POWER INFRASTRUCTURE SUPPLEMENT BASED ON RENEWABLE ENERGY POWER SYSTEMS: A REVIEW

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Abstract
Rural electrification is an integral component of poverty alleviation and rural growth of a nation. The demand for electrification cannot be accomplished because of the increasing gap between rural electrification rate and population growth. Therefore this review aims to study recent trends of energy usage from renewable energy sources, such as Photovoltaic, Wind, Hydro and Pico hydro. Pico hydro is the preferred electricity generation sources in most rural households followed by Wind, Photovoltaic. It discusses criteria for optimization of the Hybrid Renewable Energy System (HRES). HRES is getting popular in the present scenario of energy and environmental crises.

KEYWORDS: Rural electrification, Hybrid Renewable Energy System, Wind, Hydro.

1. Introduction

India has one of the fastest growing economics in the world and ranked 6th place in the worldwide consumer of energy. Being the seventh largest country in the world, 6000 villages inhabit 72.2% of its human resource (census 2001). About, 40% of the total energy is in rural areas. Domestic sector constitutes major energy demand and its consumption accounts for 60% of energy used. The main energy sources are coal and oil, whilst hydro, wind, nuclear and biomass provide additional sources. Although hydropower has good potential, it has yet been utilized to its full potential. India holds 7% of the world's coal reserves, whereas for oil 0.5%. Following are some of the salient aspects having direct and indirect bearings on energy supply, to rural. Both the traditional energy and commercial energy are in short supply and the demand supply gap is in increase. Pressure on traditional energy resources such as wood is continuously increasing due to growing population. Heavy dependence on commercial fuels such as coal and oil as a short term measure for meeting increasing demand is alarming in view of depleting fossil fuels and pollution. Energy supply to far-off rural areas is associated with high transportation and transmission losses of about 22.4%. Thus emphasis should be laid on the auditing of the energy in such a way that ensures affordable, environment friendly and clean energy.

2. Impact of rural electrification

Importance of electricity as a crucial infrastructure input for economic development of the country has been well established. Recent studies of rural electrification indicate the following broad consensus concerning the impact of electrification in the rural areas [1].

A. Quantifiable benefits: cost saving and increased productivity

1. Industrial and commercial uses of electricity
   (a) Motive power – replacing liquid fuel
   (b) Lighting – replacing liquid fuel or gas
   (c) Processing food – replacing liquid fuel, gas, biomass, animal waste.
   (d) Transport – replacing liquid fuel
2. Household uses of electricity
   (a) Lighting – replacing liquid fuel, gas, biomass
   (b) Cooking – replacing biomass, animal waste, wood, liquid fuel, coal, gas
   (c) Drinking water – replacing liquid fuel for pumping

(d) Home appliances (fan, TV, radio) – replacing batteries, biomass, coal

3. Agricultural uses on electricity.

(a) Water pumping – replacing liquid fuel, coal, muscle power

(b) Heating and drying – replacing biomass, coal, liquid

(c) Milling, chaff cutting, threshing, etc. – replacing liquid fuel, hydro or muscle power

B. Benefits those are difficult to quantify

1. Modernization, dynamism and attitude changes – catalytic effects
2. Quality of life, community services and participation
3. Income distribution and social equity
4. Employment creations

In recent years attention has risen regarding the issue of rural access to electricity supply and regarding the relation between energy (electricity) and poverty. Cecelski (2000) reviews several ‘‘success factors’’ in widening rural access to electricity, including subsidies, credit and leasing options for PV systems.

2.1. Features of rural electrification

Rural electrification is an important component of Integrated Rural Development. In India, it has been given less importance be- cause of the following reasons. Villages are located from 3 to 80 km away from existing grid or even more. They are located in difficult areas like forests, hill areas and deserts. The number of households may range between 2 and 200 with dispersed distribution of loads. Power demand in villages is quite low and rural domestic consumers are mainly peak time consumers and contribute for poor load factors of 0.2–0.3.The income level and hence the paying capacity is low. Previous definition of village was (source: Ministry of Power) – A village will be deemed to be electrified if electricity is used in the inhabited locality, within the revenue boundary of the village, for any purpose whatsoever. Modified definition of village from 2004 to 2005 is A village would be declared as electrified if –

(a) Basic infrastructure such as Distribution Transformer and Distribution lines are provided in the inhabited locality as well as the Dalit Basti/ hamlet where it exists. (For electrification through Non-Conventional Energy Sources a Distribution transformer may not be necessary.)

