Note the seal and the reset switch on the left side of the box. Also included at the service entrance are a main cutoff switch and four fuses. This view also illustrates the difficulty of installing neat conventional wiring on walls plastered with mud.

Positive temperature coefficient (PTC) thermistors

For smaller consumers (less than about 100 W), positive temperature coefficient thermistors have been proposed because of their low price. These are solid-state (semiconductor) devices whose resistance is temperature-dependent and increases rapidly once a certain temperature has been reached. In normal operation, this device presents negligible resistance to incoming current. However, when excess current is drawn through a PTC by the consumer, the heating effect of that current causes its resistance to rise, effectively cutting off the current. A small residual current maintains the PTC in a high resistance state until the load is disconnected.

The PTC resets automatically after being disconnected and waiting for the unit to cool back down. However, this characteristic has been a source of some consumer dissatisfaction. Once a PTC cuts off electricity to a home because of an overload, it takes some time to cool down and reset; in the meantime, the occupants have to founder in the dark.

The temperature-dependence of PTCs may cause some of the same operational problems as noted above for MCBs. Furthermore, their rating is not precise. To minimize the problem arising from high ambient temperatures, the box containing the PTC(s) should be located in a cooler part of the house.

PTCs cannot tolerate short circuit currents. A fast-acting fuse therefore is placed in series with the PTC to protect it from rupturing from the high current that accompanies an electrical short in the household. The PTC and fuse are mounted in a small sheet steel box with holes for ventilation. A seal is used to indicate whether the box has been tampered with. For the consumer, one inconvenience of mounting the fuse in the box with the PTC is that, when the fuse blows, only someone from the utility is authorized to break the seal and make the repair.[15] This may mean that the consumer has no access to electricity for several days.

PTCs are available in various current ratings. Their cost is proportional to this rating and starts at about $2 for those rated at 50 W or less. Because PTCs can be connected in parallel to achieve ratings not available, the number of components required to be kept in stock can be reduced. They are commonly used for homes with 25 and 50 W service. MCBs are used to limit loads 100 W and beyond as these are the least costly cutoff devices in this range.

Electronic current cutouts (ECC)

The triggering of both thermal MCBs and PTCs depends on the higher than normal temperatures generated in the device by any excessive currents drawn by a consumer who has connected too much electrical load in his household. But the fact that these devices cannot clearly distinguish between a temperature rise caused by high ambient temperature and one caused by excessive consumer load has created problems, because their operation in various locations within the home or during different seasons cannot be predicted with certainty.

[15] The fuse is located inside the box to protect the PTC, which is the property of the utility. Leaving the fuse outside would permit the consumer to replace the fuse wire himself, and he is apt to replace it with ordinary wire, which would offer no protection, rather than with the properly rated fuse wire. The consumer is charged a fee for having his fuse replaced.

40

Fig. 22. A view of a pakka home in Aserdi, with a kaccha home on the right.

The ECC has been developed to address this concern. This is an electronic circuit which includes a current-sensitive electronic switch (thyristor or triac), which is triggered by the current drawn by the consumer. Temperature plays no role in the process and has little effect on its operation. The operation of the ECC is more predictable, with the tripping current within ± 5% of the preset limit. A single ECC is adjustable for any maximum demand up to 250 W. ECCs for the next increment of consumption (250 to 600 W) are also available.

When the consumer exceeds the preset limit to which he has subscribed, the ECC switches off power into his home. Resetting it can then be performed by the consumer himself. It requires manually switching off the main supply into the home, reducing the connected load to an acceptable value, and then switching the supply back on again. One of the problems with ECCs is that they act very fast, cutting off the consumer simply when there are voltage transients on the line. Another is that, because of the operation of the triacs, they may trip when the connected load is too small. Radio interference is also a frequent complaint.

An ECC can be assembled locally in several hours and is sold at a retail cost of about $10.

WIRING HARNESSES

Commonly, homes in the area are one- or two-story structures. Walls are of mud and stone masonry, plastered with mud, with the upper floor, supporting columns, and roof- supporting structure of wood. Homes fall into either of two categories, and according to BPC policy, each is treated differently when it comes to housewiring. The first category are *pakka* (solid or permanent) homes; the second are *kaccha* (less durable) homes. The primary distinguishing feature between the two is that the former have corrugated galvanized roofing (Fig. 22) whereas the latter have thatch roofing (Fig. 23).

Housewiring is installed after construction of the home has been completed and is generally installed on, as opposed to within, the walls and ceilings. There are two basic types of wiring: conventional wiring, which only can be used in *pakka* homes, and *tayari* or "ready-made" wiring harnesses, which must be used for *kaccha* homes but which have also been used in *pakka* homes.

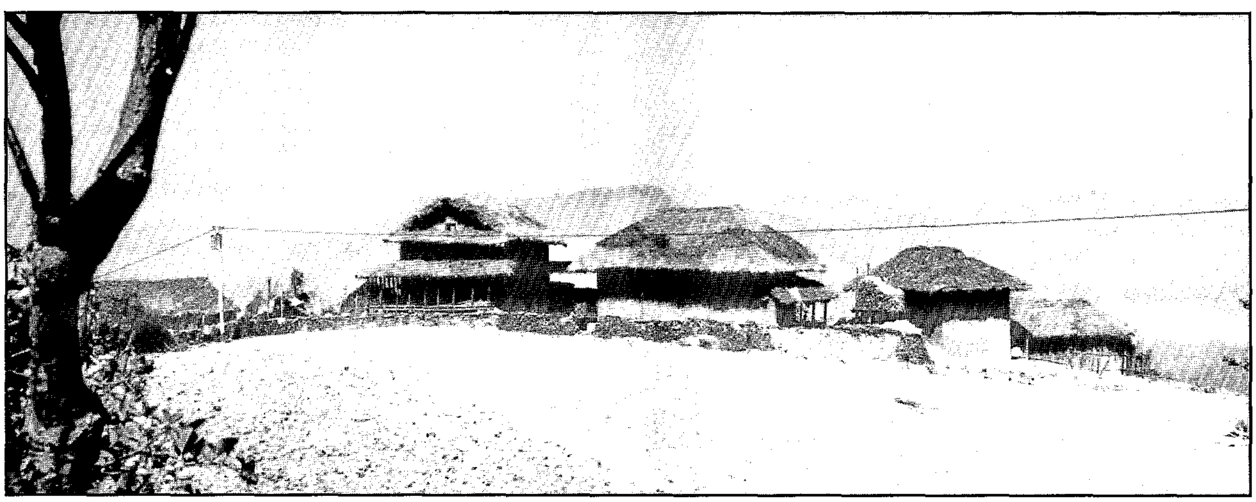

Fig. 23. A view of several kaccha homes in Phoksingkot. The service drops have not yet been installed.

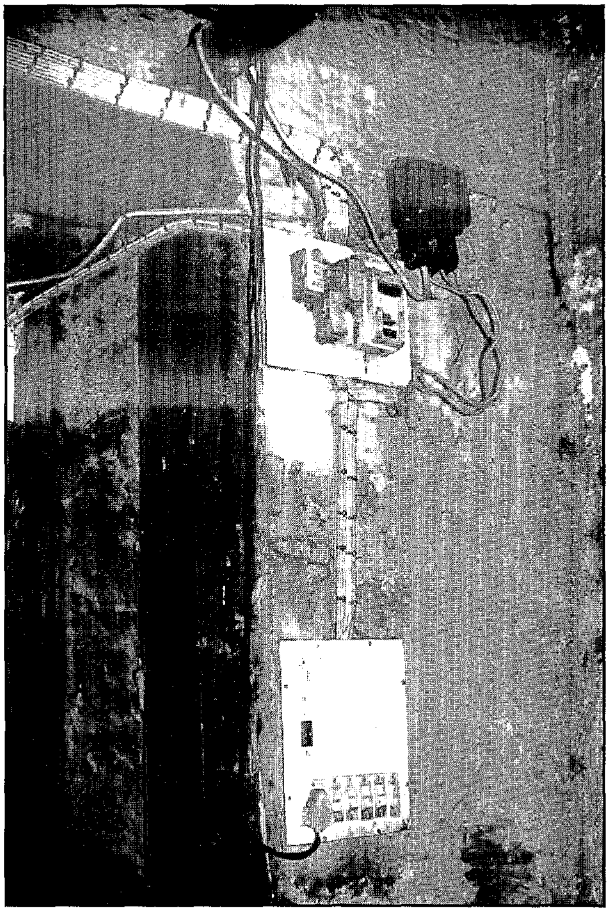

Fig. 24. Cleanly installed conventional wiring in a home in Galyang. The service drop is the heavy conductor from the left, leading to a Norwegian cutout and then on to the wooden junction box (with fuses and main cutoff switch).

Conventional housewiring is composed of exposed, single-core conductor clipped at regular intervals onto wooden lists (thin, flat strips of wood of suitable width nailed to the wall as illustrated in Fig. 24). Lighting fixtures, switches, and power outlets are permanently fixed onto walls, supporting posts, or other parts of the home. The service entrance—a wooden junction box on which are mounted the current limiter, fuse(s), and possibly some power outlets—is usually mounted flush with the surface of the wall. At AHREP, this work is only done by an authorized contractor. He must be selected from a short list of several individuals who have been identified by the local users' organization and who have passed both a written exam and an interview. A technical officer from BPC determines the location of the service entrance and the electrical ground (the latter is installed only in

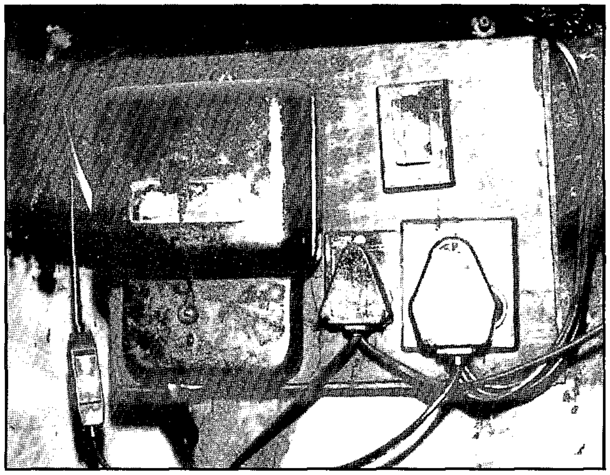

Fig. 25. A Norwegian cutout and fuse mounted on a wooden box at the service entrance to a home with tayari wiring. In this case, the two power outlets are used to connect the wiring harness leads to the service entrance; at other times, the harnessed is connected within the box.

homes where electric cookers or other equipment is used). After the contractor hired by the homeowner has completed his work, the technical officer from BPC makes a second visit to verify the quality of the workmanship and to determine if any portion of the work has to be redone.

While conventional housewiring in homes with concrete or cement-plastered brick walls commonly found in the urban areas can be simple and neat, it becomes more difficult to install in village homes with mud and stone-masonry walls because of the unevenness of the walls and the difficulty of securing the wooden lists to the walls (see Fig. 21). Furthermore, availability of the required skills for housewiring in rural areas is limited, and the cost of labor for conventional wiring can therefore be significant.

For these reasons, "ready-made" wiring harnesses have been developed. Each harness includes a current limiter and fuse mounted on a wooden junction box, from which radiate a number of power cords—good-quality, double-insulated wires each terminating in a light bulb or power outlet (Fig. 25). Rather than wall-mounted switches, in-line switches are included just before each bulb (Fig. 26). To ensure good connections and eliminate any problems arising from frayed wire, the tips of the stranded conductor are soldered. Figure 27 illustrates the major components of a typ-

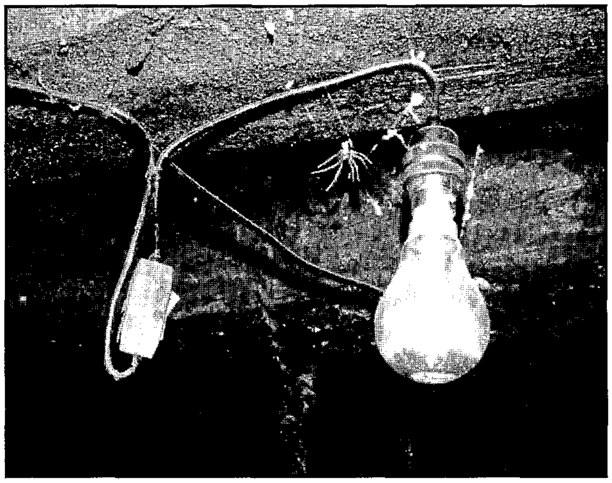

Fig. 26. A section of a ready-made wiring harness, with light and in-line switch, secured to a ceiling beam.

ical wiring harness.

To date, these harnesses have been custom-made under supervision in the local BPC/AHREP workshop in Galyang. Before a home is wired, it is visited by staff from BPC who determine, with the owner, the level of service to which he wishes to subscribe as well as the number of lights and power outlets and their locations. It was expected that, once sufficient experience had been gained, it might be possible to prepare standardized harnesses. However, this may not be possible because of the variety of home layouts.

Installation of a wiring harness in the home involves installing the service entrance box; making the connection with the incoming line; running the wiring to lights, power outlets, and switches mounted in the desired locations; and then tacking the wires to beams, poles, etc., as necessary. Approximately three to five hours are required to install a harness for a home with 250 W service.

While the concept of the harnesses was to provide a safe, low-cost means of wiring for *kaccha* homes, homeowners in a number of *pakka* homes were also found to favor this approach. Not only did it reduce cost significantly, but it also provided for a bit more flexibility. It is not difficult to envision that, after some experience has been gained, homeowners might wish to shift the location of a bulb somewhat to shed more light in another portion of the room or to eliminate working in the shadow. Another problem encountered with conventional wiring is that contractors charge by the quantity of material that they install. This encourages the installation of unnecessary components, for example, using three or more fuses where one would suffice, thereby unnecessarily adding to the cost of housewiring (Fig. 21). Because the purpose of "ready-made" wiring prepared by BPC is to reduce costs, only essential components are included.

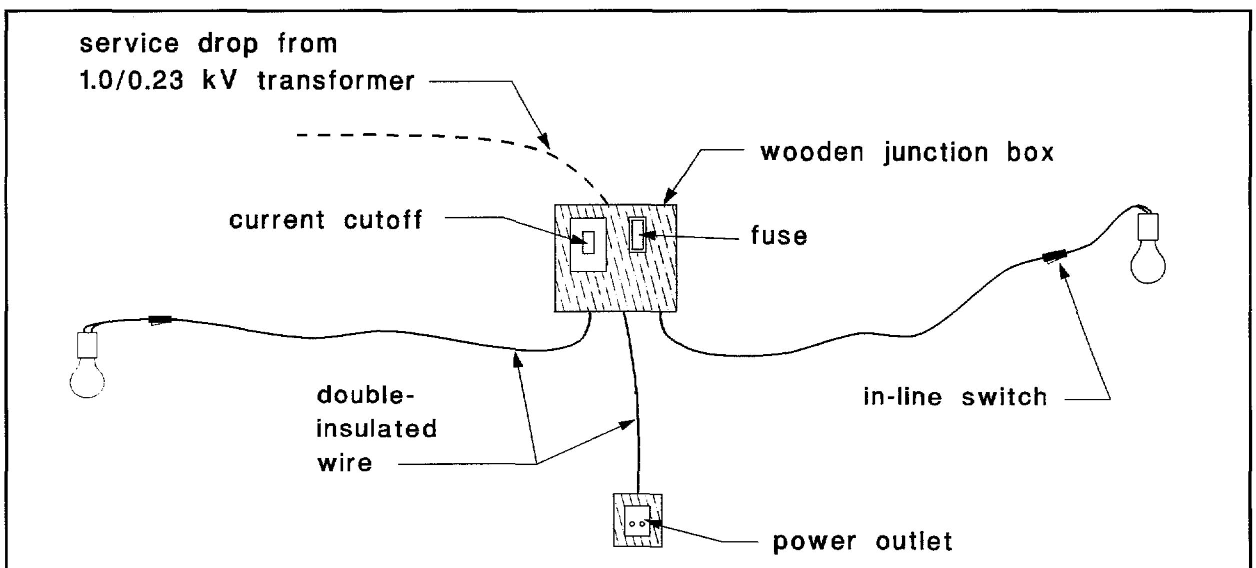

Fig. 27. Components of a typical tayari (ready-made) wiring harness for use in the home.

"Ready-made" wiring might appear somewhat restrictive. However, by using a readily available adapter which permits a light socket to serve also as a power outlet (Fig. 28), some villagers have found a simple means of obtaining additional service from an otherwise limited system, without the need for any contractor.

Approximate costs for the wiring harnesses are as follows:

- two bulbs, with 4 meters of double-insulated flexible conductor for 25 W service: $5.
- three bulbs (or two bulbs and two power outlets), with 8 meters of conductor for 50 W consumers: $8.
- four bulbs and one power outlet, with 15 meters of conductor for 250 W consumers: $12.

In the project area, the cost of conventional wiring generally begins at $30 to $40 per household and can be higher for larger homes.

COOKERS

In areas facing increasing scarcity of fuelwood for cooking, electricity is frequently seen as an alternative energy source, especially if it is relatively low-cost energy generated by a hydropower plant. However, the problem with this end-use is that cooking loads for most consumers tend to coincide, resulting in high peak loads in the mid-morning and evening hours and little load for the remainder of the day. A typical rural demand, primarily for lighting, might peak at 100 W per household, but adding a single hotplate for cooking could easily raise this figure tenfold.

To cater to these peaks, more substantial and costly generation and distribution systems have to be constructed, while they remain little used most of the day. If electricity is to be more cost-effectively used for cooking, it is necessary to reduce the peaks associated with this end-use, by staggering cooking times (which would be difficult in any society), by several families sharing one stove (also difficult in practice), or by developing new approaches to cooking with electricity. Four such approaches are described below. These approaches also permit considerably more users to benefit from the electricity generated from a powerplant with a small capacity than would otherwise be the case.

Fig. 28. An adapter inserted between the light socket and the light bulb permits an easy way of getting a line extension (the white conductor). Note how the "ready-made" wiring is secured to the beam.

