

The Marginalization of “Small is Beautiful”: Micro-hydroelectricity, Common Property,
and the Politics of Rural Electricity Provision in Thailand

by

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B.A. (Reed College) 1991

M.S. (University of California, Berkeley) 1997

A dissertation submitted in partial satisfaction of the

Requirements for the degree of

Doctor of Philosophy

in

Energy and Resources

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA, BERKELEY

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Fall 2004

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Fall 2004

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Abstract

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This study analyzes forces that constrain sustainable deployment of cost-effective renewable energy in a developing country. By many economic and social measures, community micro-hydro is a superior electrification option for remote mountainous communities in Thailand. Yet despite a 20 year government program, only 59 projects were built and of these less than half remain operating. By comparison, the national grid has extended to over 69,000 villages.

Based on microeconomic, engineering, social barriers, common pool resource, and political economic theories, this study investigates first, why so few micro-hydro projects were built, and second, why so few remain operating. Drawing on historical information, site visits, interviews, surveys, and data logging, this study shows that the marginal status of micro-hydro arises from multiple linked factors spanning from village experiences to geopolitical concerns.

The dominance of the parastatal rural electrification utility, the PEA, and its singular focus on grid extension are crucial in explaining why so few projects were built.

Buffered from financial consequences by domestic and international subsidies, grid expansion proceeded without consideration of alternatives. High costs borne by villagers for micro-hydro discouraged village choice.

PEA remains catalytic in explaining why few systems remain operating: grid expansion plans favor villages with existing loads and most villages abandon micro-hydro generators when the grid arrives. Village experiences are fundamental: most projects suffer blackouts, brownouts, and equipment failures due to poor equipment and collective over-consumption. Over-consumption is linked to mismatch between tariffs and generator technical characteristics. Opportunities to resolve problems languished as limited state support focused on building projects and immediate repairs rather than fundamentals. Despite frustrations, many remain proud of “their power plant”.

Interconnecting and selling electricity to PEA offers a mutually beneficial opportunity for the Thai public and for villagers, but one thus far thwarted by bureaucratic challenges.

Explanations of renewable energy dissemination in countries with strong state involvement in rural electrification should borrow approaches from political economy concerning the ways in which politics and constellations of other factors eclipse rational economic behavior. At the village level, common pool resource theory reveals causal linkages between appliance use, equipment limitations, power quality, and equipment failures.

Dedication

For my father and for Chom

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Acknowledgements

Without support from the EPA STAR Fellowship, the Switzer Environmental Fellowship, and the Energy Foundation Fellowship, this research would not have been possible. I would like to thank my qualifying examination committee: Professors Richard Norgaard (Chair), Jeff Romm, Daniel Kammen, Rick Wilk, and Dr. Ashok Gadgil. Their support and guidance enabled me to explore the ideas that formed the basis of this research. My dissertation committee – professors Kammen (Chair), Norgaard, and Romm provided exceptional feedback, and are to be commended for their patience and flexibility in providing me the opportunity to work on research and writing from across the world in Thailand.

I give special thanks to my Switzer Network mentors Jim Williams and Margaret Torn who generously and skillfully coached me through many phases of the Ph.D. process, and welcomed me in their home for extended visits from Thailand. Jim & Margaret's council and enthusiasm were crucial in all stages of my research: in defining research questions and methodology, in preparing for the qualifying exam, in refining and carrying out research, in write-up and in filing.

The ERG community has been a steady source of inspiration. I look forward to a lifetime of remaining in close contact with ERG colleagues – professors, students, alumni, and staff. ERG staff deserve special recognition for their consistent excellence in helping students to negotiate the U.C. bureaucracy and keeping ERG running smoothly.

I am indebted to the many villagers who took the time to answer my questions – and especially thankful for the micro-hydroelectric project operators and village headmen who opened their homes and provided meals and lodging during my field visits. I would

like to thank friends who served as translators for field visits: Samrit Thuwarungrueng, Tira Foran, and my wife Chuenchom Sangarasri Greacen.

Large thanks are due to the staff at the Department of Alternative Energy Development and Efficiency (DEDE), and the Provincial Electricity Authority (PEA) who took the time to answer my endless questions. I would like to thank the Power Division at the Thai Energy Policy and Plan Office (EPPO), which provided an office used in the part of the writing phase of the dissertation, and granted me the opportunity to draft technical policies for grid interconnection of village micro-hydro projects and other small renewable energy generators. I would also like to thank the staff at the Chiang Mai University Department of Industrial Engineering with whom I collaborated on village-scale micro-hydro research during the last half of 2002 and early 2003.