(b) Electricity is provided to public places like Schools, Panchayat Office, Health Centers, Dispensaries, and Community centers.

(c) The number of household's electrified should be at least 10% of the total number of households in the village.

Electrical power sector was recognized as one of the Millennium Development Goals in 2000, for the up liftment of the masses and poverty alleviation. The Five Year Plans of Government of India, World Bank, International Monitory Fund, etc. have identified this socially relevant sector and initiated several measures like Electricity Act 2003, Deregulation, Unbundling, Independent Power Producers (IPP), and Electricity Regulatory Commission.

3. Electricity demand

The demand for electrification will continue [2] for decades to come in rural areas particularly in less developed countries because hundreds of millions of households lack any form of electricity service[5]. Accordingly, [5] introduced a global model to ensure universal access to electricity for all rural households in less developed countries over the next decades and found that the gap to universal access remains large and that universal access to electricity will not be achieved by 2030 in Latin America, sub-Saharan Africa, and in some parts of Asia. For example, more than half million demands for electricity come from rural households in the Brazilian Amazon [4]. Many electrical demands need to be addressed in other rural areas around the world. According to [7], the world needs to produce 10 times the global electricity consumption to reach universal access to electricity to light up the entire world at 1 kW per person [7]. This finding indicates that the pressure on electricity generation energy resources will continue to increase globally and remain in short supply. The demand–supply gap increase is mainly caused by population growth [3]. [8] Forecasted that in the following two decades, the world electricity generation is expected to increase by 84% from 2008 to 2035, which indicates that electricity has the fastest growing demand as an end-use energy worldwide in the midterm run than consumption of liquid fuels, natural gas, or coal in all end-use sectors except transportation.

3.1. Drivers of demand

Many factors affect electricity demand, such as weather, economic growth, social and demographic factors, end-user prices and subsidies, policy factors, technological development and energy conservation, industry structure, energy intensity, energy savings and demand side management, peak load and seasonal variation, population growth, industrialization, and urbanization.[13, 14, 9]

3.2. Right of access to electricity

Access to electricity has become part of the basic human rights that needs to be fulfilled and established within the framework of international and national human rights laws [10], thus permitting all low-income households basic access to lighting, information, communication, leisure, and security [4]. This paper argues that 50 kW h of electricity per month should be given to low-income households. In 2003, the South African government introduced free basic electricity to assist low-income households [15] and 1000 kW h as basic annual access to electricity per capita until 2100[12, 13].

3.3. Electricity demands of rural households

The electricity demand in rural areas significantly depends on affordability, which is influenced by income, feasibility, and availability. Electricity demand is also influenced by the amount of electricity generation resources, which are influenced by site characteristics particularly for renewable energy. However, rural households have low electricity demand. For instance, 10 W is considered a light package per household in Kenya [14]. [15] Denoted that 50 W per household is sufficient in Kenya. [16] Denoted that 75 W is the average daily energy requirement per household and that this amount of energy has a significant positive influence on the lives of people in the rural community. These few watts are more than enough and can provide survival indoor lighting services for remote and inaccessible areas such as the Humla communities in Nepal [17]. However, for a community where the grid connection seems to be the only option, tariffs should be set extremely low [9] to assist and enable low-income households in less developed countries to afford the service because grid connection capital costs are still beyond their means [18, 19]. This condition signifies that without subsidizing electricity generation, grid connection for low-income households is likely to be unfeasible [19]

4. Types of Small Power System

Small power systems are mostly used for providing power to isolated and rural areas. Increase in mini-grids has risen parallel with price reductions in solar, wind and inverter technologies. Depending on the connection of power systems to the main grid, small power systems can be broadly classified into grid-tied system and off-grid power systems. Fig. 6 shows each type of power systems in detail.

4.1 Off-Grid Systems (Stand-Alone System)

Almost all the small power systems that are designed and optimized to meet the power demand of remote places are off-grid power systems. An off-grid systems does not have a connection to the main electricity grid. Standalone systems vary widely in size and application from wristwatches or calculators to remote building or spacecraft

4.2 Grid Tied Systems

A grid connected system is connected to a larger independent grid typically the public electricity gird[20] and feeds energy directly into the grid. The feeding of electricity into the grid requires the transformation of DC into AC by a synchronizing grid-tie inverter (also called grid- interactive inverter).