Cast-iron heat-storage cooker

One approach used in Norway in the early part of this century and for which numerous patents were filed in the United States was to store energy in the form of heat from a low-wattage heating element in an insulated, cast-iron block. Rather than consume 1 kW or more for short periods of time, somewhat less than 1 kW was consumed most of the day and night and stored in this block in the form of heat. Cooking was then accomplished by removing an insulating cover and placing the cooking pot or pan on this block so that heat could be transferred to the food. Temperatures were sufficiently high to permit frying. These cookers consumed considerably more than 200 W, and therefore efficient use of the cookers was not as important; for example, the pot did not have to be covered all the time to conserve heat.

While this heat-storage cooker seemed promising, there were several obstacles to its use in Nepal. Electric hotplates are readily available in Nepal in sizes ranging from 750 W to 1500 W for as little as

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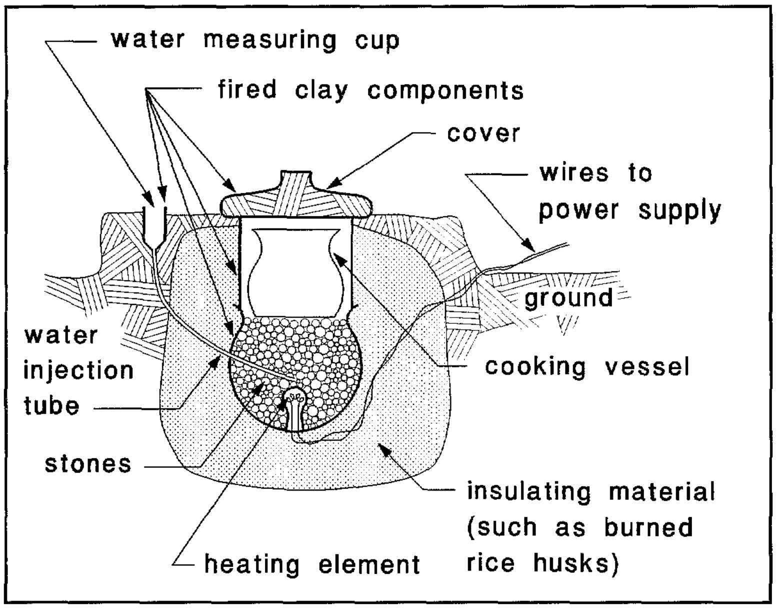


Fig. 29. A cross-sectional view of a possible design for a steam-convection heat-storage cooker made of local materials.

$1 to $2, while the cost of the cast iron alone for a heat-storage cooker would be closer to $10. Furthermore, the weight of the cookers (on the order of 20 kg) would make transporting them onerous. More important, because Nepali cooking vessels are never flat, heat transfer between the heated block and the vessel would be inefficient.

Steam-convection heat-storage cooker

Initial research efforts attempted to address the problems associated with using a cast-iron block by replacing it with a bed of small stones in which was centered a resistive heater (Yoder, 1981). A bed of stones is advantageous because it can accept cooking vessels of a variety of shapes and stones are locally available. However, a major difficulty with this storage medium is the slow transfer of heat from the stones to the cooking vessel. Heat transfer is inhibited by the very small contact area between the stones and the vessel as well as between adjacent stones themselves, compounded by the fact that stones have low conductivity. The solution that was first researched was to inject a few milliliters of water through a tube directly into the center of the hot stone bed. This generated steam which would condense on the vessel, transferring heat in the process. The condensed water would then drip back into the bed of stones to repeat the cycle. While a "properly" designed and instrumented unit was used in the laboratory, Fig. 29 represents a possible design using local materials.

Cooking that relies on water/steam heat transfer at atmospheric pressure is limited to temperatures approaching the boiling point of water. Frying, baking, and roasting are not possible. However, in the Nepali context, this may not be a serious constraint because most cooking involves boiling rice, pulse[16], vegetables, and potatoes. When maize is substituted for rice, it is finely cracked and boiled. Millet, and sometimes wheat and barley, are ground and cooked as a porridge. Most meat is prepared by boiling. Consequently, cooking is largely water-based and can be achieved with the temperatures attainable in a steam-convection heat-storage cooker.

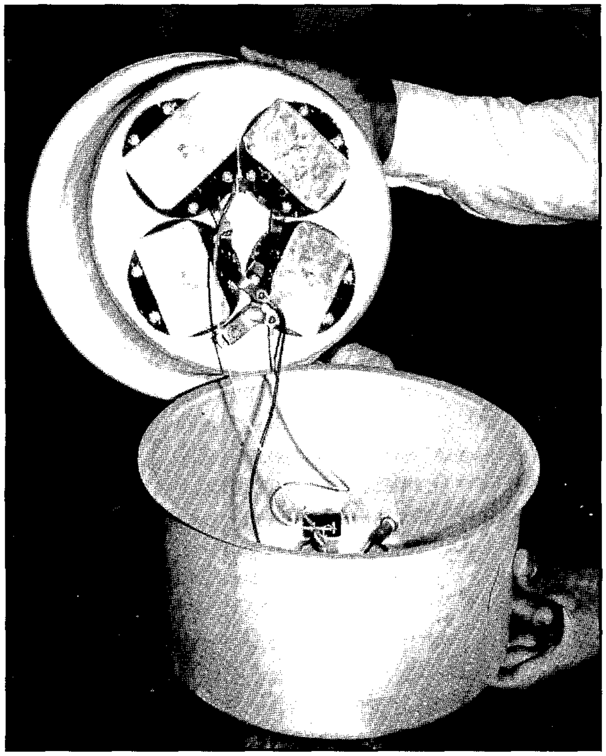
It was determined that approximately 0.7 kWh, excluding losses, is required for each of two daily meals for a Nepali family of five to six (equivalent to approximately four adults), with at least 10 hours between meals. The research concluded that, with 275 W of continuous power input, it was possible to cook a Nepali meal for such a family twice every 24 hours with this cooker.[17]

The projected cost of the steam-convection heat-storage cooker is on the order of $10 assuming local materials are used. Even assuming annual replacement of the unit, this cooker design would already be financially attractive in several urban areas where fuelwood (which has to be purchased) is costly. The cost-competitiveness of various types of stoves is discussed later (p. 54).

While this version of a heat-storage cooker is workable, social acceptability is probably limited by the

[16] Seeds of certain leguminous plants, such as peas, beans, or lentils.

[17] This is equivalent to an overall system efficiency of 23%. The effectiveness of heat transfer to the cooking vessel was also confirmed; heat could be transferred at rates of up to 2,500 W.



LIONEL MACKAY

Fig. 30. A view of the two sections of the bijuli dekchi just before final assembly. Four heating elements are installed on the bottom of the inner pot. The socket and pilot light are visible in the outer pot.

fact that removing the cover of the cooking vessel to observe the familiar rolling boil results in a high evaporative heat loss. In common with other electric cookers, its use also implies the loss of the social and space-heating value of an open fire.

On the technical side, one of the major potential problem areas with this cooker design is the durability of the connection between the heating element and the incoming power line. This connection is a common source of dissatisfaction with many other cooking devices in Nepal. Its repair in the case of a steam-convection heat-storage cooker is time-consuming and involved.

Bijuli dekchi

In parallel with research on the steam-convection heat-storage cooker, DCS developed a low-wattage cooker with no external heat-storage: the *bijuli dekchi* ("electric pot"). This cooker is similar to rice cookers available in the West—heat is immediately absorbed into the food as it simmers for an extended period of time. It was envisioned that this cooker could also be used to store heat in the form of hot water, which could then be used for cooking when needed.

Each *bijuli dekchi* is fabricated of two locally made aluminum pots of slightly different sizes which nestle within each other. Flat heating elements[18] are attached to the underside of the inner pot (Fig. 30), and the temperature is controlled by a thermostat to prevent overheating. The rims of each pair of pots are crimped together. Silicone was originally used as a sealant to prevent water from entering when the pots are washed. The air space between the pots serves as insulation between the inner pot with its contents and the outside air. Efficiencies approaching 80% are possible and, after cooking, food can be kept warm for several hours. Making any repairs on the heating elements, thermostat, or pilot light is somewhat inconvenient, because the rims of the pots have to be pried opened and then recrimped.

Bijuli dekchis were initially manufactured by the Rural Electrification Programme of DCS and more recently by a private entrepreneur in Butwal. The 2-, 4-, and 8-liter capacity pots are available at a cost of about $25 to $30 per pot. It was envisioned that the largest pot would be used to heat water when no other use was made of the electricity. For cooking rice, lentils, or other food, or for preparing tea, hot water could be transferred into a smaller pot, which is more efficient for cooking. Furthermore, because of the limit on the 250 W service, only one cooker can be connected to the supply at any time. Because of the good contact between the elements and the pot, care must be taken to avoid localized overheating and burning of the food. Maximum temperature for the small cooker is limited by a thermostat to 120 °C to prevent the rice or other food from burning. For the large cooker (used for heating water), the limit is set at 80 °C to reduce the chance that the pot will boil dry, as it is usually left on for many hours at a time.

An evaluation of the use of each of the three sizes of cooker (Wijhe, 1990) led to the following findings:

- The most popular cooker has an 8-liter capa-

[18] The total capacity of the heating elements was initially 200 W, but more recently, these have been made in a range of larger sizes.

city and is used for heating water. This is followed by the 2-liter cooker used primarily for cooking rice, lentils, milk, and tea. Vegetables are rarely prepared in the cookers.

- Most negative comments were received concerning the 4-liter cooker, which is used when larger portions of rice are required. If used to capacity, rice was not thoroughly cooked, and it cooked slowly. Increasing the heating element rating to 250 W might resolve this issue.

- Some households wanted increased lighting in the evening, which precluded use of the cooker for heating water. Decreasing the rating of the heating element to 150 W would still permit adequate heat for heating water and would leave an additional 50 W for lighting.

The slow-cooking nature of the cookers was the most common complaint. The most common technical problems had to do with bad sockets. Either the plug was forced too much and broke the socket or it was not properly installed, leading to sparking and burning of the plug and socket. There were also occasional problems with malfunctioning pilot lights and thermostats.

These disadvantages aside, *bijuli dekchis* appear to have distinct advantages over readily available hotplates:

- they decrease considerably the maximum load required for cooking (from about 1,000 W down to 200 W), and

- with twice the efficiency of locally made ceramic hotplates, they make good use of electricity for cooking.

These factors permit electricity to be used most cost-effectively for cooking. Other advantages are the absence of smoke, no need to attend to the cooking, and pots that are easy to clean. In addition, to encourage cooking with electricity, the cookers are sold at subsidized prices.[19] The cost of energy for potential users of cookers who need access to at least 250 W service is also "subsidized".[20]

In spite of these advantages for the consumers, it was clear that cooking habits would have to change: The pots could not be opened for observing and stirring food, cooking a meal would take considerably longer, different dishes had to be cooked in succession, and the daily repertoire of household chores would have to accommodate these changes. Resistance to these changes could easily hinder the widespread dissemination of these cookers. For this reason, BPC involved motivators as an integral component of its rural electrification effort (p. 43).

What conclusions have been drawn about the effectiveness of these measures to promote reliance on electricity for cooking?

A survey was undertaken nearly three years after the initial electrification in the AHREP area (Pant, 1992). At that time, at least one cooker was found in each of 64 households in the area, but 12 of these were regular project staff and were therefore not considered further in the survey. Two-thirds of the remaining households with cookers were surveyed. Another dozen households without cookers were also surveyed.

The major conclusions from this study are the following:

- A total of 260 consumers (representing slightly more than half of the 450 consumers) in the AHREP area under consideration had access to 250 W service or greater and therefore could make use of a cooker. However, only one-quarter of these (64, including 12 project staff) purchased them, indicating limited popularity of the cookers. Even the number 64 is misleading, because the survey indicated that only one-third of households which had purchased

[19] The subsidy on a complete set of cookers began at 50% and has been reduced slightly over time. On single-unit purchases, it began at 20% and increased to 35% in 1993.

[20] One has to be careful in saying that electricity users who have peak-demand service of 250 W have access to "subsidized" electricity. It is true that <u>if they used all the power all the time</u>, they would be paying about half the per-kilowatt-hour rate of the smaller consumers. However, if they used only half this energy, they would be paying the same rate as the smaller consumers. And if they consumed less, they would actually be paying a higher rate than the smaller consumers.

cookers were using them regularly. Another one-third were also making some use of them at the time of the survey. Because of the subsidy on the cookers, some consumers saw them as cheap metal pots and resold them, possibly to persons outside the service area. In all, in spite of the subsidies, only about 5% of all electricity consumers in the service area made regular use of the cookers and these were consumers in the wealthier households. Possibly another 5% also made occasional use of them. The cookers clearly have not achieved the popularity or prestige associated with other appliances such as radio cassette recorders, fans, and fluorescent lamps.

- Most of the owners of the cookers were or had been working on the project and were familiar with the project office and project staff. Therefore, they had easier access to information and encouragement to purchase cookers. Because the use of a cooker was a completely new concept for villagers, it was difficult to convince most villagers to buy them simply on the basis of information provided by the motivators and through demonstrations.

- It had been envisioned that water would be heated close to boiling in the 8-liter cooker during most of the night hours, thereby making use of otherwise unused energy. The water could then be used for cooking food in the smaller pots as needed during the day. Most users, however, either cook in cold water or heat the water just before cooking, apparently because: (1) an unsightly lime formation appears in the cooker if it is used as envisioned; (2) lighting, if used in conjunction with a cooker, would be limited to only one or two bulbs during the night; (3) according to certain religious precepts, stored hot water is perceived as "impure"; and (4) consumers are concerned that the life of the cooker is reduced if used excessively. Hot water is more commonly used for washing and for cooking animal feed, and this is generally done during the daylight hours when it does not interfere with lighting.

- For owners of cookers, "technical problems" were among of the most pervasive reasons for not using them. These problems were exacerbated by the fact that no one in the village was technically qualified to undertake simple maintenance and that owners could no longer find assistance at the AHREP office.

There has been limited demand for *bijuli dekchis*, and variations of the original design are now being made for specific customers, such as institutions or hotels requiring cookers of sufficiently larger capacity (in physical size and/or wattage). Modifications to pots include adding handles, removing the thermostat (which often seemed to fail), and painting them to increase their attractiveness.

It was found that, in spite of sealing the crimped rims of the pots and the openings for the socket and pilot light, water would eventually enter between the pots. This probably occurred when warm pots were submerged in cool water (the reduced pressure due to contraction of the air within the "sealed" areas between the pots would eventually draw in water, which led to corrosion within the pots). A new design in progress includes holes which have been drilled into the base of the outer pot to permit drainage of water that enters between the pots.

Forced-air heat-storage cooker

This alternative design for a cooker has recently been developed by the Intermediate Technology Development Group (ITDG).[21] While it has not been researched or implemented in the AHREP area, it is included here to illustrate yet another attempt to address the challenge of using electricity for socially acceptable and affordable cooking in rural areas.

The design was developed to address obstacles to wider use of the *bijuli dekchi*: the radical change required in the approach to cooking and the fact that it can be used only for water-based cooking. With a continuous input of 250 W, the forced-air heat-storage cooker can produce a significant quantity of heat fairly quickly. A liter of water can be brought to a boil in 10 to 12 minutes at its peak

[21] Further details are available through ITDG Nepal, Box 2325, Kathmandu, Nepal (Phone: 977-1-220572; Fax: 977-1-220161, Attn ITDG).

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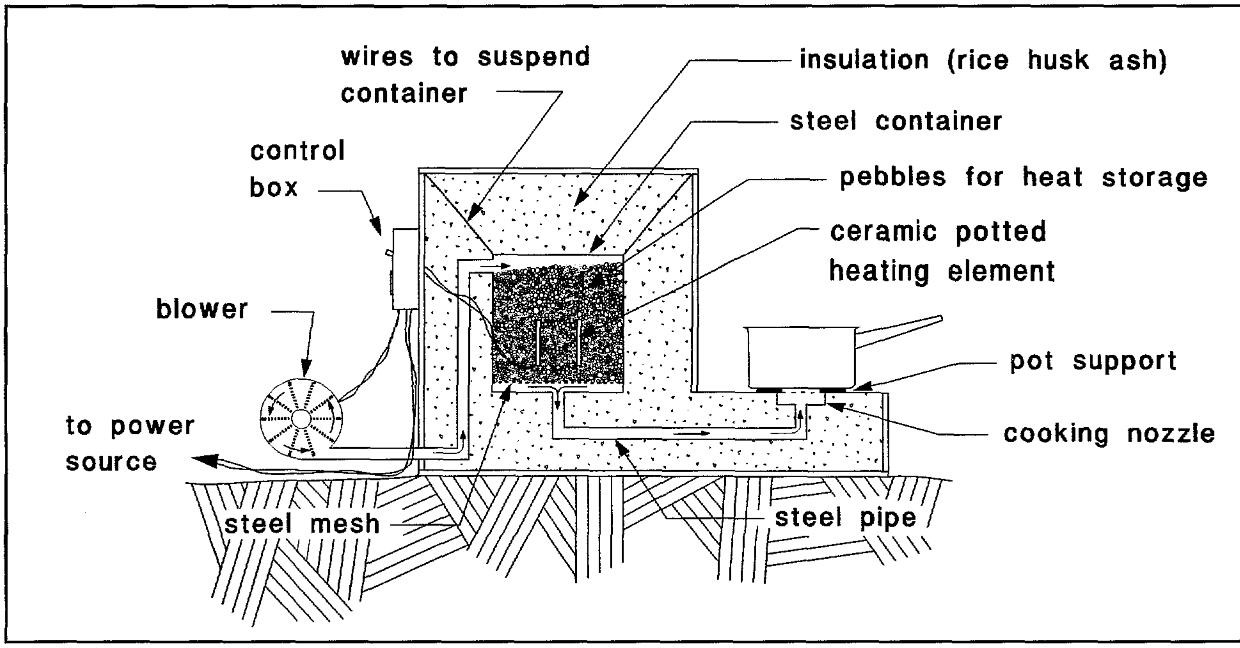

Fig. 31. Schematic cross-sectional view of a forced-air heat-storage cooker.

output. In contrast to the *bijuli dekchi*, it can also reach temperatures sufficient for frying.