In helping with logistics involved in filing the dissertation from Thailand, a number of people have gone well beyond the call of duty to help me: Arne Jacobson and Jane Stahlhut at ERG, Shirlaine Baldwin in the Grad Division.

Through it all, I owe the biggest thanks to my family: my mother and father for their encouragement and lifelong commitment to education, and my sister for encouraging me to pursue that which makes me most come alive; Chom for her support and her crucial insights, and her brother Anubut and mother Sermsri for their support. Finally, I thank my son Ty for his companionship and frequent encouragement for me to take breaks to draw with crayons and play with toy trucks, and my daughter Isara whose calm disposition during her early weeks of life was a delightful virtue during the concentrated final weeks of writing this dissertation.

Chapter 1: Introduction

If economics and environmental impacts were deciding factors, one might expect that by today thousands of communities in rural mountainous parts of Thailand would be served by electricity from village-scale micro-hydroelectric¹ plants instead of the national grid. The topography and rainfall are ideal for the technology: steep hillsides are abundant in much of the north, northwest, and south; rainfall is generous, and thick forest cover helps ensure that many streams have water throughout the year. The technology is appropriate for the demographics and environment of these areas. Settlements in these areas are generally remote and sparse, so that long grid extensions are required to serve small numbers of people. As a consequence, in many cases electrification with micro-hydroelectricity has a lower overall cost than extending the grid.² The systems generally have little or no reservoir, so environmental impact is minimized.

Yet visitors to villages in Thailand's hill areas generally find either the national grid, or no electricity at all. Moreover, of the paltry 59 village-scale micro-hydroelectric plants that have been built over the past 20 years, more than half have been replaced by the grid or fallen into disrepair. Some of the few remaining projects demonstrate the ability of this technology to provide local employment, capacity building, and resource management benefits in addition to affordable electricity. Despite these benefits micro-hydroelectric systems are rapidly being replaced by the grid.

¹ Definitions of what constitutes the upper limit of "micro-hydropower" vary from 100 kW (Jiandong 2003) to 300 kW (Harvey, Brown et al. 1998). In Thailand, projects under 200 kW are considered "micro" (DEDP 1998). The terms "micro-hydropower", "micro-hydroelectric", and "micro-hydro" are used interchangeably.

² An economic analysis is presented in Chapter 4.

My research addresses two questions in a rigorous way: first, *Why were so few micro-hydro projects built?*; and second, *Why have many of the existing projects been abandoned?*

International context

The global stakes for sustainable deployment of clean, cost-effective electrification are high. Conventional electricity generation worldwide already currently accounts for 38% of worldwide CO₂ emissions, which threaten to irreversibly change the environment (Dubash 2002). Electricity consumption in developing countries is expected to increase rapidly (World Bank 1992; World Energy Council 1993; Kessler 1994; Pearson 1996; Anderson 1997; G8 Renewable Energy Task Force 2001). It is now widely recognized among climate change scientists that stabilizing atmospheric CO₂ at twice pre-industrial levels while meeting goals of moderate economic growth implies a massive transition to carbon-free power, particularly in developing nations (Hoffert, Caldierra et al. 1998). Renewable energy appears destined to play an important role in this transition, especially considering that nuclear power faces critical unresolved challenges in long-term management of nuclear wastes; perceived adverse safety, environmental, and health effects; and potential security risks stemming from proliferation (Ansolabehere et al. 2003). With the emergence of global climate change as a credible and serious threat, decades of relative neglect of renewable energy have recently been somewhat reversed, as evidenced by over \$1 billion leveraged by the Global Environmental Facility (GEF) for renewable energy for rural electrification, with large amounts as well from the G-8, prominent energy companies, and governments in a number of countries. The emerging global warming crisis demands that these funds be invested effectively and efficiently.

As a component of developing country electricity infrastructure, rural electrification poses a special challenge: 3 billion people enjoy modern energy services today, but 10 billion will need them if universal service is to be provided within the next half century as more than a billion people are added to the human population each decade (Anderson, 1997). Grid extension has made impressive gains: nearly 1.3 billion people in developing countries have received electrification grid service in the past 20 years, but during this same time period the population of these countries has grown by 1.5 billion (Barnes and Floor 1996). Increasing privatization of electric utilities and fiscal austerity programs generally leave even fewer resources for public expenditures on unprofitable rural grid-electrification (Dubash 2002). And it seems questionable that the private sector will respond adequately to the task of grid-based rural electrification. Entities involved in rural electrification in the emerging era of budget cuts would be wise to consider a wide range of technology options and management arrangements, even if they challenge established practices and concepts of ownership and control.