5. Hybrid Power Systems

Hybrid power systems are designed for the generation of electrical power using number of power generation devices such as wind turbine, PV, micro hydro and/or other conventional generators using fossil fuels. Such systems can range from small system capable for providing power for a single home to large system which can power a village or an island. Hybrid power systems are thought to provide power to many remote communities especially in the developing world where the national grid is economically and technically not viable.

5.1 Photovoltaic System

Solar photovoltaic is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity.

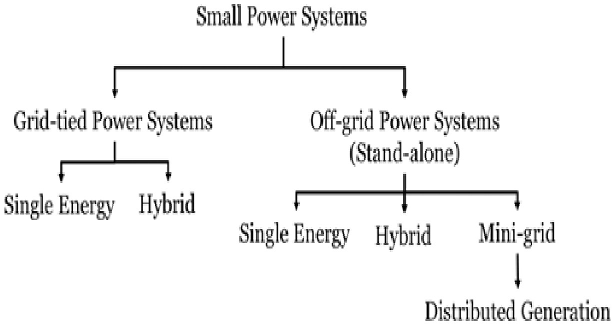

Fig. 6 Classification of small power systems based on grid connection

Solar panels convert solar energy from the sun directly into useable electrical energy. The world's largest individual PV power plants are Agua Caliente Solar Project (Arizona, USA) and California Valley Solar Ranch (USA). Both power plant produces more than 250MWP. [21 22] However because cost of solar panels are still high, their use are limited to less than 1 percent of electricity generation worldwide.

Because it cannot produce energy round the clock, there is always the need of storage devices like battery bank. Among systems installed in 2011, the median reported price was \$6.13/W for residential and small commercial systems up to 10kW, and \$4.87/W for commercial systems larger than 100kW.

PV energy systems are termed as one of the cost effective solutions to meet energy requirements of remote areas. Economic viability of hybrid PV system for decentralized power generation has been carried out and has proved its usefulness for small villages with up to 100 families.[23] Muselli et al.[24] studied on the system sizing of PV-hybrid system including a back-up conventional diesel generator. The starting and stopping thresholds of back-up generator were calculated with respect to battery nominal storage capacity. El-Hefnawi[25] used a mathematical technique using FORTRAN programming language to calculate minimum number of storage days and PV array area taking in consideration of pre-operating time of the diesel-generator for hybrid PV system. Shrestha and Goel[26] demonstrated a method to find optimal combination of PV array size and battery to meet the load. The load and insolation was found out using statistical models.

A closed form solution approach to the problem of evaluating loss of power supply probability (LPSP) of standalone PV battery hybrid system was proposed by Abouzahr & Ramakumar.[27] In iterative optimization technique of hybrid PV system, optimal mix can be decided on the basis of cost of electricity generated which is further justified on the basis of extension from the nearest power line, the tilt and azimuth angle. Performance of hybrid PV system is evaluated on the basis of reliability of power supply under widely varying load conditions. Egido and Lorenzo [28] reviewed methods for computing capacity of PV arrays and battery storage and suggested analytical model based on loss of load probability (LOLP). Ru et al. [29] determined the battery bank storage capacity in grid-connected PV system.

5.2 Wind System

Since early recorded history, people have been harnessing the energy of the wind. Earlier use of wind power were to propel the boat, pumping water or grinding grain. The first windmill used for the production of electricity was built in Scotland in July 1887 by Prof James Blyth of Anderson's College, Glasgow. Later in the winter of the same year Charles Brush was also credited with being the first person to use a wind powered machine to generate electricity in the US. [30] In order to use hybrid wind energy system effectively and economically, chosen site should have good potential of wind energy throughout the year. At present, wind power is harnessed with small and large wind turbines of various types and configurations. It is one of the fastest growing alternative energy source. Unlike solar power, it has longer operating time and can produce powers during cloudy days and night. Europe alone produces about 35,000 MW of electricity using wind power. The limitation is that, when wind does not blow, these wind turbines do not produce power. During such time to meet the demand other power sources are needed. Hence both wind and solar needs a storage devices to store surplus energy and use it when there is not enough power produced to meet the demand. In contrast, the comforting prospect is that people can generate their own energy to meet their daily energy demand by installing small solar and/or wind farm.