Figure 31 illustrates the design. The core of the stove is made of an 18-liter steel container full of small pebbles (6 to 10 mm in diameter), except for a recess of about 20 mm at the bottom and slightly more at the top. While both paint cans and containers fabricated of 30-gage stainless steel have been used, one would assume that the former would eventually have to be replaced (although they continue to work after two years of usage). Placed vertically within the volume of pebbles is a ceramic cylinder, within which is embedded a 250 W heating element.[22] The can is suspended within rice husk ash, which serves as an insulator.[23] For cooking, heat that has been stored in the pebbles is extracted by a 35 W centrifugal blower forcing air through the hot pebbles. After passing through the pebbles, most of the air exits through the cooking nozzle. A smaller portion of hot air exits through a smaller (simmering) nozzle. At peak output, the cooking and simmering nozzles have capacities of about 1,200 and 120 W, respectively.

The controls include separate on-off switches to control the blower and heating element, but there is no provision for controlling the flow through each nozzle separately.

Food is brought to a boil over the cooking nozzle and then shifted to the simmering nozzle, which provides sufficient heat to complete the cooking. If temporarily unoccupied, the simmering nozzle has been used to preheat food. Promotion of this cooking stove must include an explanation of the proper method of using the two nozzles.

Over a period of about nine hours, the pebbles attain a temperature of about 500 °C. Heat is then available at a maximum temperature of 400 °C but averages closer to 300 °C for slightly over an hour. This heat is adequate for cooking for a family with the equivalent of four adults.

Storage efficiency is reported to be about 50% and heat transfer efficiency is also about 50%, leading to an overall efficiency of about 25%. (Because the heat in the air being blown up past the pot is lost

[22] In Britain, this element is called Fecralloy (FeCrAl). It has a better resistance to oxidation at high temperatures than nichrome wire and is claimed to have a service life about three times longer at a working temperature of 700 °C.

[23] Although a good insulator and easily available, the ash from burned rice husks is easily airborne and presents a health hazard during assembly or repair of the stoves. During these times, care must be taken; all food must be covered and safety masks should be worn.

50

by the system, one would expect the cooker's efficiency to be somewhat less than that of the steam-convection heat-storage cooker described earlier, where heat escapes only through the pot).

Field trials have been conducted in two villages supplied by small hydropower plants. While the cookers at one site were removed after the trial period, those at the second site have apparently been maintenance-free and used daily for the past two years (Fig. 32).

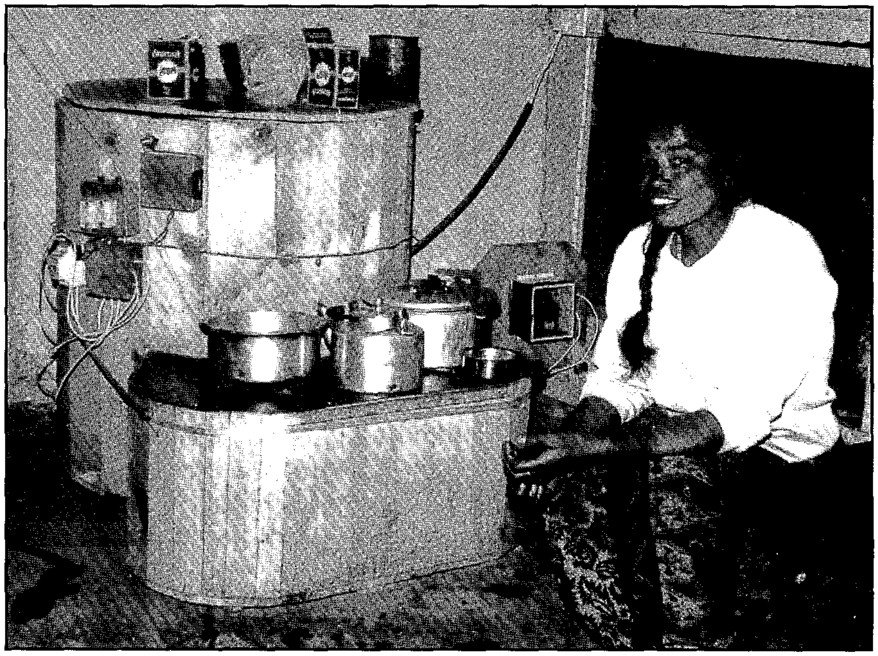
BHOLA SHRESTHA

Fig. 32. A forced-air heat-storage cooker installed in Salleri. The stove is assembled of wooden slats, with the cooking surface of sheet metal. The blower is in the background just to the right of the stove.

In areas where a power-based tariff with subscribed peak-demand levels above 250 W are available, one feature that could be added to the cooker would be a tap on the heater coil to enable charging the cooker at high and low power settings. This would permit better use of the connected power.

It might first appear that users could be frustrated by the fact that there is no indication of the heat remaining in the storage medium, leaving them in a difficult position when the bed of stones cools and the food is not yet cooked. However, in actual usage, this has not proved a problem. Users quickly get used to associating the temperature of the heat escaping the cooking nozzle with the heat remaining in the cooker.

This cooker offers an overall advantage similar to that associated with the other electric cookers described earlier: Their use would reduce the significant work burden placed on women (and children) in the home. No time is required to scrub blackened cooking pots; there is no need to attend to the fire frequently, to fan it, or to adjust the fuel supply; indoor pollution and associated respiratory and other problems arising from the smoke produced during the cooking are eliminated; and time spent combing the surrounding countryside for fuelwood is reduced.

Although the forced-air heat-storage cooker does permit temperatures sufficiently high to cook properly and to maintain traditional approaches to cooking—which is not true of the other designs developed—the costs of the stove do not make it an attractive alternative. In Kathmandu, a cooker with a wooden outer container (as in Fig. 32) would cost on the order of $80 for one incorporating a stainless steel container and pipes and $65 for one using a paint can container and galvanized pipe. To this would have to be added the cost of installation (an additional $10) and transportation of materials to the site. For the cooker using a paint can and galvanized pipe, the wooden outer container accounts for about 30% of the total cost, the blower accounts for about 25%, and the stove top and nozzle, element and electrical components, and pipes and brazing each contribute about 10% to the total costs.

OTHER END-USES

In all tariff categories, electricity for lighting takes highest priority in the AHREP area. The majority of consumers in the villages leave at least one bulb on throughout the night and about a third leave more than two bulbs on. Significant use is made of lighting because homes can be large, with soot-covered walls; homes are cleaned and cattle are fed in separate sheds before dawn; and lights pro-

6

vide protection from wild animals and snakes. Even in homes with 250 W service where adequate power exists for cooking, lighting often takes priority.

For all consumer classes in the rural areas, bulbs in the 15 W to 25 W range are the most popular, although use of bulbs less than 15 W is also significant for 25 W subscribers. In semi-urban areas, this trend holds true only for those at the lower subscribed levels. At a level of 250 W and up, the use of 40 W bulbs prevails.

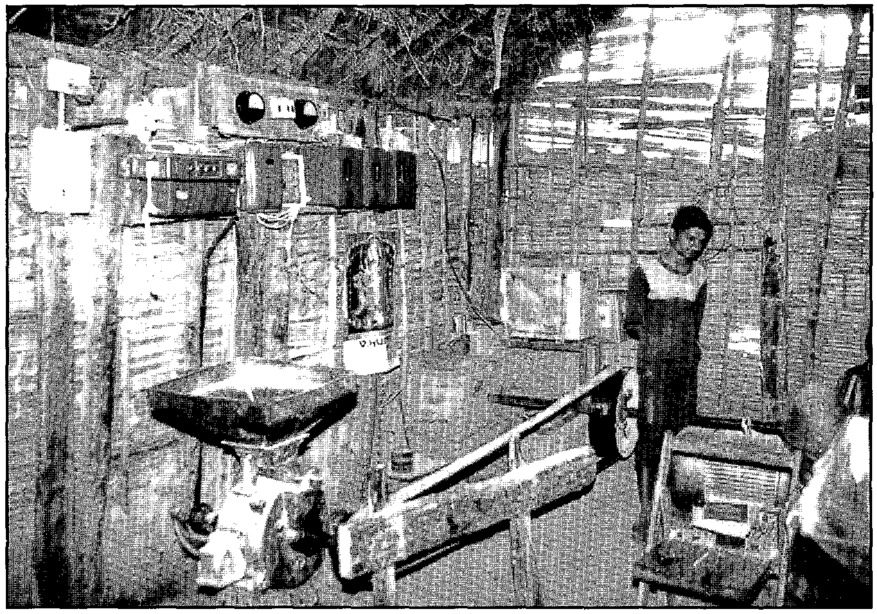

Fig. 33. The mill in Aserdi is supplied through a three-phase transformer located in a box in the far corner of the house.

The cost of electric lighting does not appear to diminish its appeal. In the first place, villagers are willing to invest 20 to 30 times more on housewiring than they are for traditional kerosene lamps. Second, they average about twice as many electric bulbs as they had kerosene lamps. Rural households formerly consumed 1.0 to 1.5 liters/month at a cost of about $0.25/liter, which is less than what even the poorest 25 W subscribers now pay for electricity (about $0.40).

While the distribution system is designed to keep voltage drops within acceptable limits, one problem consumers encounter is the short life of incandescent bulbs. This has been attributed to occasional faults on the main line, which transmits most of the powerplant's 5.1 MW output to the south. These faults cause the plant to lose a significant load. This sudden load rejection causes the turbine to overspeed temporarily, which in turn leads to high transient voltages, which, as noted earlier (see footnote on p. 13), significantly reduce bulb life.

Use of fluorescent tubes would eliminate this problem. Because they are significantly more efficient, these tubes would also allow peak-demand consumers to obtain more than three times the illumination at the same cost. But high initial cost discourages their use. In terms of initial costs, a fluorescent fixture (Nepali-made with no power-factor correction) costs about $5, while an incandescent socket (also Nepali-made) costs $0.25; a fluorescent tube costs $1.50, while incandescent bulbs with capacities in the range of 10 W to 100 W cost $0.20 to $0.30 each, with both types imported from India.

The next most common use of electricity in the AHREP area is to power radios or radio/cassette recorders. Also, fairly recently, a mill was established in Aserdi, in which a 7.5 kW motor drives a flour mill and rice huller (Fig. 33). Two pumps in series, raising water nearly 400 meters from a spring to serve the area's domestic water need, will be a major use of electricity in Phoksingkot. There are few other uses of electricity in the villages.

Recognizing the need to make more income-generating use of the electricity available in rural areas to generate increased financial returns to the consumer as well as to the project, AHREP continues to research possible end-uses. However, there are real obstacles to surmount: The paucity of disposable income, management and technical expertise, raw materials, and transportation and other infrastructure makes it difficult to realize new uses in rural areas.

While AHREP staff would like to present the typical rural consumer with options for making more productive use of electric power (especially because the tariff structure makes it possible to use power 24 hours per day at no additional cost), a further constraint is that it is technically difficult to make

Fig. 34. One of several 8-liter bijuli dekchis being used in a popular restaurant in Galyang.

such use of only 25 W or 50 W, which is the maximum power available to most.

For these reasons, AHREP staff are now focusing on end-uses which might be undertaken by consumers in the semi-urban areas who are located near the main road to markets in the towns and cities and who therefore have increased access to expertise, raw materials, and disposable income.

One area of focus has been the commercial use of low-wattage cookers (the *bijuli dekchi*). These cookers have found little favor in rural areas because few families have the financial resources to cover the cost of the cooker and the recurring cost of electricity. Furthermore, in spite of decreasing forest cover in the countryside, fuelwood can still be obtained at no cost.

The situation is different, however, in semi-urban areas such as Galyang. This town serves as a meal stop for long-distance buses, which disgorge their passengers at the tea shops and small restaurants. The rationale for promoting electric cooking in these restaurants is that their owners would otherwise have to purchase the significant quantities of fuelwood they consume, using financial resources they could then divert to electric cooking, especially if the tariff encourages such a change. Current efforts are focusing on demonstrating in actual tea shops that electric cooking is less costly than with fuelwood (Fig. 34). Because of the increased efficiency of electric cooking, it was found that one shop studied typically consumed 15 kg of fuelwood daily (equivalent to approximately 60 kWh of heat) to perform the same cooking as was achieved using 6 kWh of electrical (or heat) energy. In this case, because electricity is competitive with fuelwood for cooking, the consumer could save on his energy payments, the electric utility could generate increased revenues, and the negative environmental impact from extracting fuelwood from the dwindling forests could be reduced.

Additional efforts have focused on other end-uses: fruit drying, cheese making, and converting a bakery from fuelwood to electricity. However, it has generally proven difficult to identify marketable end-uses for further research and development.

Complementing the activities above, AKP staff are holding training courses of several weeks' duration in enterprise creation. The target audience is primarily individuals residing in the semi-urban areas. Course registration requires that a perspective trainee come to the course with a $4 registration fee and a proposed enterprise in which he would like to become involved. The course presents classes in such areas as marketing surveys and accounting and includes speakers from the banking sector and government departments. Initial courses appear to have generated much enthusiasm, but time will ultimately determine their success.

One additional benefit of these classes is that they should provide AHREP staff with ideas of potential end-uses which might be appropriate in the region, uses on which it might focus future research and development efforts.

ORGANIZATIONAL INNOVATIONS

Typically, all tasks associated with electrification, from generation of the electricity through to collection of bills, are carried out by the electric utility. Direction and inputs come from above, and the consumer is a passive recipient who, through the purchase of energy, provides the utility with the revenues with which it strives to cover its costs. While this approach may be appropriate in the urban areas, there are several reasons utilities find it difficult to work in rural areas:

- increased logistical complications involved in mobilizing utility staff for the construction of rural distribution systems (such as long supply lines, poor site accessibility, and lack of staff accommodations and amenities);
- increased costs associated with these added logistical requirements, as well as the need to continue paying urban staff not only urban wages while they work in rural areas but also additional per diem or "hardship" pay; and
- difficulty in effectively continuing to operate and maintain rural systems at some distance from central offices.

Reliance on personnel from outside the community also distances the utility from the consumers it serves, making the utility less accessible to them and less effective in resolving issues as they arise.

USERS' ORGANIZATION

Rationale

To address the obstacles mentioned above and attempt to reduce the cost of electrification in rural areas, BPC decided to involve the local communities themselves in the construction and operation of their distribution system. It was envisaged that the following advantages might accrue as a result of such a policy:

- reduction in the costs of distribution system construction;
- reduction in the administrative burden which BPC would otherwise have to bear; and
- strengthening of community unity and commitment to the project.

This concept was given substance through the creation of electricity users' organizations (UO). As an incentive for their formation, it was decided that BPC would deal only with UOs rather than with individual consumers on all matters related to the supply of electricity to communities. If a community is interested in receiving electricity, it is the responsibility of its members to organize themselves into a UO, with the assistance of BPC as necessary.

The following responsibilities were assigned to the UO:

- gathering and submitting applications for connections to BPC;
- organizing contribution of local materials, most notably wooden poles, and labor;
- collecting periodic bills and fees from consumers;
- assuming responsibility for routine control and maintenance of the distribution system within the UO's area; and
- serving as a communications link between the community and BPC.

Experience to date

The first area to be electrified through an electricity UO was the village of Aserdi, which has somewhat fewer than 200 households. It was selected because of its relative proximity to the Andhi Khola powerplant, the enthusiasm of the villagers, and their willingness to contribute voluntary labor and poles to get electricity to their village. This village had already shown signs of community motivation by having organized a drinking water committee responsible for the construction of a water supply system within the village. Its somewhat remote location—it has no road access—also provided the opportunity for a more rigorous evaluation of the concept.

54

The second area, which is currently being electrified through a UO, includes four mountaintop villages with approximately 240 households in the Phoksingkot Village Development Committee (VDC) area.[24] The population is faced with difficult access to the area's only year-round water supply, located on the steep mountain slopes more than 300 meters in elevation below the highest village. The compelling reason for undertaking this project was to provide electricity for pumping, even though this area would be costly to electrify. Furthermore, the community was also willing to make a large cash contribution of $10,000 toward this project. (This village has a number of retired soldiers who receive a pension, and they make a proportionately greater contribution than other villagers.) A water and electricity UO responsible for the electricity and water distribution systems and for the water pumping system has been formed.

The concept of an electricity UO is relatively new, although it has been applied for other purposes, such as drinking water supplies, irrigation, and roads. To date, three electricity UOs have been formed, and another four are expected in 1994. As experience is gained, lessons learned will be incorporated in future efforts. Consequently, presentation of the following description of UOs and their role in project implementation is not meant to imply that the optimum design for such an organizational structure has already been found. This description is simply one possible organizational approach to rural electrification.

The following paragraphs describe the steps undertaken from the time of initial villager interest in electrification to energization of the system and the role the UO plays in this process.

Project initiation

After requests for assistance in electrification have been received by BPC from the VDC in a particular area, the area is included in a rolling five-year plan. As the time for project implementation approaches, engineers from BPC prepare a feasibility study of the area. Such a study includes the following:

1. **A general description of the area to be electrified**: names of villages to be included; the number of homes; forecasted initial domestic load (based on assumed load per household, generally set as approximately 100 W to 200 W for rural and semi-urban areas, respectively), industrial load, and growth rate for each; and a general map of the area showing villages, location of the existing 33 kV line with any branch lines and transformers, location of proposed 33/1 kV transformer, and approximate alignment of the proposed distribution lines to serve the area.

2. **Description of the distribution system**: load flow diagram including section lengths of main lines and branches, with type of conductor (ACSR or bundled cable) and number of phases, and the magnitude of the load at each node (Fig. 35).

3. **System design**: conductor size for each line section based on projected load at an appropriate future time (e.g., in 20 years) assuming a maximum permissible voltage drop at the end of each line; actual voltage drop in each section and cumulative voltage drop from 33 kV transformer to each node; main transformer size; and total energy losses in the line.[25]

4. **Cost analysis**:

   - costs for each of the following components: line (based on unit costs for each conductor type, size, and number of phases); 33/1 kV substation (or the portion of this which will serve the new area); 1/0.23 kV service transformers and installation; service drop based on assumed length per household (e.g., 30 m); cost of PTC/MCB box based on an assumed distribution of the numbers of consumers among the different consumption levels; and annual BPC operation and maintenance costs;

   - financial return: assumed number of consumers in each class; monthly revenues

[24] A VDC is composed of locally elected officials who run the affairs of a geographical area which may include a number of villages. Following the advent of democracy in Nepal in 1990, the VDC replaced the village *panchayat*.