In this context, decentralized community-managed “small is beautiful” technologies like micro-hydroelectricity appear to be particularly promising approaches to providing electricity – if social and technical arrangements can be structured to keep the technology working for communities in the long run. By investigating the mixed record of the deployment of community-based micro-hydroelectricity in Thailand, this research seeks to identify and understand these social and technical factors.

Thai context

In Thailand, community scaled micro-hydroelectric cooperatives represent an important precedent for community ownership and control of clean electricity

infrastructure. As such, they provide a functioning (if Lilliputian) alternative to centralized power systems run by parastatal utility companies (Palettu 2002) and to the profit-oriented large investor ownership model of electricity infrastructure advocated by the World Bank and the IMF that has swept the developing world (Tellam 2000). The technologies used for centralized power generation in Thailand -- especially coal and large hydro power -- are increasingly criticized on environmental grounds (Kuankachorn 2000; Janchitfah 2001; Janchitfah 2002), while power plants that burn imported fossil fuels are seen to jeopardize economic security by fostering an unsafe reliance on imports (Amatayakul and Greacen 2002). The parastatal utilities themselves are increasingly accused by the Thai government, the private sector, and multilateral development agencies as being inefficient, monopolistic, and prone to amassing excessive debt, hurting both ratepayers and taxpayers alike (Barnes 1988; NEPO 2000; Crispin 2001; Greacen and Greacen 2004). NGOs and citizens groups also fault these same parastatals for being undemocratic and unfair in their treatment of affected communities (Hirsch and Warren 1998; Janchitfah 2001; Janchitfah 2002). Customer-owned distribution systems such as municipal and rural cooperative utilities in the United States, Europe, and elsewhere have provided valuable yardsticks by which to judge the efficiency and service of the state and investor-owned utilities. Some argue that the same types of yardsticks and alternatives are necessary in Thailand (Palettu 2002).

More broadly, community-managed micro-hydroelectricity accords well with a number of progressive trends within Thai policymaking. These include a move towards decentralization embraced in a newly adopted constitution (Thai Kingdom 1997),

capacity building for rural enterprise, and increased environmental protection including reduction in emissions of greenhouse gases (Amatayakul and Greacen 2002).

Dissertation overview

Rural renewable energy has roots that extend deep into complex and politicized terrain. To understand why village-scale community-managed micro-hydro appears to be losing to the grid, my research is by necessity an interdisciplinary journey through the engineering, economic, political, and social aspects of Thai rural electrification, renewable energy, and particularly village-scale micro-hydroelectricity. The analysis operates at a variety of scales – from the international politics of aid to the day-to-day operations and use of village systems.

Chapter two establishes a framework for this investigation, drawing on theoretical perspectives including engineering, microeconomics, “social barriers” to technology adoption, political economy, and common pool resource theories. The chapter concludes by proposing seven hypothetical explanations for the marginal status of micro-hydro in Thailand.

Chapter three analyzes survey data on the system performance and challenges encountered in the field for 59 village micro-hydro projects in Thailand. This broad perspective is complemented with an in-depth technical analysis of two micro-hydro systems that uses datalogging and household appliance surveys to explore linkages between consumption patterns, equipment shortcomings, low voltage, and equipment failures.

Chapter four explores micro-hydro in the context of the ideal of economically optimized rural electrification planning. The chapter addresses relative economic benefits

and costs of micro-hydro versus the grid. A simple quantitative model based on empirical Thai data is developed to determine spatial/demographic conditions under which micro-hydroelectricity may be economically optimal. A related analysis considers the relative costs of micro-hydro and the grid in the electrification of 20 villages currently served by micro-hydro. The chapter considers implications of the opportunity to connect micro-hydro generators to the grid, including a basic financial assessment of 27 projects.

Chapter five presents a history of Thai rural electrification with a focus on issues of technology choices, bureaucratic arrangements, implications for centralization and public voice in decision-making, and the role of international aid and domestic political and economic transformations in shaping this trajectory. The chapter also presents a contemporary overview of community micro-hydro in Thailand and draws on the previous two chapters to construct a multi-layered analysis of why micro-hydroelectricity is unable to effectively compete with the grid despite economic and social advantages.