Feijoo et al. [31] used wind speed distribution (Rayleigh) and found out its impact on wind farms using Monte Carlo simulation. Li et al. [32] used regression and artificial neural network models for the estimation of wind turbine power curves. Salameh and Safari [33] studied the effect of the windmill's parameters on the capacity factor based on long term wind speed data. Capacity factor of wind turbine is one of the deciding parameters to choose a particular type of wind turbine at the selected site, as an essential component of hybrid wind system. The windmill with the highest average capacity factor has been recommended wherever possible. Boccard[34] studied the discrepancy of realized values and estimates of capacity factors. Celik[35,36]proposed a simplified algorithm to estimate yearly wind fraction based on the simulation results of 8 year, hour-by-hour wind speed data of five different locations.

The method requires Weibull wind speed distribution parameters on a monthly basis, the energy to load ratio and battery to load ratio and some model parameters as input.

A closed form solution approach for evaluating LPSP of stand-alone wind system with energy storage device was presented by Abouzahr & Ramakumar. [37] Karki and Billinton [38] presented a simulation technique generating probability indices using Monte Carlo simulation approach which helped determine appropriate wind power penetration in an existing power system considering economic and reliability aspect.

5.3 Hydro System

Water wheels are the predecessor of modern day turbine used to convert the hydraulic power into mechanical power and further into electrical power using generator. The evolution of the modern hydropower turbine began in the mid-1700s when a French hydraulic and military engineer, Bernard Forest de Bélidor wrote Architecture Hydraulique. [39] In 1880, a brush arc light dynamo driven by a water turbine was used to provide theatre and storefront lighting in Grand Rapids, Michigan; and in 1881, a brush dynamo connected to a turbine provided street lighting at Niagara Falls, New York. These two projects used direct-current technology. The world's first hydroelectric plant (1882) is located in Appleton, Wisconsin, which produces 12.5kW. World hydroelectric power generation has risen steadily by an average of 3 percent annually over the past four decades. In 2011, roughly 16 percent of global electricity has been provided by hydropower from over 160 countries. Countries like Norway, Paraguay, Ethiopia, Venezuela, Bhutan and Nepal get the greatest share of their electricity from hydropower. [40]

Unlike unpredictable and rapidly fluctuating solar and wind power, hydro power has a long seasonal cycle. The water flowing in the rivers and streams change slowly according to seasons of the year. Hence the need of energy storage device is not required. It was the most widely used form of renewable energy, accounting for 16 percent of global electricity generation in 2010.

5.4 Pico-hydro power

Pico hydro is the smallest hydropower plant [41, 42, 44, 47], with a capacity of less than 5 kW [100, 133–138]. Pico hydro is known as "family hydro" in some countries because they can be owned by a single household [42, 44, 47]. The simplicity of Pico hydro technology [70] has attracted the attention of many experts and even non-experts interested in generating electricity from renewable resources. Considerable attention has been given to Pico hydro technology because it is seen as a cost-effective and promising option for supplying electricity to rural areas [51, 52, 42, 56]. The Pico hydro scheme is the most cost-effective option among off-grid options (wind, PV, diesel generator, etc.) for rural electrification whenever a Pico hydro site is available [51]. The suitability of this technology should be urgently ascertained [52]. The following are the most famous Pico hydro turbines for off-grid electrification in rural areas: Pico Power Pack, Peltric turbine, low cost DC Pico hydro system, Stream Engine, Turgo turbine, Power Pal, axial and cross-flow turbines, and pumps as turbine.

The design of Pico turbines can hardly be modified to improve performance [51] because hydro technology is a rapidly maturing technology [44] and because hydro technology is one of the oldest energy sources known to mankind and the first one used to generate electricity [50] with an efficiency of up to 90% [71].

Schemes on making Pico turbines affordable should be made, such as offering long-term funds. Such schemes have been successful among low-income households.[45, 46,47,57,58,59,60] discussed the factors in the success of hydro Pico schemes for rural electrification in less developed countries and employed Pico in new applications or usages (e.g., an energy recovery device) [62,63].

Although the main users of this technology are low-income households, multimillion-dollar companies such as Motorola have found PV an attractive and interesting alternative to grid and other renewable options for wireless communication network base stations in remote areas [63]. Ref. [64] discovered an interesting application for pico turbines in utilizing the kinetic energy of the water that flows through domestic pipes and using it for battery recharging.

The main advantages of Pico hydro technology are sustain-ability, low maintenance and scheme cost (about half that of PV) [63], sharing [43, 44], flexible design, option for local manufacturing, and easy installation, operation, and maintenance [41, 46, 47]. As an energy-utilizing device [61, 62], Pico hydro is an environmental-friendly energy resource [65].