[25] When sizing the lines in this analysis, villages along the line which may not initially connect to that line are still included.

66

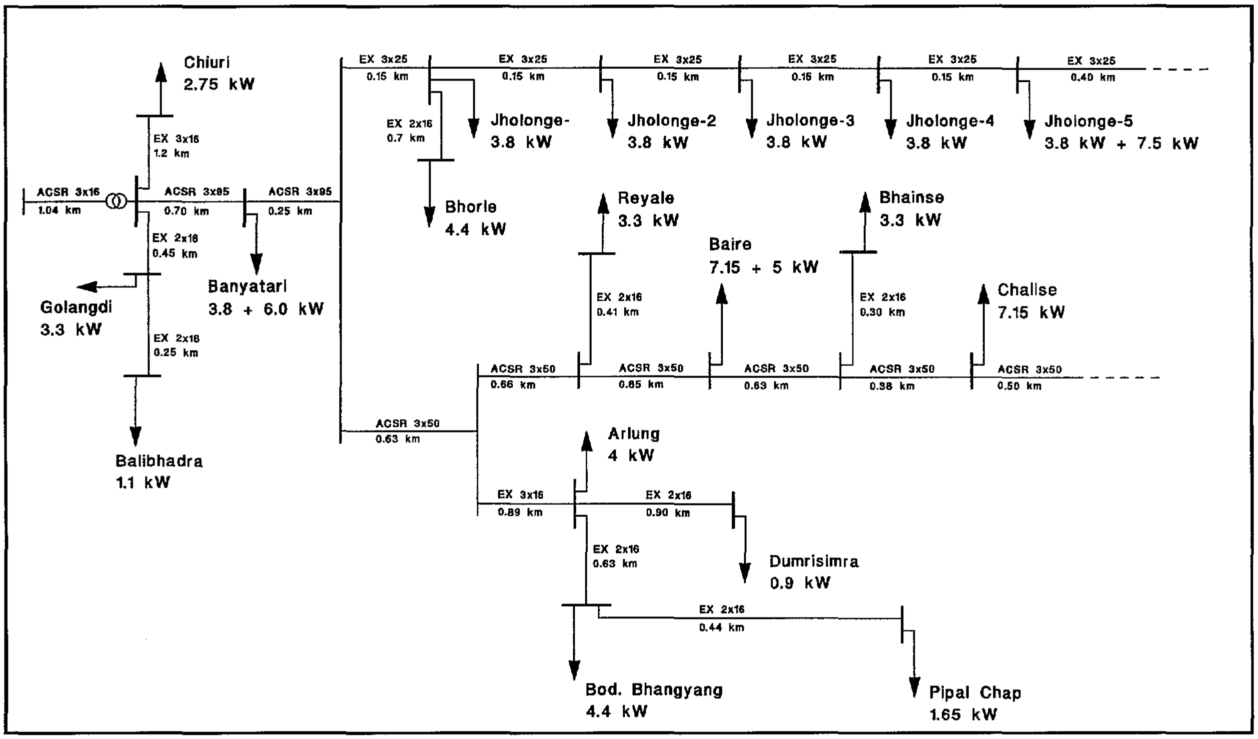

Fig. 35. A portion of a load flow diagram prepared as part of a feasibility study. "EX" refers to bundled cable. (Extracted from "Electrification of Thumpokhara VDC, Feasibility Report", prepared by BPC)

from domestic consumers and from each industrial load based on the tariff structure and an assumed consumption; total annual revenues (with 10% reduction as return payment to the UO); and

- rate of return and simple payback period.

5. **Definition of the sequence and scope of each phase of the project**: the sequence in which lines will be constructed and villages connected.

The findings of the feasibility study are presented to the VDC, as are the conditions under which BPC is willing to undertake the project. If the VDC is interested in pursuing electrification, it is responsible for calling a meeting of the villagers of the area and a representative of BPC to discuss the proposed project and these conditions. If interested, the villagers must agree to the terms under which the project is to be implemented and elect members to their UO committee. Later, when project construction is under way, meetings between BPC and representatives of the UO are held when necessary. Villagers are also informed about various aspects of the electrification effort in the area through village motivators (p. 43).

For the Aserdi project, it was also felt that the organizational infrastructure for this organization should be minimized. A 15-member committee for the UO was formed. It was felt that the committee should initially have a larger membership in order to ensure that the required voluntary labor could be recruited. It would have been difficult for only three individuals to assume this responsibility. However, only three of the 15 members were actually involved in dealings with BPC. Once the project was operational, the size of the UO committee was reduced.

Project construction in Aserdi

When all was in order, villagers began by assisting in staking the distribution lines and clearing the right of way for the lines, after which BPC finalized the list of materials required. At the next meeting of the UO, the final distribution system design was presented, along with requirements for labor and local materials.

During the construction period, the power lines were built with voluntary labor from the UO. The villagers were responsible for transporting the materials and equipment to the site, digging the holes for poles and anchors for the guy wires, helping to string the cable, and performing other work required in the construction of the line. This work was done under the supervision of BPC and with technical assistance from the construction company. The overseer first briefly described the work to be done and supervised the first few efforts. Less supervision of the actual work was necessary as the project proceeded. All wooden poles used to support the branch lines within the village were contributed by the villagers. BPC provided some of the tools, and villagers also provided their own. Erection of the poles and stringing of the lines were done by the construction company, together with BPC and the UO.

Each day, the number of villagers required for the following day's work was determined, and the UO located the necessary manpower. The UO and BPC each kept records of those who contributed labor. In Aserdi, the connection fee was waived because the villagers contributed free labor and/or materials. For the Aserdi project, it was estimated that the contributions of villager labor and materials accounted for about 9% of total cost. They contributed 15% of the labor costs and 6% of material costs for the project. Their labor contribution toward construction of the branch lines in the village accounted for about 60% of all labor costs. The wage for a laborer was approximately $1 per day, and the price for a wooden pole was about $15.

Along with actual line construction, two men from the village were involved in activities of BPC and trained in line maintenance so that they would be ready to be employed by the UO in the role of service men.[26] Also in preparation of actual operation, a bank account was opened for the UO at the local bank. Monthly payments due BPC to cover the costs of the energy consumed would be collected by the UO and deposited in that account. In addition, BPC deposited a nominal sum into the UO's account as starting capital and provided the UO with some construction tools.

Staffing

Of the tasks assigned to the UO, the collection of fees was considered a half-time job. Other responsibilities included assisting prospective consumers in completing application forms for new service (which is done with the assistance of the motivators) and infrequent line maintenance. In Aserdi, BPC and the UO decided that one individual serving as the service man and performing these tasks would be sufficient. He receives a monthly salary of about $10 paid from the monthly electricity fees submitted to BPC. Most of the work on the line itself up through the service entrance, such as adding new customers and replacing defective cutouts, is undertaken by staff from BPC.[27] When necessary, some minor repair work in Aserdi is done by the service man with the assistance of villagers who are employed by BPC. However, with new UOs located farther from BPC, villages will probably not have access to local villagers employed by BPC.

Collection responsibilities

The service man for the UO is responsible for collecting the monthly electricity payments from subscribers in the village according to the tariff structure established by BPC. The amount owed by the UO to BPC is transferred to BPC's local bank account by the 10th of the following month; otherwise, there is a 5% penalty for the remaining portion of the month and 10% for the next month. If the consumer is still delinquent, he is disconnected and reconnected only after paying a fine. The reason for non-payment has usually been the lack of ready cash.

When timely payment is made, a portion of the revenues is returned to the UO and used to pay the serviceman's salary.

[26] It had been envisioned that both villagers trained by BPC would eventually work for the UO. However, because of a delay in construction, both became salaried workers who contributed effectively to BPC operations. Because the UO did not have the financial resources to take over paying these two individuals and because of the limited nature of the work required of the UO, it decided to employ a villager trained in India as service man.

[27] BPC's costs for maintaining the main lines since energization has been estimated as $100 to $200 annually.

MOTIVATORS

BPC's objective was not simply to provide electricity for sale to rural consumers. It was equally interested in ensuring that electricity be productively utilized to increase the disposable income of its rural consumers, that it be used safely and efficiently, and that it contribute to conserving the natural environment. Consumer education was therefore deemed an important component of its work.

BPC's approach in addressing the issues above was to hire and train a team of "motivators"[28] selected on the basis of their interest in community development and their ability to master new concepts and communicate effectively. Previous work experience and formal education were not deemed important. Candidates were selected from local community members who appeared suitable for the task and were known by the project staff. During a two-week trial period, BPC introduced them to various aspects of its electrification work and encouraged them to discuss their own ideas and reactions to the work. Seven motivators were eventually selected on the basis of their understanding of BPC's approach to development, their willingness to learn and participate in discussions, their ability to work together as a team, and their ability to communicate.

These were young individuals (18 to 22 years of age), including three married couples. Although it was felt important to hire women for this work, few single women were available for outside employment. It was felt that hiring couples would also enable them more easily to accomplish their household chores in addition to their employment responsibilities. It was also easier for couples to travel anywhere together and to spend nights away from home.

Training for the team lasted about five months and involved work both in the field and classroom. The principal objectives of this training were the following:

- increase the trainees' communication and teaching skills;
- impart an understanding of the integrated nature of development work and AHREP's philosophy and approach to this work; and
- develop their knowledge of the relevant technical issues: tariffs, safety, use of cookers, household wiring, etc.

The training was planned to model the informal, non-authoritative stance that motivators were expected to assume in their work.

While most villagers are aware of electricity because of visits to the towns, few have direct experience with its use. The motivators therefore made an initial visit to each home in the village being electrified, often as a couple, to meet with all members of the families and discuss the roles of the various actors (BPC, AHREP, and AKP), how to use electricity, and safety issues. This provided the villagers with an overview of the issues they would encounter as a result of electrification.

Once all households had been visited once, the motivators then scheduled a dance, drama, and slide program they themselves had prepared. It covered such subjects as electrical safety inside and outside the home, uses for electricity, electrical cooking, the concept of a peak-demand, the cost of electricity and the need for a tariff, and housewiring.

This program was followed by a second house visit with a sample of the ready-made wiring to discuss housewiring, the tariff structure, and applications for electricity and to address other questions the future consumers might have. Flash cards linked to the drama were also used during this second visit to reinforce points raised during the drama.

The motivators were also involved in other BPC activities: fabricating ready-made wiring harnesses; visiting villages along the 33 kV line to inform villagers to keep away from transmission towers and discuss other safety issues; meeting with community leaders interested in electrification of their areas; and preparing maps and gathering data on villages to be used for planning purposes.

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28 Although the term "motivator" is commonly used, these individuals are essentially extension agents— they inform more than motivate. However, it is clear that some of this extension work may increase consumers' awareness of the issues and thereby "motivate" them to change in light of this new awareness.

58

The use of motivators is still in its relative infancy, and their involvement in the electrification process continues to evolve. It is felt that their involvement has been a critical factor in the success of the electrification process in the rural areas, yet it is still difficult to provide objective evidence to support this claim. While no studies with this purpose in mind have yet been undertaken, one would assume that without the involvement of motivators, electrification in the more remote areas would have followed the more conventional pattern, in which only relatively few households avail themselves of electricity and lighting is the only end-use.

Lessons learned to date regarding the use of motivators include the following:

- Women members of the team have not been released from their household chores to the extent that had been envisioned. They are often overworked and tired and, possibly as a consequence of this, occasionally show less interest than would be desirable. Some have since resigned; others have negotiated workable schedules at home.

- Local individuals were hired because it was felt that their intimate knowledge of the local situation would be valuable and that this would eliminate any problems with finding accommodations. However, it was found that, for reasons of status and/or family ties, motivators did not find it easy to work within their own communities. Also, their youth may also have contributed to the problem. As the motivators themselves grow more confident in their role and as the villagers see them as more knowledgeable, their acceptance grows.

ASSESSMENT OF INTERVENTIONS

This chapter assesses effects of various interventions which have been implemented by BPC on the cost of rural electrification and on the consumers themselves. The two issues which are therefore of interest are the following:

- the extent to which new designs have reduced the cost of rural electrification and
- the extent to which they been successful in increasing the rural population's access to the benefits of electrification.

Before embarking on this effort, two issues must be highlighted. The first is that, however frustrating it might be, developmental change does not happen overnight. The electrification of the AHREP area was launched barely five years ago, and one cannot necessarily expect major impacts over such a short period. However, some tentative conclusions regarding the effects of certain interventions can be drawn from trends observed during this period.

The second is that changes, beneficial or otherwise, which have occurred in the AHREP area may or may not be attributable to the availability of electricity. Any studies to determine the bases for these changes must also include as controls both non-electrified areas as well as the areas electrified under conventional designs; otherwise, it would be difficult to isolate the reasons for any changes which have been observed.

For example, when reviewing the specific case of the AHREP area, there appears to be an increase in the number of individuals leaving rural households after electrification. Does this finding imply that rural electrification contributes to the movement of populations from the rural areas to the urban centers? Unfortunately, from the information available, it cannot be determined whether this phenomenon is directly attributable to electrification, that is, whether a smaller (or greater) number would have left over five years had the area not been electrified. A similar database for unelectrified portions of the country outside the project area would be necessary to answer this question.

INNOVATIONS IN DISTRIBUTION SYSTEM DESIGN

The principal interventions which were undertaken with the objective of reducing the cost of electrification in rural areas are the following:

- a 1 kV rather than a more conventional 33/0.4 kV or 11/0.4 kV distribution system,
- a new design for fabricated steel poles and towers,
- current cutouts rather than kWh meters for small consumers,
- ready-made wiring harnesses for the home, and
- users' organizations for running community electricity systems.

In the original analysis of different approaches to supplying a generic rural area from a 33 kV line, the cost for constructing a 1 kV system was calculated to be about 30% less than that for a conventional 400 V system (Table 1). Because some of the assumptions made and procedures used in this cost comparison were not clear and because one purpose of adopting the 1 kV intermediate voltage level was to serve areas up to 5 kilometers from a 33 kV line (Aserdi is only half that distance), an independent effort was made to more precisely compare the costs of the 1 kV system with those of more conventional distribution designs. A well-defined service area and set of design criteria were established, patterned on the actual situation found in the Aserdi/Phoksingkot area. To obtain a clearer idea of the cost savings, if any, incurred by adopting a 1 kV intermediate voltage, the costs for electrifying this area using both the 1 kV as well as more conventional voltages were calculated using costs in 1994 dollars and assuming that BPC would be charged with the construction. The results of this analysis are summarized in Annex B.

This analysis concludes, as did Hagen (1987), that the 1 kV system is less costly than the following systems:

60

- immediately stepping down the 33 kV to 400 V and distributing power at this voltage to, and within, the Aserdi/Phoksingkot area and

- bringing a three-phase 33 kV line to each of the areas to be served and stepping down the voltage to 400 V within each load center.

However, the analysis also concluded that if the 33 kV (transmission) voltage were first immediately stepped down to 11 kV and then brought into each service area where the voltage would be further stepped down to 400 V, costs would be similar to those associated with the 1 kV system.

Furthermore, if there were any interest in extending electrification farther than 5 kilometers from the 33 kV line as originally assumed, it could be concluded that an 11 kV distribution system would be less costly than one operating at 1 kV. With the light loading commonly found in rural areas, a minimum-size (25 mm^2) 11 kV ACSR line could continue a considerable distance before accumulating an appreciable voltage drop. Alternatively, the existing 11 kV system could cater to a larger average consumer demand than the 130 W assumed. As designed for the analysis, the main 1 kV line has already approached its maximum voltage drop at 5 kilometers from the substation and could not be extended farther or serve a larger load without an increase in conductor size and cost.

An explanation of why the initial analysis, when applied to the Aserdi/Phoksingkot area, led to the incorrect conclusion that there would be a considerable cost savings through the use of the 1 kV distribution voltage is also included in Annex B.

In summary, the recent analysis seems to indicate that, at least under certain circumstances, adoption of a 1 kV distribution voltage does not necessarily result in significant cost savings. And there are three other reasons which might discourage it use:

- there may well be a desire to extend a system beyond the 5 km originally considered,

- energy losses in the 1 kV system are higher than those in the 11 kV system, and

- 1 kV is a non-standard distribution voltage in Nepal.

It should be made explicit here that the 1 kV system may not have proved particularly advantageous in the Aserdi/Phoksingkot area because of the fairly high consumer density in a fairly confined area. On the other hand, it might prove advantageous under circumstances where consumer clusters are smaller and more dispersed. The logistical difficulties associated with the transport of transformers into remote areas is also an important consideration. The use of a 1 kV distribution voltage would also be appropriate in circumstances when a micro-hydropower plant serving a remote, isolated load center is located too far from the load for a secondary voltage (400/230 V) to transmit power over this distance. This could be a fairly common situation in remote areas of Nepal.

It should also be noted that reliance on 11 kV would require the use of considerably heavier transformers. Because transportation is frequently done by porters along mountain trails, this factor alone may imply there are few alternatives to the use of a 1 kV distribution system.

Another point to consider is the relative ease of operating a 1 kV versus an 11 kV system. Implementing 11 kV systems could lead to an increased number of transient line faults, especially during the monsoon season, and to the more frequent need to replace fuses. While a three-wire distribution system is used in both cases, the neutral on the secondary of the 33/11 kV transformer is grounded at the substation, and this makes it easier for line-to-ground faults to occur in cases such as when branches brush up against a line. Because the 1 kV system is ungrounded, simultaneous ground faults must occur between two different conductors and ground (or across conductors) for a fuse to blow, and this is less likely to happen. However, this problem is more a function of the approach used in grounding than of the distribution voltage used.

In the light of this analysis, another conclusion can be drawn. Until sufficient data is gathered to possibly formulate rules of thumb, there would appear to be a need to assess more carefully which distribution voltage would be the most appropriate for each given situation.