Chapter six reviews evidence for each of the seven hypotheses proposed in Chapter two, and discusses the relevance of each as an explanatory factor. Based on the match between empirical evidence and hypotheses, I draw conclusions regarding the relative importance of these factors, and consider the implications of this research for further developments of theory.

Chapter seven considers implications of the research for policy initiatives including policies that allow the interconnection of micro-hydroelectric and other small renewable energy generation to the grid, and the deployment of decentralized village-scale renewables in countries with low rates of rural electrification.

The remainder of this chapter (Chapter one) discusses theoretical and practical contributions of this study, describes the methods employed in this research, and provides an introduction to some salient technical and social dimensions of village-scale micro-hydroelectricity.

Study methods

My methods include in-depth interviews, archival research, surveys, and computerized data logging. Historical information, government reports (Thai and US), and personal interviews provided much of the information for my analysis. In addition I made site visits to investigate installations, and used datalogging equipment³ (15 minute interval data for several months duration) to record micro-hydroelectric system performance at micro-hydroelectric systems in two villages.

Between September 1998 and May 2004, I conducted 62 semi-structured interviews with government officials, villagers, village leaders, university researchers and professors, and utility and industry officials. Topics included various aspects of rural electrification policy and practice, including the broader rural development context and specific actions with respect to renewable energy and micro-hydroelectricity.

In the course of the fieldwork I visited a total of 15 villages. In villages in which the micro-hydroelectric project is no longer functioning I briefly interviewed the village headman (and if available) the former operator and/or other villagers. These interviews covered basic details of when and why the project stopped working. At each village with an operating micro-hydroelectric system(s), I conducted (with the help of a native Thai

interpreter) semi-structured interviews with the village leader, the powerhouse operator and/or tariff collector, and village residents. These interviews covered a variety of topics including physical characteristics of the system, operating and management arrangements, problems with the system, and ways that the system benefits or troubles the community.

To study appliance ownership and electricity consumption patterns, I surveyed adults in 65 households in the villages of Mae Kam Pong and Huai Bu. The survey interviews were conducted in person with the help of an interpreter.

Further data concerning Thai micro-hydroelectric projects was obtained in collaboration with the “improvement of administration at village micro-hydro” project based at the Industrial Engineering Department, Faculty of Industrial Engineering, Chiang Mai University, which started in June 2002.

Of the 110 total interviews, about 80% were in Thai language. For interviews conducted in year 2001 and 2002 I used a translator. Thai interviews in 2003 and 2004 were conducted without a translator. Most interviews were recorded with in-depth field notes (facilitated by the time lag in translation). Four interviews were recorded on audiotape. For all taped interviews, interviewees were asked permission prior to taping. All interviews were transcribed in order to facilitate analysis using computer programs to search for key words and phrases.

Conditions of participation conformed to the policies of the Committee for the Protection of Human Subjects at the University of California, Berkeley (CPHS number:

³ Datalogging equipment consisted of an Onset Computer HOB0 H8 (4-channel, external) datalogger, 3 split-core 50 Amp (CT-B) current sensors, and a custom-built

2001-8-133). In order to protect the identity of interviewees I identified each informant by a broad location descriptor (district, province and country) of interview and date.

In addition to formal interviews I employed a form of participant observation by becoming involved as a volunteer in a number of renewable energy activities in Thailand. On the one hand, this gave me the opportunity to “give back” to Thailand. On the other hand, volunteering helped me gain trust and access to the inner workings of Thai energy policy and implementation. I have been careful to not work directly on the micro-hydro projects I study (so as to not influence the object of research), but rather to choose related activities that provide insight into processes and relationships among the bureaucracies engaged in rural electrification and between village residents and outside actors engaged in rural electrification activities. The assistance I provided has been either technical in nature, or has involved helping Thais network with the international community of energy professionals. The resulting situations and experiences have afforded an emergent textured understanding of the politics between electrification bureaucracies, and policy processes that would have been impossible with just two or three months of intensive research. Information from these experiences is not directly used in the dissertation. Rather, it helped inform my choice of interviewees, questions asked, and provided opportunities for triangulation of findings.