Pico hydro technology is similar to other renewable technologies in terms of site availability [51, 56, 66, 67]. Pico hydro technology requires more civil work than others, which is likely to increase the total cost of the scheme [71]. Despite the maturity and significant improvement of this technology, flow rate fluctuation is still one key challenge faced by hydro power systems in dry season (minimum power production) and monsoons (turbine shutdown to avoid being washed away) [68]. Given that hydro-electricity is mainly based on the head and flow of the site [16], room for upgrading the scheme rarely exists once the turbine is installed. As a result of flow rises and falls, power supply in many hydro sites cannot meet the yearly projected demand [16]. Combining the pico hydro with the hybrid system, which is another power generating source, can satisfy the intended demand and maintain power continuity all year long [16].

Pico hydro has a large potential global market in less developed countries, which is estimated to be around 4 million units [69]. Even in more developed countries such as Japan, considerable interest has been given to this technology because of high tariff and because this technology is considered an individual contribution to lessening climate change [70].

6. Hybrid Renewable Energy System (HRES)

The first village hybrid power systems consisting of PV and diesel generator was installed on December 16, 1978 in Papago Indian Village, Schuchuli, Arizona, USA. The power produced by the system was used for providing electricity for community refrigerator, washing machine, sewing machine, water pumps and lights until an electric grid was extended to the village in 1983.[35]

In recent years, more than one renewable form of energy are being used in HRES. Micro hydro power (MHP), PV and small Wind power sources with or without energy storage devices are widely used for providing electric power to consumers in remote areas. Different alternative energy resources have different production characteristics such as, water in river changes flow according to the seasons, the solar irradiation is greater in summer than winter and higher in day and non at night and similarly wind speed is greater in summer etc. This is why they are usually used in hybrid system configurations. Small hybrid system is best suited for off-grid electrification Fuel for HRES is abundant, free and inexhaustible hence electric energy produced by these system is independent of fuel price Standalone commercial PV or wind systems do not produce power round the clock and throughout the year. Combining PV and wind has the benefit of reduced battery bank capacity and diesel requirements (in case it has conventional generator as back up) among other benefits. However, for better performance of hybrid PV-Wind system, good potential of solar irradiation as well as wind energy is a must at the site. Factors like environmental factors, PV capacity (the number of PV panel), wind generator capacity (the size of wind generator), storage device capacity (the number of battery), generation site (distance between power plant and consumer), etc. play an important role in operation, maintenance and cost of the hybrid PV/wind diesel system. Nehrir et al.,[36]reported the evaluation of general performance of stand-alone hybrid PV/wind system using computer-modeling approach (MATLAB/Simulink).

Lim[37]presented a method to design the optimal combination and unit sizing for wind-PV and tide hybrid system. Notton et al.,[38]presented a mathematical model for sizing hybrid PV system on the basis of LOLP. The authors have highlighted that the optimal solution can be obtained if PV contributed for 75% of the energy requirements. Elhadidy and Shaahid[39] analyzed hybrid system consisting PV, wind, diesel generator with battery backup in hybrid energy system. They studied the impact of variation of PV array area, number of wind generator and battery storage capacity of HRES. Chedid et al.[40] proposed decision support technique for policy maker about the influencing factors in the design of grid linked hybrid PV-wind power system. They used analytic hierarchy process (AHP) to quantify various parameters that lead to confusion in planning hybrid system. Their study was based on political, social, technical, and economical issues.

The block diagram of a stand-alone hybrid MHP-PV-WG is shown

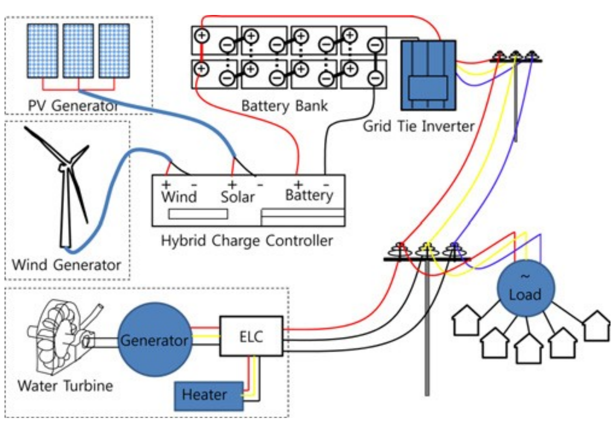

Fig. 8 Schematic diagram of typical hybrid micro hydro power (MHP)-PV-Wind systems

In Fig. 8. A hybrid charge controller is used to connect two power sources (PV-WG). Depending on the load the excess power is used to charge the battery bank. The battery bank is used to store the surplus energy and to supply the power to the load in case of insufficient power generation from the hybrid system. The inverter (DC/AC) is required to change the DC voltage to AC voltage to meet the consumer load demand. The outputs of all battery chargers, the battery bank and the DC/AC converter input terminals are connected in parallel. The instantaneous change in solar irradiation and wind speed characteristics highly influences the energy production thus a careful design is needed for hybrid system for reliable power supply to the consumers under varying atmospheric condition. In the same way a careful design should be made to keep the system cost low.