There is also the need to continue probing into whether there are more attractive alternative distribution system configurations which could further reduce the cost of rural electrification. One possibility, initially mentioned but apparently never pursued, would be to use a single-phase, 11 kV distribution system.[29] The analysis indicates that for the light loading assumed, which is typical of many rural areas, the size of the 11 kV ACSR conductor is determined by strength requirements and that the voltage drop is minimal for this size conductor. The voltage drop of about 1% to the end of the main three-phase 11 kV line in the case analyzed would be several times higher if a single-phase 11 kV line were used. However, with the excess carrying capacity of the existing conductor as originally sized, the maximum voltage drop would still remain within acceptable limits.

A single-phase system would have some cost advantages over the three-phase 11 kV system analyzed. These include those associated with the use of two rather than three minimum-size conductors for the main line and one (although larger) rather than three single-phase transformers in the larger load centers.[30]

Because the primary (11 kV) line serving the area would be single-phase, distribution within each load center would also have to be solely single-phase rather than be served by a three-phase 400 V backbone. However, to avoid the need for significantly larger and costlier single-phase branch lines to carry single-phase 230 V power longer distances to the consumers within the load centers, a 230/460 V system could be used as the backbone. This would require three conductors from the 460 V secondary of the distribution transformer, with one conductor from a center-tap on the secondary winding. This would provide 230 V between each of two conductors and the conductor on the center-tap. Balancing loads would then permit this third conductor to be somewhat undersized. (If the system were properly balanced, this third conductor would carry no current.) Distributing single-phase power on such a three-wire system from a 460 V secondary would be competitive with distributing three-phase power on a four-wire system from a 400 V secondary.

Several other conclusions can be drawn from this recent analysis:

- Materials and labor associated with construction of a rural electrification distribution system in the Aserdi/Phoksingkot area to serve about 500 consumers in an area about 2 km wide by 5 km deep bordering on the 33 kV line would cost approximately **$120 per consumer**. This is less than the cost of $180/consumer incurred in the actual construction of the first part of the system, which only served the 170 consumers in Aserdi (with costs therefore apportioned among fewer consumers) and which included the cost of service drops with poles, service entrances, and housewiring.
- Costs for material and labor for a primary 11 kV three-phase three-wire ACSR line (25 mm^2) over hilly terrain are on the order of **$3,700 per kilometer**.
- The project also relied heavily on the use of bundled cable. While the cost of bundled cable is considerably more than that for open ACSR conductor, there is not much difference in the cost once the conductor is installed. The increased safety associated with insulated bundled cable permits lower and less costly poles and permits suspending the cable from wooden poles, trees, and sides of buildings, further reducing the cost of installation.

To put these values in perspective, the median cost per consumer for a number of large rural electrification projects worldwide is very roughly **$600 per consumer**, although there is considerable variation

[29] Single-phase primary distribution lines are widely used on the North American continent and were initially developed specifically to serve rural areas, with their low consumer density, more cost-effectively. It has since been increasingly used in other countries as their distribution grids have expanded into more rural areas, where the conventional three-phase system proves too costly as well as unnecessary.

[30] Perceived limitations of single-phase power for driving electric motors are frequently raised as an argument against its use. While the availability of single-phase motors initially would be an issue in a country which has had no market for such motors, it should be made clear that motors with capacities of up to 10 hp are commonly available in a number of countries. The fact that most large farms in rural America rely solely on single-phase motors for their entire operation should be an indication that there is no technical obstacles to their use to meet the needs of rural Nepal. In addition, motors of up to at least 100 hp can also be driven off single-phase lines through the use of rotary phase converters.

62

from one project to the next.[31] Furthermore, costs for the construction of primary distribution line are generally in the range of **$5,000 to $15,000 per kilometer**. BPC has therefore illustrated that rural electrification can be accomplished at costs considerably less than those commonly encountered.

For the purpose of applying the conclusions from the Andhi Khola experiences to non-BPC projects, two factors must be noted. First, although the costs above include labor, labor rates in Nepal are very low (about $1.20 for a villager man-day and $1.60 for a technician man-day); the cost of labor for line construction is about 6% of installed costs.

Second, it is probably fair to assume that the private-sector implementation of rural electrification projects is more cost-effective than reliance on a government-run utility. Consequently, one would assume that if the same materials and standards used by BPC were used by such utilities, their costs would be higher.

Another innovation after the adoption of an intermediate distribution voltage is the introduction of galvanized steel poles. The principal advantage to this innovation is not its cost: 8-meter poles at a unit cost of about $100 are roughly twice as costly as concrete poles. Rather, their advantage is in the ease with which they can be transported and installed in remote areas. It would be difficult even to consider the electrification of remote mountain-top villages by means of concrete poles each weighing half a ton. Use of poles such as those fabricated by NHE simply contribute to making electrification a reality. However, given the fact that approximately half the cost of line construction is attributable to the poles, there is a need to determine whether a more cost-effective design can be developed.

To the consumer with limited financial means who is responsible for covering the costs of house-wiring, there are clearly cost advantages to using ready-made wiring which can be easily installed. In addition, there is the advantage of increased flexibility of design. While conventional wiring would cost at least $30 to $40 per household, the introduction of a third innovation—the ready-made wiring harness—implies a savings of 80% or more to the consumer.

The use of cutouts further reduces the cost of electricity supply. In Nepal, a single-phase meter costs on the order of $20 per meter, compared to $4 to $7 for a cutout. Furthermore, when cutouts are used, monthly consumer bills are constant, obviating the need for and cost of meter reading. In developing countries, the cost of meter reading (not collection) may commonly range from $0.05 to $0.20 per consumer and is generally higher the more rural the setting.[32] Billing costs are often of a similar magnitude. If one were to use a meter, amortize its cost at 5% over 10 or more years, and add meter reading and billing costs, the total monthly cost to the consumer would be at least $0.30—nearly doubling the monthly bill for the smallest consumers.

One possible disadvantage of cutouts is that they may be easy to bypass. However, this can be as much a problem with meters. A reliance on self-policing by a users' organization, where such an illegal action of any one consumer would have a negative effect on other consumers and motivate them to act and resolve the problem, may be the most cost-effective approach to addressing this issue.

Occasional load measurements made on the Aserdi line seem to indicate that another possible disadvantage is that the maximum allowable current cannot be precisely set (see p. 18). As a consequence, peak consumer loads can be more than expected.

31 For comparative purposes, some recent per-consumer electrification costs for specific projects are as follows: $300 to $500 for Nepal; $500 for Bangladesh; $550 for rural projects in El Salvador; $650 for Bolivia; $700 for Kenya; $650 for urban systems in South Africa and $900 for a rural village of 460 in the Transkei; and $1,300 for a more remote area in Costa Rica with a density of only seven homes per kilometer of line. Note that there may be considerable variation in the approach used in calculating these costs, that there can be a wide disparity in the consumer density of the areas being electrified, and that, at times, costs may not include all the overhead or consultancy costs incurred in an actual project.

32 Some per-consumer costs for meter reading in more populated rural areas are as follows: $0.03 in Bangladesh and Guatemala; $0.05 in Nepal; $0.10 in Guatemala; $0.15 in Costa Rica; and $0.15 in El Salvador for a system introduced by NRECA and $0.70 for the traditional approach.

65

Two-tier single-phase meters have been successful as a component of a demand-side management program in semi-urban areas under AHREP, encouraging higher load factors and reducing peak system loads. But these meters have been donated to BPC. The cost of new two-tier meters would be considerably more than ordinary single-phase meters and would generally not be cost-effective. One lesson from the Andhi Khola experience, however, is that alternative tariff structures and associated approaches to metering may ultimately result in advantages to the utility in the form of reduced peak demands. There is then a need to assess whether these savings to the utility more than offset any additional cost for alternative metering approaches.

There are also cost savings attributable to reliance on UOs, although these savings are also difficult to ascertain. In the Aserdi project, the cost for the service man averages not much more than $0.05 per consumer each month. With the large manpower pool common to government-run utilities, it is probable that this cost would be higher in rural systems run by these utilities.

IMPACT OF TARIFF

It would seem that the novel power-based tariff schedule introduced in the AHREP area should benefit both the consumer and utility. For the consumer, it should make available additional energy for the same monthly bill and encourage him to adopt additional end-uses which would presumably generate increased benefits. For the utility, by reducing peak loads, it should permit a larger consumer base for a given system design and result in an increased load factor.[33]

But to what extent has the tariff schedule adopted led to the realization of these projected benefits?

Studies at the project site have shown that the load factor for the service area averages 60% to 80%, considerably higher than for rural consumers found elsewhere in the country. This implies that the consumers who have subscribed to the power-based tariff are using electricity for purposes beyond merely lighting during the evening and early morning hours. Indeed, one common end-use during daylight hours continues to be lighting, in part because, even during these times, the lack of windows frequently leaves certain areas of the home dark. Some electricity is also used for cooking and for radios. Clearly, a higher load factor in itself is not an appropriate indicator of increased benefits to the consumer, because, while it does indicate that some off-peak use is being made of the available power, it does not guarantee that it is put to good use.

The major obstacle facing small rural consumers who have limited disposable income, but who would like to derive further benefits from using the excess electricity available within their subscribed peak-demand level, is that few benefit-generating end-uses are accessible to them. One end-use available to those subscribing to the 250 W tariff level is low-wattage cooking, but for various reasons, this has had limited appeal (see p. 33). AHREP staff are clearly aware of this difficulty and continue to attempt to ferret out appropriate end-uses.

From the vantage point of the utility that has responsibility for the powerplant and distribution system, the benefits BPC has incurred to date which are attributable to the tariff structure have not yet been of any consequence. This does not mean that the power-based tariff would have no impact; rather, it simply means that the number of consumers in the AHREP service area and their individual demands have not yet reached the point where the design capacity of the system would have been exceeded even if the conventional energy-based tariff had been implemented. In other words, the benefits associated with being able to serve more consumers than would otherwise have been the case had a conventional tariff been in place have not yet had the chance to manifest

[33] It has also been suggested that such a tariff schedule permits a more predictable level of income to the utility because this income can be easily calculated by summing the well-defined monthly bill associated with the subscribed demand level of each consumer. For isolated, micro-hydropower plants where the fuel is essentially free, this tariff would be appropriate because the marginal cost of energy is minimal. In such systems, it is the plant's peak capacity that determines both its capital cost as well as the maximum number of consumers it can serve, and only these two parameters would in turn be used to calculate the tariff necessary to cover the amortized capital and operating costs. Future energy consumption, which would be difficult to project but which forms the basis for determining conventional energy-based tariffs, could be of little consequence in setting a power-based tariff.

Table 4. Number of rural and semi-urban consumers at various tariff levels over a 4-year period.

Description	Semi-urban[a] 1990	1992	1993	Rural 1990	1992	1993
Subscription level[b]						
25 W	2	2	2	30	26	19
50 W	39	46	70	86	116	116
250 W	164	169	188	51	26	23
500 W	62	59	78	0	0	0
700 W	1	1	2	0	0	0
1,000 W	5	4	3	0	0	0
Industry	1	1	1	0	0	0
Total consumers	274	282	344	167	168	158

[a] Semi-urban consumers are those in the villages of upper and lower Galyang, Bhati, Falang, and Amila Kharka. Rural consumers are those in Aserdi.

[b] The 25 W, 50 W, and 250 W consumers have cutouts while the consumers in the higher classes have two-tier metering.

themselves. However, as consumer demand approaches system capacity, the benefit of being able to serve a much larger consumer base would be significant.

Other observations regarding the tariff might be added here. One is a somewhat temporal problem with the tariff: Especially for consumers with no experience in electricity usage and no familiarity with tariff structure, the tariff schedule probably has little real meaning. One would expect that, as experience is gained over time, consumers would make greater (but not necessarily better) use of the energy available to them. Limited data indicate that this is indeed happening.

One indication of consumers' better understanding of the tariff schedule is their electing to change their subscribed demand. The clearest trend illustrated in Table 4 is a significant number of 250 W rural consumers in Aserdi electing to decrease their subscribed peak-demand level down one level to 50 W. The large change in Aserdi probably demonstrates that villagers changed their mind about their eagerness to use the heavily promoted low-wattage cookers as they gained a better idea of the financial implications of the various tariff levels. It also appears that a few consumers in the lowest tariff category have, for financial reasons, decided to terminate service.

From these data, a similar trend toward a lower peak-demand level is not as clear for the wealthier consumers who live on or near the main road around Galyang. However, while there has not been a similar decrease in the number of 500 W consumers to reflect any dissatisfaction, a number of metered consumers at the 500 W level have indicated a preference for a metered rate between 250 W and 500 W.

Another observation is that several reports comparing the relative merits of different tariffs have used the cost per kilowatt-hour. These reports imply that a consumer who pays Rs 1/kWh, for example, should feel that he has a better deal than if he had paid Rs 3/kWh. However, especially for rural populations, it is usually the bottom line—the monthly bill—which matters, not the unit cost of electricity. Therefore, a small consumer who subscribes to 50 W for Rs 35/month and uses 7 kWh/month (at an equivalent cost of Rs 5/kWh) does not feel that he is getting a better deal if he uses 35 kWh/month simply because this is equivalent to Rs 1/kWh (assuming that he even understands this nuance). In both cases, he pays Rs 35/month and that is what is important to him.

As noted earlier, a power-based tariff schedule does not motivate the consumer to conserve energy, but this would generally be of little consequence for isolated run-of-river hydropower projects because the unused water (and the energy it represents) would be wasted anyway. On the other hand, if the plant were grid-connected, energy wasted by the consumer would represent a loss of potential revenues to the utility because it could otherwise sell this excess energy to the grid.

However, the fact that the Andhi Khola powerplant is grid-connected does not necessarily imply that an energy-based tariff is the preferred option. The two extreme scenarios described below are possible, as is a continuum in between:

- If BPC could sell its power to the national grid and secure a good price for this energy, then an energy-based tariff might be preferable because this would encourage conservation of energy which could then be sold to the grid, earning revenues that should reduce somewhat the cost of energy to the rural consumers.

- If the wholesale rate for energy sold to the grid is minimal, then conditions exist similar to those in the case of an isolated plant. A power-based tariff should be encouraged, along with appropriate end-uses to make most use of the off-peak energy because, from a strictly financial point of view, nothing more would be gained by conserving electricity and selling excess to the grid.

In the case of the Andhi Khola powerplant, reality falls somewhere in between. To assess which tariff is more advantageous to BPC and its rural customers, a comparison should be made between the benefits gained by the consumers and the utility with a power-based tariff that may encourage more consumer consumption and benefits and those gained by the utility with an energy-based tariff, which would generate income to the project that might then be used to reduce the price of energy to the local consumers.

It would appear that, because excess power from the Andhi Khola powerplant is sold to the grid, the most important rationale for the use of a power-based tariff to date is not that it might encourage productive off-peak end-uses but that it reduces peak loads, which permits more consumers to have access to electricity supplied through a distribution system with a limited capacity. If no limits had been imposed on individual consumer demand by means of cutouts, increased transformer and line capacity would have been required to be able to supply peak demand, implying increased project costs. The effect of a peak-demand tariff that reduces capital (energy meter) and recurring (meter-reading and billing) costs should also have a beneficial impact on both the utility and consumers.

And finally, while it has not resulted in increased productive use of the power, at least for the smaller consumers, it does serve as an incentive for advocates of development to devise end-uses without which rural consumers cannot productively use electricity available to them to their economic advantage.

REDUCING HOUSEHOLD ENERGY EXPENDITURES

A commonly expressed objective of rural electrification is to reduce household expenditures required to meet the family's energy needs—to replace kerosene used for lighting and, less frequently, for cooking; candles used for lighting; batteries usually used for radios and flashlights; and fuelwood for cooking and space heating. To what extent has this objective been met in the AKP area?

For rural households, electricity is used primarily for radios and lighting, but even so, there is still some use of kerosene for lighting and batteries especially, for flashlights. Table 5 presents a comparison of previous and present costs for energy used for lighting, radios, and flashlights. "Previous expenditures" in this table include only the costs for that kerosene and those batteries which have been replaced by electricity, averaged over each consumer category. These are therefore equivalent to the average cost savings incurred by no longer having to purchase as much kerosene or as many batteries.

The comparative costs in the table are only approximations of the actual situation because some households may not have both a radio or flashlight. (In actuality, a majority of households use flashlights. And nearly three-quarters of the electrified semi-urban households in the project area used radios in 1992. At that time, somewhat less than half of the electrified rural households used radios, up nearly 50% over usage in 1988 before the introduction of electricity.)

From this table, it is apparent the average consumer at the time of the survey was spending considerably more for electricity than he had previously spent for energy used for lighting and radios.

Table 5. A comparison of the present average expenditures (US$/month) for electricity used for lighting and radios in the project area with the previous expenditures for kerosene and batteries, which were used where electricity is now used.

Tariff category	Previous expenditures[a] Kerosene	Batteries	Total	Present expenditures Electricity
25 W	0.20 (—)	— (—)	0.20 (—)	0.40
50 W	0.20 (0.60)	0.10 (0.30)	0.30 (0.90)	0.80
250 W	0.20 (0.70)	0 (0.60)	0.20 (1.30)	2.20
metered	— (1.70)	— (1.20)	— (2.90)	2.50-5.00[b]

Note that figures in parentheses represent average expenditures for consumers in the semi-urban areas; others are those for consumers in the rural areas.

[a] The cost of kerosene is assumed at Rs 10, or US$ 0.20, per liter and batteries at Rs 20, or US$ 0.40, per pair. All "Previous expenditures" are rounded off to the nearest tenth of a dollar.

[b] This range of expenditure represents the monthly expenditure for a majority of the metered consumers who pay both an energy and demand charge.

Furthermore, the significant additional cost of housewiring for the electricity option has not been included in the costs.

The conclusion that can be drawn from this observation, that reducing household energy expenditures is not an overriding concern of many households, is echoed is numerous studies in other countries.[34] While other options remain available, reliance on electricity, which often results in higher monthly costs, still appears the option of choice. It is not the case that consumers are ignorant of the cost disadvantage of electricity. A survey of the project area indicated that virtually all consumer in the rural areas and most in the semi-urban areas acknowledged that kerosene was less expensive than electricity for lighting. However, they seem to perceive additional benefits associated with electricity, benefits which to them are worth the additional cost. The principal ones noted were superior lighting quality, ease of access and use, and cleanliness.