In 2000 I volunteered with the System Development Division of the Provincial Electricity Authority (PEA) to provide technical assistance on a project to investigate the use of renewable energy to electrify remote islands. The experience provided insight into

voltage transducer.

processes of technology choice within PEA, and the ways that projects are proposed and defended within the government budget allocation process.

In late 2001 and 2002 I volunteered with NEPO to draft policies allowing net metering and streamlined interconnection of renewable energy generators (under 1 megawatt). Later I represented NEPO as these policies were amended and adopted by a technical committee of utility and government officials and ultimately adopted into law under a Thai Cabinet resolution. This experience, and subsequent creation of an NGO, *Palang Thai*, to work to facilitate the policy's implementation, has provided significant opportunities to observe inter-bureaucratic rural electrification politics in Thailand, and their masking in technical language.

My research was also informed indirectly by a number of experiences with community-scale renewable energy projects with which I was involved during the course of my doctoral studies. These included working with villagers in Kre Khi village and E Wi Jo village in Tak province, Thailand, to build two community micro-hydroelectric systems; designing and working with North Korean engineers to build a 7-turbine wind-farm in a village in western North Korea; working with Cambodian diesel mini-grid operators to engineer improvements in their distribution systems and to convert their diesel generators to biogasification; and visits to a variety of village-scale solar, wind, and micro-hydroelectric systems in China and Nepal. These experiences have: (1) helped provide insights into the degree to which challenges that emerge in the Thai context are common to village-scale renewable energy projects, or are, in fact, unique to Thailand; (2) provided insights into ways in which the lessons from Thailand are

applicable to other contexts; and (3) suggested approaches to improve Thai village-scale renewables that have been successful in other countries.

Introduction to village scale micro-hydroelectricity

Micro-hydroelectricity uses energy in falling water to spin a turbine to produce electricity. While a variety of configurations are possible (such as low-head or instream turbines) the most economical applications are generally in areas with substantial height drop⁴ (10m to 100 m is typical) using a run of the river⁵ configuration. Run of the river systems comprise 100% of the Thai village scale systems studied in this research.

The key civil, mechanical, and electrical components of a run of the river micro-hydroelectric system of the type commonly found in rural Thailand are reviewed briefly below (see Figure 1).

⁴ The vertical component of the drop is referred to as “head”

⁵ A “run of river” project has no storage reservoir. Water is directly drawn from the stream, or using an intake structure with a small intake pond. Run of river projects generally have far fewer environmental impacts than projects with reservoirs (Santos 1992).

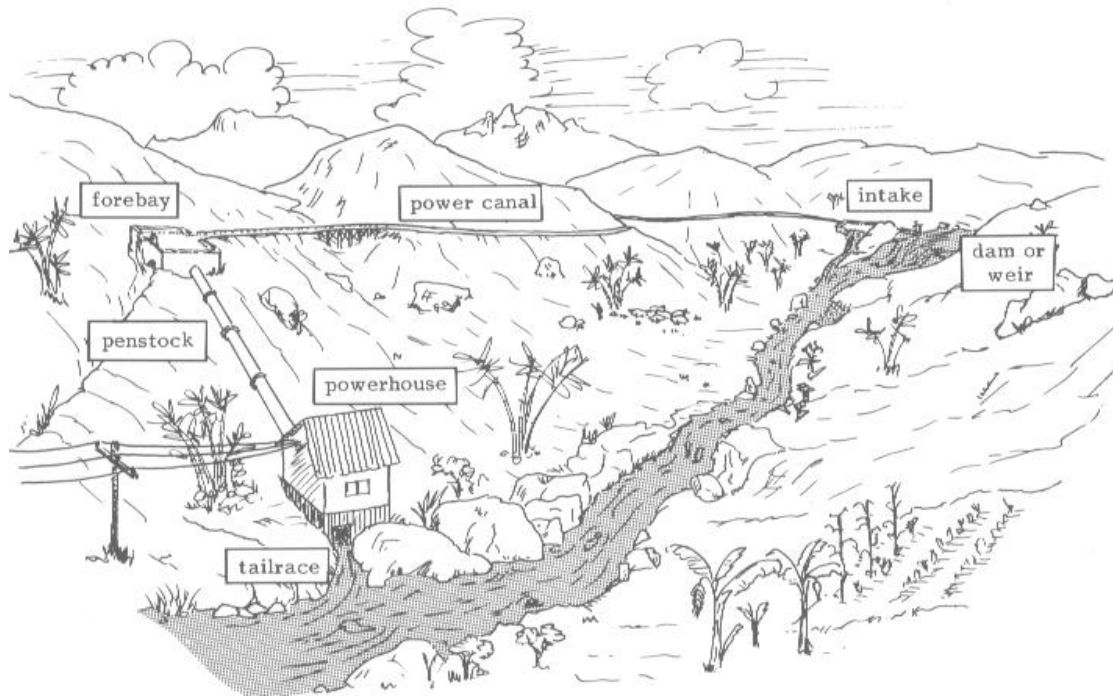


Figure 1: Basic components of a village micro-hydroelectric system. Source: Inversin 1986