7. Future of Hybrid Renewable Energy Systems

Over 1 billion people still lack access to electricity. The United Nations General Assembly declared the decade 2014-2024 as the Decade of Sustainable Energy for All, underscoring the importance of energy issues for sustainable development and for the elaboration of the post-2015 development agenda.[41] In a distributed hybrid systems, power is produced at or close to the point of use. Distributed energy systems avoid the costs and losses of transmission and distribution. Therefore, there is need to identify locations for installing PV and wind energy systems and their interconnections with the utility grid, in order to minimize the cost of electricity without disturbing the existing network.

Renewables play a major role in the energy demand in many countries around the world. In recent years, prices of renewable energy technologies, primarily wind and solar continues to fall, making renewable increasingly competitive with the other conventional energy technologies.

Two most important concerns for any hybrid systems are the system's power reliability during varying environmental condition and the overall cost of the system. Most of the authors tried to optimize either or both of it. A detail bubble diagram of the scope of the paper is shown in Fig. 9

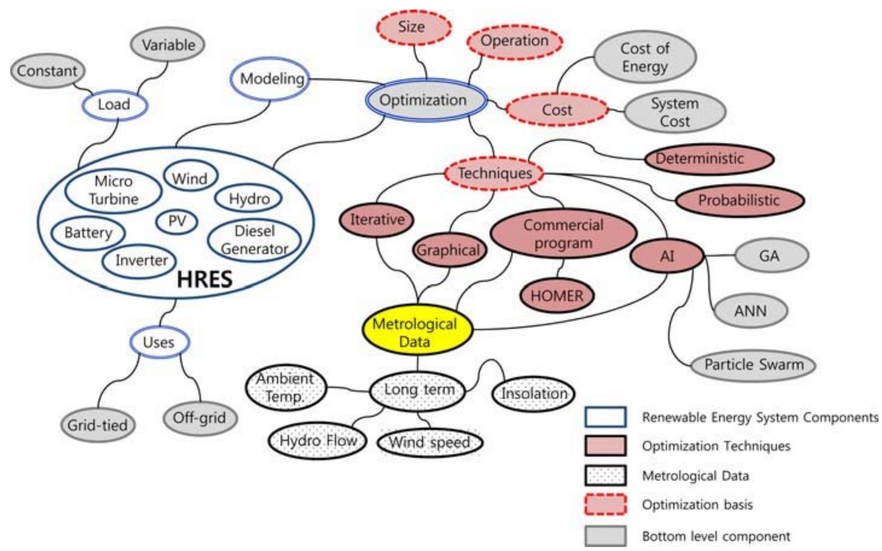

Fig. 9 A scope diagram showing the coverage of this review paper

Conclusion

Rural areas suffer from energy poverty and lack of human and economic development. Renewable energy, such as Pico hydro-power, solar PV, and wind turbines, is the most promising option for feasible, sustainable decentralized rural electrification generation systems, particularly in rural areas with massive renewable energy resources. This option should be considered because of the high cost of grid electricity and transportation cost of fossil fuel to remote areas (along with increased fuel market prices), as well as the environmental concern about the exhaust of burning fossil fuel. Provision of affordable electricity to remote households is an essential aspect of human and economic development in rural areas worldwide and an obligation of governments toward their citizens. For many developing countries, this obligation is a huge challenge because of their weak economy, which is a key barrier to rural electrification. Thus, developed countries should not be perplexed in assisting less developed countries in their renewable resource-based because low-income households in these countries need merely a few watts for their daily energy demand. According to the availability of electricity generation resources in rural areas and to the selection criteria of feasibility and sustainability, Pico hydro is the top choice of rural households, followed by wind, PV, and diesel-fueled generators. Although Pico is the most cost-effective option, PV is the most dominant renewable energy technology for rural electrification because of the availability of solar energy resource all over the world.

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