Use of batteries for flashlights has also decreased in electrified areas, presumably because a number of families have placed lightbulbs in outdoor areas. However, in the project area, there is still some uses of batteries for flashlights which are difficult to replace, such as for nighttime irrigation activities. This use averages to slightly more than one cell per month and somewhat less in the better lit semi-urban areas.

Although it would have to be researched in the field, there is a possibility that villagers could increase the benefits attributable to electrification through the use of rechargeable batteries, at least to the extent that batteries are used. Furthermore, reliance on these batteries would permit the benefits of electrification to extend beyond the electrified areas. In Nepal, where D-cells cost $0.20 each, batteries provide electricity at a cost more than $50/kWh.[35] This clearly represents an extremely high-cost source of energy, more than 1,000 times costlier than energy purchased from the national grid.

[34] Nafziger (1990) notes the following: ". . . Brodman's (1982) study in Indonesia notes that 'of all the households using electricity for lighting alone, 96 percent increased the proportion of their expenditures allocated to lighting.' Closer to Nepal, Virmani (1982) cites the case of Mangolpuri, a resettlement colony near Delhi where the average cost of lighting per month in electrified houses is IRs. 51, as compared to IRs. 7.50 in nonelectrified houses. Finally, in Nepal itself, WECS (1988) cites the case of people 'often living in remote, hilly areas without good access to capital' paying up to five times the standard government rate per kWh for electric lighting."

[35] Chinese D-cells available at the local market were measured to have a capacity of about 3 Wh.

The comparatively high initial cost of rechargeable batteries would deter most from considering this option, even if it were available. However, the cost of these batteries per charge is negligible, on the order of $0.02, or a tenth of the cost of standard dry cells available on the local market. To address the high initial cost, an electrified village shop (or even a household with 25 W service but with the necessary capital) could purchase a set of batteries and a battery charger and rent charged batteries to villagers. The only risk facing that entrepreneur would be that villagers might not return the discharged batteries to him. But this issue should be fairly easy to address within a community. Such an approach could also facilitate the proper disposal of spent batteries, as this could be done by the entrepreneur himself. At present, spent ordinary dry cells are simply discarded.

Another intervention that could increase the benefits of electrification to consumers might be the promotion of fluorescent lighting units to replace incandescent bulbs. While these provide the consumers considerably more lighting at the same consumption level, the main obstacle to their widespread use seems to be their relatively high initial cost (p. 37). However, because fluorescent tubes should have a life of at least 10 times that of an incandescent bulb (operating at a proper voltage and considerably longer under conditions apparently found in the AHREP supply area), their life-cycle cost should be less than that of incandescent bulbs. However, it should be noted that these fluorescent units must be furnished with power-factor correcting capacitors. Otherwise, cutouts relying on MCBs or PTCs may trip even though the fluorescent tube rating is less than the consumer's subscribed peak-demand level.

To address the problem of high initial cost, BPC might consider making fluorescent tubes available to its consumers and guaranteeing their life for a certain number of years at a cost to be covered by a surcharge on the monthly electricity bill. The consumer's new monthly bill, with surcharge, need not be more than his old monthly bill. For example, it is conceivable that a consumer who uses electricity solely for lighting and powering a radio might actually reduce his level on consumption from 50 W to 25 W and not forgo any of the benefits he presently receives. Such a scheme could be attractive if the consumer would pay less for his new 25 W tariff (with tube guarantee included) than he formerly did for the 50 W service and replacement light bulbs. Whether such a scheme is workable could be determined by gathering field data on the comparative cost and performance of locally available fluorescent tubes and bulbs.[36]

REDUCING FUELWOOD CONSUMPTION

Arresting and eventually reversing deterioration of the forest cover by replacing fuelwood used for cooking with electricity is a common argument advanced for electrification. To what extent has this happened in the Andhi Khola area?

As noted earlier, the quantity of fuelwood consumed by specific households is difficult to obtain. This was confirmed by a recent survey, which found that fuelwood use in rural areas seems actually to have doubled during the initial period of electrification, a conclusion that is generally felt not to reflect reality. But, leaving aside the issue of the reliability of fuelwood consumption data, it is clear that the use of the *bijuli dekchi* or other electrical cooking appliances is rare, and that there has been no significant use of electricity for cooking.

Actually, because of the increasing scarcity and cost of fuelwood and in spite of the availability of reliable electricity in the area, a significant trend toward greater kerosene usage has been observed over the last five years, although this has been restricted to the semi-urban households. For villagers in most rural areas, fuelwood is obtained at no financial cost (although clearly at an environmental cost), and no attractive substitute has yet been found. Therefore, despite availability of electric cooking appliances in the AHREP area, fuelwood is still the preferred source of energy for cooking among a large majority of both semi-urban and rural households.

Why has the use of electricity not proved an attrac-

[36] Electric utilities in some industrialized nations are finding similar schemes profitable to their operation. In the United States, some find it to their financial advantage to subsidize compact fluorescent bulbs up to the sum of $15 per bulb, essentially making them free to the consumer. The principal motivation in this case is that, because a major domestic use of electricity is for lighting, it is cheaper to subsidize low-consumption fluorescent bulbs rather than build the extra generating capacity needed to cater to incandescent lighting loads.

tive alternative to fuelwood? Why has the low-wattage cooker not had the far-reaching impact that was anticipated during the research, planning, and dissemination stages of that effort? These are questions that warrant careful attention because, aside from developing community woodlots, there is little hope for finding another convenient energy source for cooking to replace that found in the quickly dwindling forests.

There are several probable reasons electricity has not been widely accepted for cooking:

- **Cost of cooking pots**: The high cost of the cookers is clearly a deterrent to their use as this represents several month's income for an average rural household.
- **Technical problems**: Consumers have complained of technical problems with the cookers and have had difficulty in having these easily resolved.
- **Cost of energy**: In spite of a decreasing supply of fuelwood, it can still be found in the surrounding areas and, even in cases where is it purchased, it is still less costly than electricity.
- **Cooking patterns**: Use of the *bijuli dekchi* requires adopting a new approach toward cooking and a change in the daily cooking routine.

It should be recognized that electric cooking is a relatively recent innovation in urban areas and much more so in rural areas. It should also be recognized that developmental change occurs gradually. Consequently, in this context, the use of cookers by only 5% to 10% of the new consumers since the technology was introduced just a few years ago can still be regarded as significant.

A considerable number of rural households in the AHREP area heat water for preparing animal feed, and there are some indications that the low-wattage cooker is used for this purpose. Possibly greater emphasis should be placed on this end-use to improve its level of usage.

Although the low-wattage cooker has not proved attractive to most consumers in the AHREP area, it is interesting to note that they have apparently found much greater receptivity in the Annapurna Conservation Area Project (ACAP). There, because of enforcement of legislation preventing cutting of the forests, tourist demand for hot water and their ability to pay for it, the colder climate, and possibly a different culture, the cooker has promoted itself. Unlike in the AHREP area, there was no active promotion by community motivators in the ACAP area, and yet there seems to be an regular demand for cookers. This example may simply point to the fact that the cooker's popularity may also be a function of a variety of external socio-economic factors.

Concerning the issue of "technical problems", there are sufficient difficulties in promoting a new technology without having to be beset by this type of problem. Furthermore, technical problems represent the easiest of all to address and should have been discovered by more rigorous field trials, possibly even in urban areas. Given the cooker's potential for reducing pressures on the forests, reducing the burden women experience in gathering fuelwood and cooking, and improving the cooking environment in the home, it would also have been advisable to guarantee households the proper follow-up assistance during at least the initial years. This not only would have been useful to promote the cooker, it also could have fed back directly into continuing improvement of the cooker design.

Comparative cost of energy

Concerning the cost of energy, the following equation compares the relative cost of cooking with electricity to that with fuelwood and kerosene. Here, only the cost of the fuel is being considered and not that of the cooker:

$$R = K \left(\frac{E_a}{E_e}\right)\left(\frac{C_e}{C_a}\right)$$

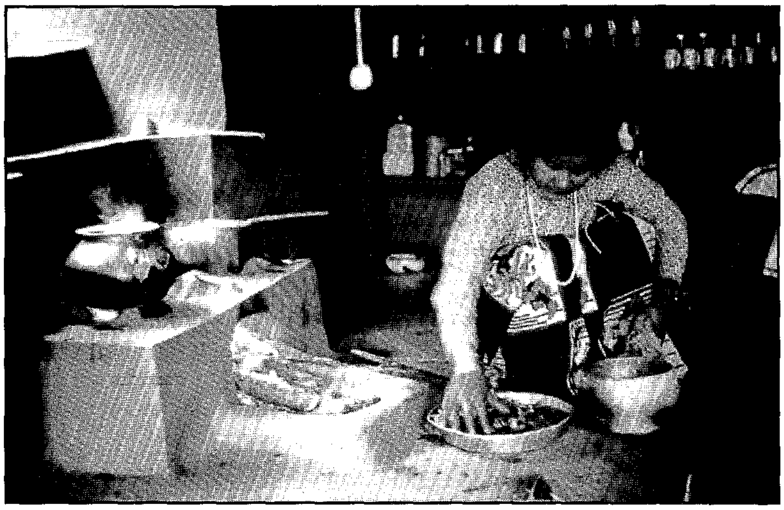
where

R = ratio of the cost of energy for cooking with electricity to the cost of an equivalent quantity of energy from wood or kerosene; cooking with electricity is cheaper if $R < 1$

K = conversion factor = 4 for wood or 10 for kerosene

E_e = efficiency of electric cooking appliance

= 25% forced-air heat-storage cooker
40% - 50% ceramic hot plate
78% *bijuli dekchi*



LIONEL MACKAY

Fig. 36. A traditional wood stove in use in a teashop in Nepal.

E_a = efficiency of alternative cooking approach
= 5% - 10% open fire, three stones
10% - 15% traditional wood stove (Fig. 36)
15% - 25% improved mud stove
25% - 45% portable lightweight metal/ceramic stove
35% - 55% kerosene cookers (Fig. 37)

C_e = cost of electricity (currency/kWh)

C_a = cost of alternative energy source (same currency/kg of wood or currency/liter of kerosene)

Alternatively, by setting R = 1 in the equation above, one can derive the minimum unit cost of electricity (C_e) which would be necessary for electricity to be competitive with available alternatives.

For example, using this equation, one can calculate that, for electricity to be competitive with wood (R = 1) in the AHREP area, where the cost of fuelwood (C_a) used in a traditional wood stove (E_a = 12%) is about Rs 1.00/kg, the cost of electricity (C_e) used with a *bijuli dekchi* (E_e = 78%) should be no higher than Rs 1.60/kWh.

To put this value in perspective, it is interesting to note that if a consumer with a peak-demand level of 250 W uses electricity only for cooking and consumes about 60 kWh/month in the process, he would be paying about Rs 1.50/kWh. So considering only the cost of fuel for cooking, electricity should be competitive with purchased fuelwood in the AHREP area. Identical conclusions would be true for kerosene, which is available for about Rs 10/liter in this area. And in urban areas where fuelwood is costlier, using electricity for cooking should prove less costly than using wood.

However, the cost of the cooker must also be included, and this alters the conclusions considerably. If one assumes that the Rs 1500 cost for a single *bijuli dekchi* is amortized over five years at no interest, this would imply a monthly payment of Rs 25. On a per-kilowatt-hour basis, this would be equivalent to Rs 0.40 and imply that the cost of electricity must be no higher than Rs 1.20/kWh for it to be competitive with fuelwood. Because at least two cookers are required to effectively cook, the breakeven price for electricity must be no higher than Rs 0.80/kWh to be competitive. Therefore, including the capital cost of one or more *bijuli dekchis* clearly makes electricity considerably less competitive that purchased fuelwood in the area.

One obvious conclusion that can be drawn from this exercise is that, until the price of fuelwood increases considerably or the price of the cooker

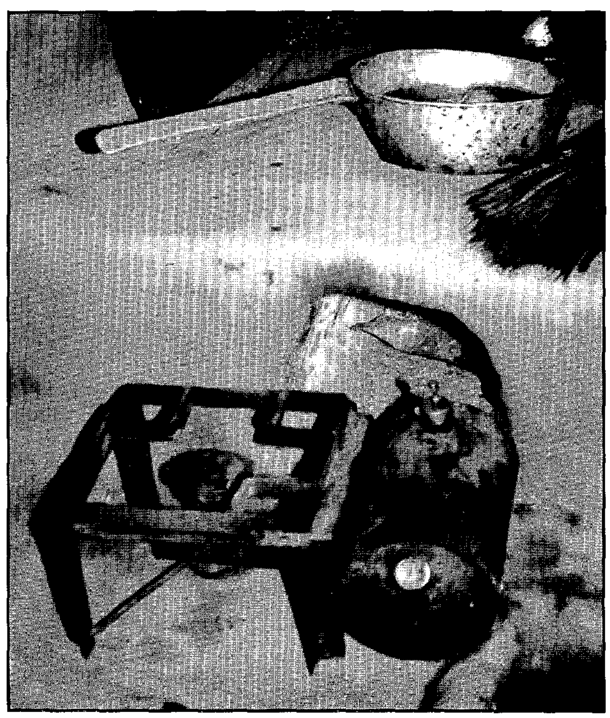


Fig. 37. A kerosene stove serves as a backup to the traditional mud stove in the background.

decreases by a significant amount, the cost of electricity will be another of the several obstacles which will have to be surmounted before electricity can have any impact on fuelwood consumption.

Rationale for a subsidy

If the technical and social obstacles to the adoption of electric cookers can be overcome, financial obstacles will probably persist because of the low levels of disposable income among a significant portion of the rural population. A greater subsidy for cookers to address this remaining constraint to their wider use might then be required.

While the issue of introducing subsidies into electrification is becoming increasingly controversial in this age of privatization, there is a sound rationale for such a strategy. It would also be acknowledged by the growing awareness among the world's leaders and planners and by international financial institutions of the need to quantify the environmental benefits associated with harnessing renewable energy resources and to promote actively the use of these resources.

A nation develops its educational and medical institutions, constructs its roads and maintains its transportation systems, and installs water and sewage facilities at a cost to itself, not because it wishes to "waste" its financial resources in subsidizing this infrastructure but because these are viewed collectively as yielding long-term benefits to the nation. But these services are largely restricted to, and mainly benefit those in, urban areas.

In an analogous manner, maintenance of Nepal's forest resources and watersheds by harnessing its hydropower resources to support cooking should not be seen as a cost, nor as a wasteful subsidy, but rather as a benefit from the national government which rural populations can readily access. Preventing the continued extraction of fuelwood from Nepal's dwindling forests (Fig. 38) generates such quantifiable benefits as preventing loss of productivity of agricultural lands due to landslides and loss of topsoil, decreasing damage from flooding and sediment transport into hydropower reservoirs, maintaining a high water table, and increasing yield of a variety of forest products (such as construction timber, wild fruits and vegetables, resins and saps, nuts, extracts for medicines, animal wildlife, and genetic diversity). The more attractive rural environment which would be the outgrowth of such a policy would also provide a setting that would present resident populations an alternative to migrating to already burgeoning urban areas, a choice many presently make because of their inability produce a livelihood in an otherwise degraded environment.

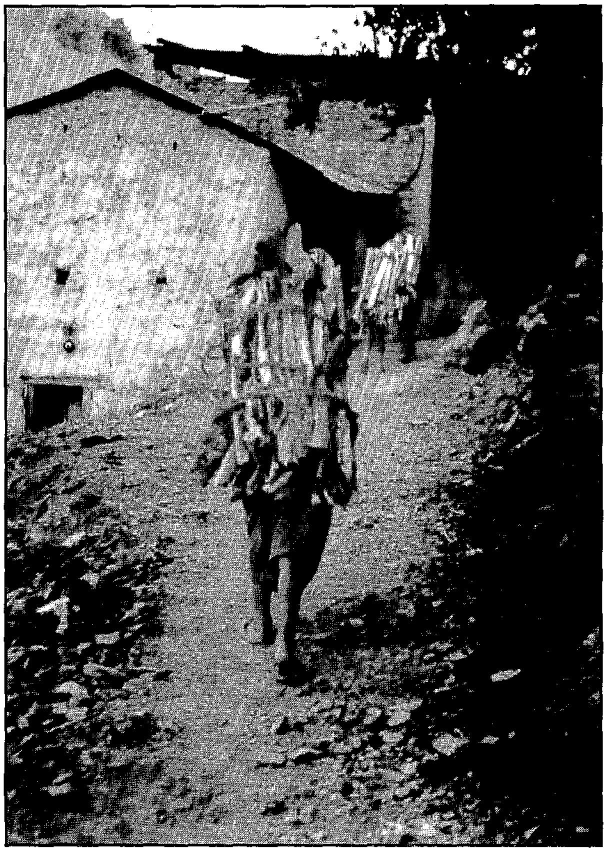


Fig. 38. Fuelwood for sale in the village of Galyang contributes to further depletion of what little remains of the local forests.

In this light, providing resources to subsidize hydroelectricity-based cooking should not be considered a net financial loss. Such a subsidy would be a small cost in comparison to the benefits accruing both to the rural populations as well as to the country as a whole and would represent a net gain.

Furthermore, if carbon dioxide emissions are contributing to global warming, as is generally held to be the case, replacing continued reliance on fuelwood with hydropower-based electricity would reduce carbon dioxide emissions and contribute to global initiatives to reduce greenhouse gas emissions and global warming. Efforts are underway to estimate the value of these benefits in terms of tonnes of carbon dioxide reduced and, perhaps, carbon credits.[37]

If the concept of carbon credits should become a reality, such a credit would have a monetary value which could conceivably be applied to the purchase of low-wattage cookers provided that hydropower-generated (or other non-fossil-fuel-based) electricity is used. If a typical family consumes 2 tonnes of fuelwood for cooking, replacing this fuelwood with electricity would offset the emission of approximately 1 tonne of carbon each year. If a carbon credit set at $10 for each tonne of carbon not emitted were applied toward the repayment of a loan on an electric cooker which is purchased over five years at 10%, this credit would cover the purchase of a stove costing nearly $40.