Civil engineering components

Water is impounded in a small dam or *weir* made of concrete or rocks placed across the stream to increase the water level so that water can be diverted, by an *intake* structure, into the *headrace* or *power canal*. The headrace can either be an open canal or a low-pressure pipe made of cement or plastic. Upon exiting the power canal water enters the *forebay*, which allows sediment in the water to settle and precipitate before the water enters the *penstock*. A *spillway* is generally provided to safely remove excess water. The *penstock* is a high pressure pipe (generally made of steel) that conveys water from the forebay to the *turbine* located inside a powerhouse. A *tailrace* returns the spent water from the turbine back to the river.

Electrical and mechanical components

Inside the powerhouse, water exits the penstock through a specially designed *nozzle*, and strikes the *turbine*, changing the energy from the falling water into rotational energy to spin the *generator*. For village micro hydroelectric projects in Thailand (as in most of the world) two types of turbines are generally used: crossflow or Pelton.

Crossflow turbines look like cylindrical squirrel cages that spin on a horizontal axis. Two side disks are connected by a dozen or more curved blades. In a crossflow turbine, the water flow passes through the blade row twice, first in the upper portion of the wheel and again at the lower portion. Crossflow turbines are the easiest to build, and are more suitable for lower head sites. With a Pelton turbine one or more jets of water impinges on a wheel containing many curved buckets, producing a force on the buckets and resulting in a torque on the shaft. Pelton turbines are more expensive, but also more efficient than crossflow turbines. Pelton turbines are generally used in high head applications.

The generator transforms mechanical rotational energy into electrical energy. All generators have two essential parts: a (1) rotor (the parts that spins) which creates a rotating magnetic field and (2) a stator or armature consisting of sets of wires arranged across the path of the magnetic flux of the rotor. Relative motion between the rotor and the stator induces an electromotive force in the conductors of the stator.

Synchronous generators are used in all stand-alone village-scale micro hydroelectric systems in Thailand. In a synchronous generator the magnetic flux is achieved by applying a direct current across the rotor field coils. This excitation current is provided by a small DC generator mounted on the same shaft as the main ac generator.

When the turbine spins the rotor shaft the rotating magnetic flux induces an alternating voltage in the stator coils.

The generator must be controlled to avoid overspeed. The *controller* or *governor* controls the speed of the generator -- and thus the frequency of the electricity generated - in one of two ways. An electronic diversion load control allows the generator to generate at full capacity all the time. Excess power not demanded by the village load is diverted to a water heating element. This type of control reacts quickly to changes in village load, and is both simple and relatively robust. The disadvantage is that full water flow is required constantly. An alternative method uses a mechanical governor. When the turbine starts to spin too fast, a mechanical or electro-mechanical control reacts by closing a valve in the penstock restricting water flow. A turbine with this type of governor uses less water, but relies on many (failure prone) moving parts and reacts slowly to rapid changes in load, causing instability in the power supply.

The *automatic voltage regulator (AVR)* is an electronic circuit used with synchronous generators to regulate voltage. The AVR regulates the generator output voltage by increasing or decreasing the DC current provided to the field coils in the rotor. AVRs in Thai installations have been particularly prone to failure.

The *distribution system* brings electricity from the generator to the end-users. The system consists of poles, wires, and meters for measuring electricity consumption. If end-users are particularly far from the generator, transformers are used to increase the voltage, generally up to 3.3 kV, for transmission, and step it back down to 240 volts for customer use.