The provision of a subsidy or carbon credit to encourage hydroelectricity-based cooking, coupled with a policy and infrastructural support to encourage maximum production from existing agricultural lands in an environmentally sound manner and to control access to forests, would go a long way toward improving future prospects for a sustainably healthy and productive rural environment.

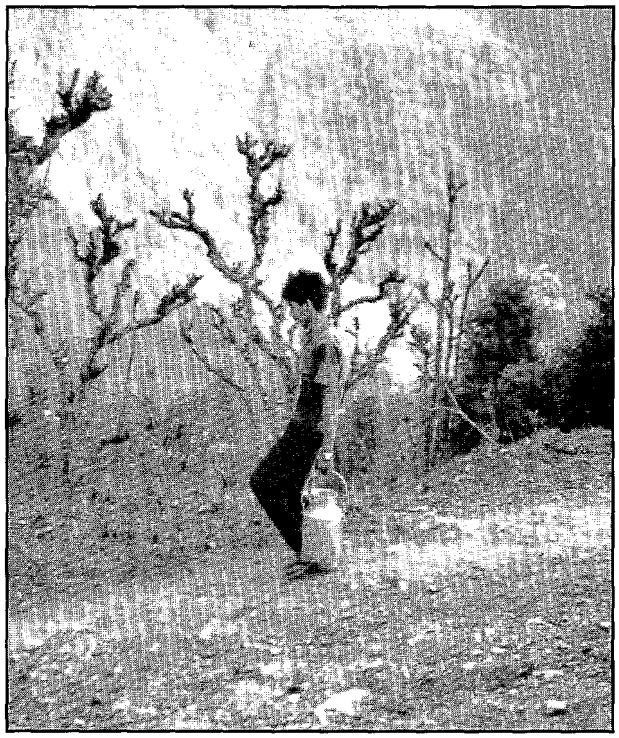


Fig. 39. A benefit of electrification: a villager bringing milk to sell at the chilling station just outside Galyang.

OTHER BENEFITS TO THE CONSUMER

It is clear that villagers are willing to spend more of their income on electricity than they previously spent on energy sources for which it serves as a substitute, specifically kerosene and batteries. They apparently place sufficient value on this commodity to be willing to incur this financial "loss". The benefits the villagers themselves attribute to electrification are not cost savings but rather a sense of tranquility, prestige of the community, and simplified tasks around the house.

While these benefits may be meaningful to consumers, rural electrification must still generate additional revenues to cover a larger portion of the costs incurred if its wider promotion is to prove attractive. To this end, efforts continue to focus on developing end-uses which would permit rural consumers to generate income from the electricity to which they now have access. But the small amount of power available to each consumer, his lack of disposable income to purchase suitable appliances even if they were available, difficult access to markets, and the lack of management and technical expertise all contribute to making the development of viable productive end-uses a perplexing, continuing challenge.

The most viable option, one being pursued by AHREP staff, is to promote end-uses in the semi-urban areas which are less affected by these constraints, uses which would make use of inputs (labor and/or raw materials) from the outlying

[37] Carbon credits represent transfer payments made by a party that is emitting excessive carbon dioxide to an industry or other emitter of carbon dioxide that has decreased its emissions to below the maximum acceptable limit. In the case referred to above, the party that has reduced its emissions is the household that has replaced fuelwood with hydroelectricity for cooking.

[38] In proposing end-uses, one must always be alert to their potential negative effects on the rural population. For example, in the case of the milk chilling plant, does an external market for milk lead to malnutrition among rural children? Is the cash generated used to purchase food that is more "attractive" but that has less nutritional value? What existing activity, such as making ghee, is displaced by the introduction of a more centralized industry, and is one centralizing or dispersing income-generating opportunities?

areas, thereby permitting those in the rural areas to benefit economically from electrification in their area. One example is the milk chilling plant near Galyang which provides a market for the milk produced by local villagers and permits them thereby to generate income from electrification, an option which might not have been available before the advent of electricity (Fig 39).[38]

ANNEX A:

CONVERSION FACTORS FOR NEPALI RUPEES TO US$

Table A-1 includes a list of conversion factors which were used to convert Nepali rupees found in reference materials to 1994 U.S. dollars.

Table A-1. Nepali rupee to 1994 US$ conversion factors.[a]

Year	NRs/US$[b]	US GDP deflator[c]	1994 US$/NRs
1978	12	47.0	0.039
1979	12	51.0	0.042
1980	12	55.9	0.047
1981	12	61.5	0.051
1982	13.2	65.3	0.050
1983	14.5	68.0	0.047
1984	16.4	70.9	0.043
1985	17.7	73.6	0.042
1986	21.2	75.5	0.036
1987	21.9	77.9	0.036
1988	23.6	80.7	0.034
1989	27.5	84.6	0.031
1990	29.2	88.2	0.030
1991	42.8	91.8	0.022
1992	42.7	94.2	0.022
1993		96.9	
1994	49.2	100.0	0.020

[a] To obtain the 1994 US$ value, multiply the Nepali rupee cost for any year by the corresponding entry in the last column.

[b] Nepali rupee exchange rates through 1992 are from the Statistical Year Book of Nepal, 1993, National Planning Commission Secretariat, Central Bureau of Statistics, Kathmandu.

[c] The U.S. GDP deflators through 1992 are from tables prepared by the World Bank International Economics Dept., International Trade Division, October 29, 1993.

74

ANNEX B:

ANALYSIS OF COSTS FOR ALTERNATIVE DISTRIBUTION SYSTEM VOLTAGES

To verify the conclusion reached in Hagen's original analysis (see p. 11) that a 1 kV distribution voltage would lead to the least-cost approach to providing electricity to rural populations bordering a 33 kV line, Vinay Bhandari (Assistant Electrical Engineer with BPC in Galyang and AHREP Planning In-Charge) undertook an analysis of the Aserdi/Phoksingkot service area as part of this study.

To ensure consistency in comparing the costs of different distribution scenarios, a common service area was carefully defined, based on the actual service area indicated in Fig. 9. Distribution hardware used by BPC, especially tubular poles and bundled cable, is used for each of the different scenarios considered. Current costs for labor and materials which would be incurred by BPC are also used.

Assumptions

The following assumptions were made:

- The distribution system takes off from a substation transformer located along a 33 kV line.
- All 509 households in the three main service areas receive electricity, and the peak coincident load of about 130 W/household is primarily resistive.
- The maximum permissible voltage drop along the line from the 33 kV (transmission) line to the ends of the branch lines is roughly 16% (note that this does not include drops elsewhere, such as in the distribution transformers and along the service drops).
- The minimum sizes for ACSR conductor are 16 mm^2 for voltages 1 kV and below and 25 mm^2 for 11 and 33 kV (this minimum size being imposed by strength requirements during fault conditions).
- The minimum size for bundled aluminum cable is 16 mm^2.
- The layout for the distribution system is as described below.

Basic scenarios

The two basic scenarios considered—a 1 kV system and an 11/0.4 kV system, both of which tap directly into the main 33 kV transmission line—are depicted in Fig. B-1. A common line routing is used in both cases.

The 1 kV distribution system begins at a 100 kVA, 33/1 kV three-phase substation transformer at the 33 kV transmission line. To keep within the maximum permissible voltage drop, ACSR conductor with the dimensions noted in Fig. B-1(a) is used for the main line. Branch lines of 2 x 16 mm^2 bundled cable bring 1 kV to the 58 1 or 2 kVA, 1/0.23 kV transformers which each serve a cluster of two to 18 consumers.

The 11/0.4 kV distribution system begins at a 200 kVA, 33/11 kV three-phase substation transformer[39] at the 33 kV transmission line. The size of the ACSR conductor used for the entire main line is 25 mm^2 as determined by strength requirements. Because of the low demand in the service area, the maximum voltage drop along its entire length is only about 1%. Three single-phase 11/0.23 kV transformers are located at the center of Aserdi and Phoksingkot, while only one single-phase 11/0.23 kV transformer is used to serve the considerably smaller load in Sangala. From each 11/0.23 kV transformer bank, ACSR lines are extended in two or three directions toward the periphery of each of the three service areas. Both 2 x 16 mm^2 and 2 x 25 mm^2 bundled cable are then used to bring single-phase 230 V lines to the vicinity of the each consumer.

39 This is significantly greater capacity than is needed, but represents the smallest standard size transformer available at this voltage.

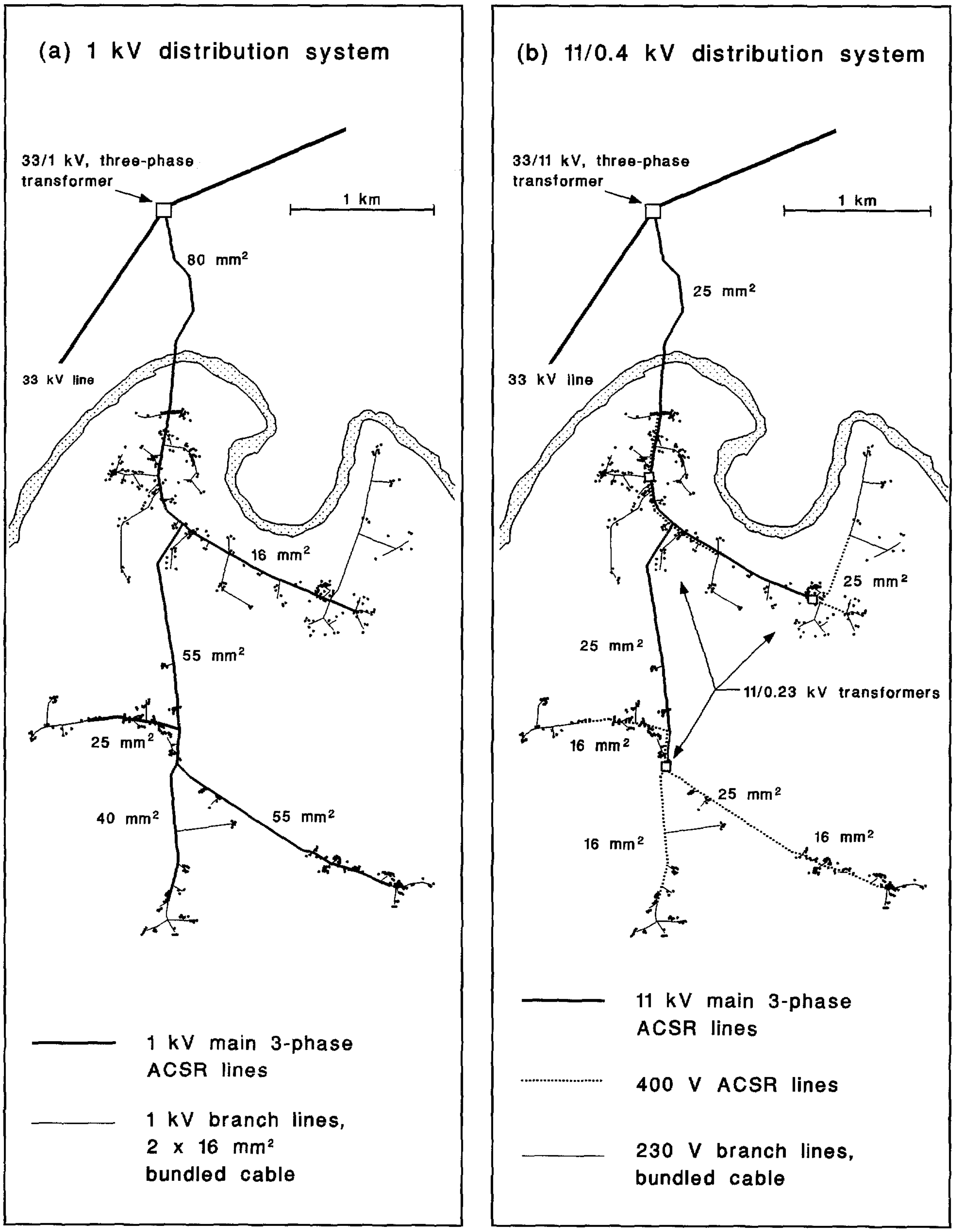


Fig. B-1. Maps of the (a) 1 kV main and branch lines and (b) 11 kV and 400 V main lines and the 230 V branch lines.

Table B-1. Cost breakdown for 1 kV and 11/0.4 kV distribution systems.[a]

Items	1 kV system Subtotals	11/0.4 kV system 11 kV	400 V	Subtotals
Main line (three-phase)				
Poles	$14,200	$12,800	$4,800	$17,600
Conductor	11,900	5,300	4,500	9,800
Hardware	2,400	4,000	1,000	5,000
Branch lines (single-phase)				
Poles	12,000			10,200
Conductor	8,000			8,200
Hardware	1,500			1,400
Transformers				
Substation[b]	3,000			2,800
Distribution	8,200			7,000
TOTALS	$61,200			$62,000

[a] These include costs of both material and labor, with labor costs accounting for about 6%.

[b] As in Hagen's analysis, it is assumed that the substation transformer serves an equally sized load on each side of the 33 kV line. Consequently, only half the cost of this transformer is included in the cost breakdown for each system analyzed.

Conclusions

Table B-1 summarizes the costs which would be incurred in the construction of the two systems described above. These do not include the costs for the service drops, service entrances, and house-wiring, because these are common to both scenarios.

This analysis concludes that there seems to be only a slight cost advantage to the use of a 1 kV system over an 11 kV system. For both options, the costliest components are the poles, which account for 40% to 50% of the total cost, with the conductor accounting for about 30%.

Other relevant conclusions drawn are the following:

- The cost of materials and labor for the construction of the distribution system, if all the 509 consumers in the area were served, would be equivalent to $120/consumer.
- The cost of materials and labor for the construction of a three-phase 11 kV line over hilly terrain (with 25 mm^2 ACSR conductor and quality poles) is on the order of $3,700/km.

Two other scenarios were also briefly considered. One was to use a 33/0.4 kV substation transformer at the transmission line and to distribute power entirely at 400 V. In this case, to keep within the maximum acceptable voltage drop would require a conductor larger than 200 mm^2 ACSR for the main line as well as stronger poles. Costs for this option would therefore be considerably greater than those for the 11/0.4 kV option.

The other option considered was to bring a 33 kV line to the center of each of the three service areas and then to distribute power within these areas at 400 V. This would be similar to the 11/0.4 kV option previously considered, with the main 11 kV line replaced by a 33 kV line. Because conductor size is still constrained by strength requirements rather than by voltage drop, there would be no advantage to raising the voltage from 11 to 33 kV; the voltage drop is already insignificant at 11 kV. But a higher ground clearance would be required for the 33 kV line, necessitating higher and costlier poles along the main line. Safety would also dictate the need for double-pole structures at deadends and angles, which would further increase the cost. The cost for an increased number of poles and pole sections therefore would make this option less attractive than the 11/0.4 kV option. Carrying three-phase 33/0.4 kV transformers weighing 600 kg over steep and narrow trails would pose additional difficulties, although banks of lighter (200 kg) single-phase transformers could be used.

It was therefore concluded that both of these options would be more expensive than the first two options considered, and they were dismissed, as they were in Hagen's analysis.

Erroneous assumptions in Hagen's analysis

One question arising from this more detailed analysis is why the conclusion from Hagen's analysis that the 1 kV option would be the cheapest alternative was not applicable to the Aserdi/Phoksinglot service area. The benefit of hindsight should shed some light on what incorrect assumptions were made in the initial analysis. By knowing this, one will be in a position to better understand some of the factors affecting the relative advantage of one system over another.

Hagen did not include the 11 kV option considered in Bhandari's recent analysis. However, the 11 kV system is similar in configuration to Alternative B, with the 33 kV line into the service area replaced by an 11 kV line, and with roughly the same cost (the increased cost of poles noted above somewhat offset by no need for a transformer at the 33 kV line). If the recent analysis showed that the 1 kV alternative is relatively similar in cost to the 11 kV alternative, why is there such a large difference between the 1 kV alternative (Alternative D in Table 1) and the 33 kV alternative (Alternative B)?[40]

A comparison of the two analyses shows the following principal reasons Hagen's analysis led to an incorrect conclusion:

- The cost of the 33 kV option (Alternative B) is overestimated: The total length of the main (i.e., three-phase) 400 V lines is considerably overestimated. While Hagen's analysis assumed 15.4 km to cover the entire rectangular service area, three-phase 400 V coverage is, in reality, restricted near the center of each service area and is not spread out as broadly as is shown in Fig. 8. Bhandari's analysis concluded that the total length of line required to serve the area is about 5 km. Therefore, the largest component of the cost for Alternative B in Table 1 should be reduced to about a third of its original value, considerably reducing the cost of this alternative.
- The cost of the 1kV option (Alternative D) is underestimated: In the actual case, one, rather than two, three-phase 1 kV lines brings power into the service area. However, although a single line serves the area, several three-phase branches are required to reach the scattered load centers within this area, and the total length of line remains about as shown in Hagen's analysis. However, because a single conductor rather than two is used to bring power into the area, the cross-sectional area of the 1 kV line was underestimated. Increasing the conductor size (from 25 mm^2 to mostly 40 mm^2 through 80 mm^2) to maintain voltage drops to permissible levels increases the cost of this alternative from those shown for Alternative D.

When the factors above are considered, the spread between the two alternatives in Hagen's analysis is considerably reduced; the cost of the 33 kV option is not much greater than that of the 1 kV. Based on this analysis, Bhandari's finding—the near equivalence in cost between the 1 kV and 11 kV alternatives—is consistent with the work that Hagen undertook once the modifications above are made.

[40] It should be noted that, in Hagen's analysis, line costs assumed were more than double those actually encountered; e.g., costs for a three-phase, 11 kV, 25 mm^2 ACSR line in Hagen's and Bhandari's analysis were $9,100 vs. $3,700, respectively. Consequently, only comparisons between the different alternatives considered in Hagen's analysis are valid. One cannot directly compare costs found in Hagen's analysis with those in Bhandari's. However, the magnitude of the consumer load as well as the dimensions of the service area in both analyses are similar. One can therefore conclude that the consumer demand as well as the length of the line and its cross-sectional area in both analyses are comparable.

ANNEX C:

COST COMPARISON OF VARIOUS ELECTRICITY-SUPPLY OPTIONS

Introduction

The demand for electricity in areas beyond the existing distribution network has usually been met by further extending the national grid. However, concern with the high costs commonly associated with this approach is frequently expressed. In response, there is growing interest in household photovoltaic (PV) systems and other options as possibly more cost-effective approaches to providing at least small quantities of electricity.

This annex has not been prepared to present a definitive ranking of options for providing electricity to those beyond reach of the existing grid. Rather, it presents descriptions of some of the issues commonly overlooked in the enthusiasm to promote alternatives. Its focus is on options for providing small amounts of electricity on a village-wide basis, primarily for lighting.

An objective of this annex is to illustrate that the grid extension option should not automatically be disregarded as an expensive option simply based on the costs of poorly designed or executed projects around the world. Rather, the Nepali experience documented in this study suggests that grid extension can indeed provide electricity to millions of new consumers at costs considerably below those of alternatives currently being promoted.

Options and assumptions

The four most common options for supplying electricity to rural consumers and covered in the following cost comparison are household photovoltaic (PV) units, micro-hydropower plants, diesel generating sets (gensets), and grid extension.

Household PV units: These units are of the type currently being widely promoted around the world and are usually comprised of a single PV array, a battery, and some basic control electronics. It is assumed that average daily insolation is 3.4 kWh/m^2 and that electricity losses between the PV array and the consumer equal 30%, most of this occurring in battery charging and storage.[41] A deep-discharge battery is assumed as most appropriate. Although less expensive automotive batteries are commonly used, these also have a shorter life, and annual costs are roughly similar. Based on accumulating experiences, it is also assumed that the services of a technician are necessary to monitor individual systems regularly and to take remedial measures to ensure their proper operation.

Micro-hydropower plants: This option assumes availability of small, locally manufactured turbines, as is the case in a number of countries, and that the projects are implemented with indigenous expertise and with assistance from the local community. Because the most favorable hydropower site is rarely in the village center, it also assumes that the plant is located at several kilometers from the load center. The plant is oversized by a factor of two to allow for growth in future demand and for any electrical losses between the generator output and the consumers.

Costs for the micro-hydropower option can vary greatly. A significant number of micro-hydropower plants have been implemented by the private sector in Nepal. For these electrification projects, total costs typically are less than half of those assumed in the following cost comparison. For example, a 5 kW project in the remote Mustang region of Nepal would cost a total of $15,000 using locally available wooden poles and all other materials transported to the site. Transportation costs alone approach 20% of this total. However, an initial cost of $49,000 is assumed in Table C-1.

Diesel generation: This option assumes gensets which are relatively well maintained, with a major overhaul for each genset as required after 4,000 hours (two years) and replacement after four years. To provide redundancy, gensets are purchased in

[41] Although high insolation values can be claimed in some parts of the world, it should also be kept in mind that an insolation value is an average over the year. During seasons of greater insolation, the consumer commonly will use less energy than is available, and it is not uncommon for a battery to be fully charged before the day is over; therefore, remaining insolation during that day is lost.

pairs, with a replacement set purchased at the end of eight years. Even though a major component of the life-cycle cost (LCC) for this option is the cost of fuel, both engine capacity and fuel consumption have been doubled in the following cost comparison to make up for any losses between the genset and the consumers and for inefficient use of electricity by some consumers.

Grid extension: To place this option in a fairly disadvantageous position in order to put it to the test, it is assumed that only 100 consumers are located at the end of a 15 km-long primary distribution line. In many cases, significantly more consumers would be found within several kilometers of a primary distribution line and, by sharing its costs, LCC per consumer could be reduced considerably from those derived. It is also assumed that, as described in this study, villages are themselves responsible for the collection of monthly electricity bills and deposit in the account of the utility. The utility's responsibility goes as far as maintaining the primary distribution lines to the villages, and the cost for this is included in the per-kilowatt-hour cost of electricity to the villagers.

Hybrid systems have not been considered because they are generally inappropriate for meeting residential electricity needs of rural villages. Besides being costly, they incorporate the complexity of more than one energy supply option as well as the technology to coordinate their operation; are reliant on a centralized battery bank which requires costly, periodic replacement; and require the institutional infrastructure to manage a mini-utility whose operation is often made more problematic by the small quantity of energy generated daily which must be shared equitably by all consumers.

The costs for the options considered are based largely on data from a recent World Bank technical paper[42] for the PV option (but modified somewhat based on experiences elsewhere), on manufacturer's information for the diesel option, and on a range of recent experiences in rural Nepal for costs of the micro-hydropower option. For the grid extension as well as other non-PV options, the costs of the distribution system and housewiring are assumed to be somewhat above those documented in this study[43]. Generally, these costs are still below those typically associated with rural electrification efforts as conventionally implemented around the world.

It is assumed that comparable energy consumption and level of demand are provided the consumers under each option. Consequently, it is assumed that energy at least equivalent to that available from a 55 W_p household PV system is available from each option, i.e., 5 kWh/month for use with approximately 25 W of high efficiency lighting for five hours nightly. The consumption figures used for this comparison and found in the references noted earlier are consistent: All are in agreement that many in rural areas have approximately the same electricity demand as assumed above and that growth over time is negligible unless there is a marked increase in household earnings.

Use of high-efficiency lighting is assumed for each option. Given the limited energy potential of household PV systems, each consumer will find it to his benefit to continue using high-efficiency lighting to make most effective use of his system. However, for the other supply options, there is nothing to ensure that consumers will not replace burned out high-efficiency bulbs with low-cost incandescent lighting, which consumes more energy for an equivalent level of lighting. Therefore, for this cost comparison to be valid requires a mechanism to ensure continued use of high-efficiency lighting for all options. This might be to use a power-based tariff with a cutoff (as described in this study) or to rely on self-enforcement by members of the community itself. In the following comparison, the cost of high-efficiency lighting is

[42] Andres Liebenthal, Subodh Mathur, and Herbert Wade, "Solar energy, Lessons from the Pacific Island experience", World Bank Technical Paper Number 244, Energy Series, Washington, D.C., 1994.

[43] In Table C-1, a cost of $4,500/km is assumed for the primary distribution line, compared to $3,700/km for a line over hilly terrain in Nepal as noted in this study. To permit comparison of these unit costs with those in other countries, a breakdown of the Nepali cost would be useful. Material costs (quality steel poles, ACSR conductor, and line hardware), which are roughly the same worldwide, account for $3,500/km. Labor costs vary considerably around the world. While the costs of labor account for the remaining $200/km, it would be more informative to indicate the level of effort required for the installation. These can then be used with country-specific labor rates to derive labor costs in a specific country. This is 45 technical person-days/km and 90 laborer-days/km (half of which were used for transportation of materials to the site).

90

assumed the same for each option and is therefore not included.

The advantage of ensuring use of more costly high-efficiency lights with other than the household PV option is that this results in cost savings, such as those associated with reducing either the design capacity of the generator, the quantity of fuel consumed, or the size of the conductor used in the distribution system.

If some consumers were to resort to conventional lower-efficiency lighting, the electricity-supply system as originally sized might no longer be able to meet the demand of the community being served. The greater generating capacity that would then have to be included in the assumptions made in the following cost comparison would imply varying degrees of increased costs for all but the PV option.[44]

For each option, the per-consumer LCC over a period of 15 years at a 10% discount rate is calculated and recorded in Table C-1. It is assumed that 100 households in an isolated village are to be served. The methodology followed in deriving the LCC is similar to that detailed in the World Bank paper referred to earlier.

It should be noted in this as well as in all cost comparisons that the precise conclusions are highly dependent on the assumptions made and that almost any point can be proved if the assumptions are not explicit, clear, and completely honest. The principal purpose of this comparison is only to obtain an approximate ranking of the options being considered and to illustrate which components contribute most significantly to the cost of each option. If one can then change system design to reduce the cost of one or more of the costlier components, then this relative ranking may well change.

Conclusions

Based on experiences around the world where national utilities responsible for urban electrification have been slowly expanding their systems into rural areas, grid extension has been found to be costly. This drawback is compounded by the small revenues generated by rural electrification. Diesel generation, micro-hydropower plants, and household PV units are often considered less expensive alternatives as the distance from the existing grid to the load center increases.

However, the Nepali experiences described in this study illustrate that, if properly designed and implemented, grid extension has the potential to provide power at considerably lower costs than those commonly associated with past rural electrification projects. This is true even when used to supply a small amount of electricity such as that generated by a household PV unit.

Under the conditions assumed, the energy supply options would be ranked in the order found below based on results in Table C-1. It might be noted here that, for the situation described, the first three options are less costly than the household PV option. This is in spite of the intentional use of very conservative assumptions with these three, for example, that 100% more power and energy is generated than is demanded by the village load. The following comments should also be made:

- The **micro-hydropower option** can easily be the least-cost electricity source, because it permits the use of equipment that can be locally fabricated and it relies on a free, indigenous energy resource. However, this option is of limited usefulness given the site-specific nature of the energy resource. Furthermore, streamflows can exhibit large variability, and low flows during some months may prevent the plant from generating its expected output. This factor can adversely affect the viability of this otherwise attractive option.
- Because gensets are mass-produced, capital costs for the **diesel generation** option are low. Unfortunately, this is countered by the problem of availability and cost of fuel (which is a major contributor to the LCC for this option). Furthermore, the lack of adequate

[44] However, it should also be noted that the costs for the diesel, hydropower, and grid extension options assume that twice the energy and power consumed are generated or purchased as are needed. Since losses themselves should account for only a small portion of this total, there is considerable excess capacity in the systems costed.

Table C-1. Breakdown of costs for various electricity-supply options to serve a village with 100 consumers.[a]

Component	Description	Life (years)	Initial costs	LCC
Micro-hydropower option				
Hydropower scheme	5 kW plant using turbine fabricated in-country	15	$10,000	$10,000
Transformer/switchgear	Step-up and step-down transformers @ $1,000	15	2,000	2,000
Secondary distribution system	7 km @ $4,500/km	15	32,000	32,000
Service drops/housewiring	100 @ $50/household	15	5,000	5,000
O&M	$100/month			9,000
Parts	$1,000/year			8,000
	Initial capital cost:		$49,000	
	Life-cycle cost:			$66,000
	Life-cycle cost/consumer:			**$660**
Diesel option				
Diesel genset/powerhouse	two 6-kW gensets @ $7,000; powerhouse: $4,000	8	$18,000	$24,000
Secondary distribution line	4 km @ $4,500/km	15	18,000	18,000
Service drops/housewiring	100 @ $50/household	15	5,000	5,000
Overhaul	major overhaul of genset every 2 years @ $5,000			17,000
O&M	fuel cost: $0.30/kWh; parts and labor: $2,000/yr			36,000
	Initial capital cost:		$41,000	
	Life-cycle cost:			$100,000
	Life-cycle cost/consumer:			**$1,000**
Grid extension option				
Primary distribution line	15 km @ $4,500/km	15	$68,000	$68,000
Transformer/switchgear	Step-down transformer @ $1,000	15	1,000	1,000
Secondary distribution line	4 km @ $4,500/km	15	18,000	18,000
Service drops/housewiring	100 @ $50/household	15	5,000	5,000
Cost of energy	750 kWh/month @ $0.15/kWh			10,000
O&M	service man @ $40/month			4,000
	Initial capital cost:		$92,000	
	Life-cycle cost:			$106,000
	Life-cycle cost/consumer:			**$1,060**
Household PV option				
PV array	55 W_p output	15	$380	$380
Controller		8	100	140
Support/conductors/misc.		15	60	60
Installation	labor		40	40
Battery	100 Ah deep-discharge lead-acid	4	140	340
O&M	$1.50/month for technician to monitor systems			140
	Initial capital cost:		$720	
	Life-cycle cost/consumer:			**$1,100**

[a] Detailed costs for the PV option are on a per-consumer basis whereas detailed costs for the other options are for the entire system.

technical expertise to ensure the continuing operation of diesel engines frequently results in plants which are much less cost-effective than expected or indicated in this comparison.

- While usually considered expensive based on conventional wisdom, the **grid extension** option holds out the promise for being the least costly and least problematical option which is most broadly replicable. This conclusion is heavily dependent on the approach taken in project design and implementation. If conventional designs continue to be used as they have in the past, costs can be considerably higher.

- For the consumer base considered, the **household PV option** is the costliest. For the other options, project costs are shared among all consumers. As soon as the number of consumers exceeds some threshold level, as in this case, such sharing reduces the unit cost of service to below the fixed value associated with the PV option.

  Although there is hope that PV costs will decrease, the costs of PV arrays are now decreasing much more slowly than they have in the past. Furthermore, most of the cost associated with a household PV system is not in the array but in the other components. The possibility of a significant decrease in these costs seems remote because most of these components are already mass-produced.[45]

Other factors to consider in determining the optimum option for a particular situation include:

- **Size of community to be served**: Because of the lack of economies of scale, the PV option provides the least-cost option for supplying small population centers and isolated consumers or loads such as water pumps or rural clinics. For example, if the consumer base considered in the costing in Table C-1 is halved to 50 consumers, the per-consumer LCC for the grid extension and micro-hydropower option would nearly double (because most of the investment costs would remain unchanged), the per-consumer LCC for the diesel option would increase to a value somewhat less than double (because while investment costs would remain largely unchanged, less fuel would be used), and the per-consumer LCC for the PV system would remain unchanged. As a consequence, the grid extension and diesel generation options now become the highest-cost options, with the renewables options—PV and micro-hydropower—being competitive with each other. With a further decrease in the consumer base to below 50, the cost of the PV option remains unchanged, with a lower per-consumer LCC than for each of the three other options.

  It must be kept in mind that, while these trends will generally hold true, the comparative ranking of these options for a particular case is a function of the number of consumers to be served, their geographical distribution within the service area, the actual designs adopted for each, and the unit cost of labor and materials. Therefore, while the PV option might seem the least costly for a community of fewer than 50 consumers for the case shown above, other options might prove considerably lower in cost for even smaller communities depending on site-specific conditions. For example, if there were 300 consumers along the entire 15 km of grid extension rather than just 100 at the end, the grid extension option could be the least-cost approach a community with only about 10 consumers at the end of a 15 km line!

- **Institutional constraints**: Lack of effective institutional approaches and properly trained personnel for maintaining rural electricity supply systems has been the most common reason for their failure. These problem areas can be most easily addressed for the PV and grid extension options. For the PV options, the technology is relatively simple and components are few; technicians can be trained relatively easily. For the grid extension option, already trained electric utility personnel would be charged with the actual generation of power and the occasional repairs needed on the main line to the load centers.

[45] In this example, even a significant halving of the cost of the PV array would decrease the LCC of the PV option by less than 20%.

83

- **Potential for expansion**: All options, except the PV option, possess the potential advantage of being able to make available increased electricity-generating capacity for essentially the same capital investment (by making use of unused energy available during non-peak lighting hours). By encouraging increased load factor, unit costs of electricity can be reduced considerably, and additional benefits could be derived by the community at a low marginal cost.

  Furthermore, if consumer demand during peak hours has already reached the system's capacity, the PV option would require an additional investment for a supplementary array (and probably increased battery capacity) for each consumer. The grid extension option may have additional capacity at no extra cost. The diesel and micro-hydropower options might require generating equipment with larger capacity.

  However, another possibility for these two latter options simply would be to incorporate a battery and a dc circuit in each household. This would permit additional consumers to be served from the same plants by storing the energy which is available and not being used during off-peak hours. For the micro-hydropower option costed in Table C-1, this would permit at least three times the number of consumers to be served from the same plant without markedly increasing the LCC per consumer, even including the cost of battery and charger/controller.

- **Environmental impact**: The micro-hydropower option usually has negligible environmental impact because most schemes are run-of-river, with no dam storage. There are a variety of negative environmental impacts associated with the diesel option: contamination of soil and water from leaking or spilled fuel and air and noise pollution. The grid extension option relies on centrally generated electricity, and while air, water, and soil pollution are possible depending on the source of the energy, the centralized nature of this potential problem implies that it is more localized and should be less costly to resolve because of economies of scale. The PV option can also contaminate soil and water if a battery recycling program has not been implemented.

- **Availability and quality of service**: All options have some problems in their area. The PV option is reliant on the vicissitudes of the weather, as might be the micro-hydropower option (depending somewhat on the size of the stream used). The diesel option is dependent on the availability of fuel. While availability of fuel might also be a problem with the grid extension option, this option is furthermore dependent on the priorities of the national utility, which, in times of shortage, would generally shed rural loads first. And for all options, their success is heavily dependent on the level of technical support afforded the systems.

From the comparison above and the Nepali experience, it is clear that grid extension, if properly designed and implemented, can prove a least-cost approach to rural electrification in a considerably larger number of cases than is now thought possible.

In summary, grid extension costs can be reduced by adopting the following approaches:

- sizing the distribution system to meet actual rural electricity needs and ability to pay rather than assuming electricity consumption, growth rates, and disposable incomes of urban consumers;

- adopting system designs that permit reduced costs in construction and operation and maintenance; and

- relying on village-based organizations to contribute to system construction and maintenance and to assume responsibility for collecting consumer bills and forwarding these to the utility.

If one agrees that costs of grid extension can be reduced significantly, what then is the greatest obstacle to the broad replication of the Nepali experience? It usually lies with the utilities, which have generally shown little interest in becoming involved in such rural electrification because it requires considerable effort and generates little financial return. Therefore, to implement low-cost grid extension, the national government and public utility must develop a regulatory framework conducive to the formation of users' organizations (or their equivalent) to contribute to the construction of systems and to accept the principal responsibility for running village-wide systems. In this manner, the utility essentially would have the demand and financial returns associated with dozens or even hundreds of families while it deals with only a single consumer—the users' organization. The utility could focus its energies on generation, transmission, and primary distribution lines, and not be encumbered with the frustrating and time-consuming aspects of dealing with many dispersed small rural consumers (meter-reading, billing, collecting, dealing with consumer complaints, etc.). These would be left to the users' organizations which can often more effectively deal with these tasks.

85

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86

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