Village micro-hydroelectric system costs

Micro-hydroelectricity is among the least expensive stand-alone rural electrification options, with typical costs of \$1000 to \$2000 per kW for community-built projects in developing countries such as Sri Lanka, Peru, or Nepal (Harvey, Brown et al. 1998). In Sri Lanka a typical 10-12 kW installation serves about 100 households and costs about \$15,000 including the associated network (Martinot 2001). In exceptional cases, costs as low as \$250 to \$400 per kW have been reported (1978 dollars, Pakistan) (Inversin 1986). Reported costs for produced electricity vary from as low as US\$0.025 per kWh (1978 dollars) (Inversin 1986) to \$0.12 per kWh (Jiandong 2003).

As such, micro-hydroelectricity is generally less expensive than diesel generation. Diesel generators have lower capital costs (around \$500 per kW for 30 kW generator), but substantially higher operating costs because of the need for diesel fuel. Diesel generators typically produce electricity for \$0.20 to \$1.50 per kWh (where the high end represents costly transport for diesel fuel to remote sites) (Shanker 1992). Micro-hydroelectricity is often less expensive than grid extension solutions as well (see Appendices 1 and 2). Simple designs and fabrication techniques allow for local manufacture and local reparability.

Micro-hydro for integrated rural development

Village-scale micro-hydroelectricity has useful characteristics that can be exploited in integrated rural development efforts. With careful planning, micro-hydroelectric projects can be integrated with irrigation and water supply projects to provide multiple benefits. In addition to generating electricity, micro-hydropower plants can provide mechanical energy during off-peak times used to directly power agro-

processing machinery or cottage industries. This permits the use of simple, inexpensive, and easily understood mechanical devices.

Because wires in a village mini-grid are all interconnected, village micro-hydro systems inherently allow electricity not consumed by one household to be used by others. In addition, because the marginal cost of additional connections is low, village power systems lend themselves to electrifying an entire clustered community – rich and poor alike.

Some organizations find that the process of working with villages to develop village power projects provides important opportunities to build capacity and skills that are useful for a variety of other rural development activities (Inversin 1986; Lewis 1997; URJA 1998). These groups report significant benefits from a village power project development process that views electrification less as an end in itself, but rather a byproduct of a process in which rural villagers develop the expertise and confidence to take on significant self-initiated development projects. Income generation, education, health care, forestry, and other elements are woven into an integrated package that seeks to derive as much social benefit as possible from village power projects (URJA 1998).

Worldwide village micro-hydroelectricity installations

Micro-hydroelectricity is a well-proven technology for village rural electrification, with installations in Europe, America, and Asia dating back to the last part of the 19th century (Santos 1992). Nepal currently has an estimated 576 village micro-hydroelectric and stand-alone mini-hydroelectric installations serving an estimated 76,500 people (Pandey 2000). By the end of 2001 in China, 18,944 micro-hydroelectric installations have been built, each less than 100 kW but with a total installed capacity of

687 MW. Considering that each village system provides power for hundreds of households, these systems in China alone are currently providing power for several million households (Jiandong 2003).

Micro-hydroelectric systems have also been installed in Bhutan (Arvidson 2000), Borneo, Burma, Cambodia, Cameroon, Guatemala, India (Interview 2000.03), Laos, Mexico, Nicaragua (Lewis 1997), North Korea (Von Hippel 1999), Pakistan, Papua New Guinea, and Peru (Inversin 1986), Philippines, the Solomon Islands, Sri Lanka, Zaire (Thornbloom 1997), and Zimbabwe. Many European countries, Canada, and the USA have village micro-hydropower installations as well (Klunne 2000).

Micro-hydroelectricity in Thailand

Despite lower costs, only 59 community micro-hydroelectric systems were built in Thailand between 1983 and 2001. In comparison, 2002 government figures indicate 69,942 villages served by grid electrification (PEA 2002). Moreover, of the 59 community micro-hydroelectric systems installed, only 25 are still in operation. But many that are operational provide a valuable source of inexpensive, community-managed electricity.

The dearth of functioning installations (or installations at all, for that matter) cannot be explained by lack of suitable terrain or water. With a few regional exceptions, Thailand enjoys abundant rainfall, and there are significant portions of the country in the north, west and south with mountainous terrain suitable for micro-hydro. One DEDE study identified 1136 *mini*-hydro (>200 kW) sites (DEDP 1998). Because of the tributary nature of watersheds, sites for *micro*-hydroelectric projects would be at least several times as plentiful.

What explains why so few projects were built, and why so few are still operating given their apparent cost and community development advantages?

Before discussing these projects in detail (Chapter 3), let us consider theoretical perspectives useful in framing an understanding of these systems in their contexts.

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