Distributed Generation in Developing Countries

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Introduction

In developing countries around the world, more than 2 billion people lack access to electricity. Distributed generation represents an opportunity to quickly increase the quality of life for these individuals. Distributed generation for on-site power offers several advantages when compared to centralized, conventional models for power generation. This paper discusses the relevant issues and aims at illuminating the opportunities when distributed generation should be the preferred source of power.

Distributed generation, or DG, includes the application of small generators, typically ranging in capacity from 5kW to 10MW, at or near to the end-user to provide the electric power needed. As applied in this paper, DG includes the complete power generation and distribution system for small villages. This includes generation, energy storage, on-site management (i.e., dispatch, control, communications), and all ancillary devices and services.

The bulk of the DG equipment today is reciprocating engines that can run on various fuels but most often are run on diesel fuel. Although relatively inexpensive and readily available from multiple suppliers, these small reciprocating engine generators are generally considered degrading to the environment (high greenhouse gas emissions and noise levels), and they have high maintenance requirements. The expectations are that emerging technologies will play a significant future role in DG especially with regard to village electrification. Microturbines, fuel cells, solar, and wind-powered generation are all now in the early commercial or field-prototype stage. These technologies were originally developed for defense and non-polluting transportation applications. The stationary power market appears to be the first large-scale commercial opportunity for these devices.

Distributed generation plants are increasing their popularity around the world, and village power electrification programs are widespread throughout Africa, Asia, and South America. More than $30 billion per year is spent on home heating fuels, batteries and candles in rural parts of the world, along with annual investments in 10-15 GW of diesel generation capacity. [1] DG aims to capture a large fraction of this rural market. Table 1 shows the forecasted annual installed MW for prime power applications (stand-by or emergency power applications are not included). The significant annual growth of 16% is very attractive to the developers of distributed generation equipment, and there is significant investment in these technologies.

Value of Distributed Generation

Where there is no power, any source of power generation is, of course, of significant value to the end-user, to the regional government, and to the prospective energy service company. However, from the electricity industry perspective, distributed generation is attractive because it has multiple other values. These values include the following:

- The generator can be sited close to the end-user, thus decreasing transmission and distribution costs and electrical losses.
- Sites for small generators are easier to find.
- Distributed generators offer reduced planning and installation time.

- Because the DG units are distributed, the “system” may be more reliable. One unit can be removed for maintenance or service with only a moderate effect on the rest of the power distribution system. This is especially important for new technologies where the long-term reliability is not proven.
- Newer distributed generation technologies offer an environmentally clean and low noise source of power.
- Newer distributed generators can run on multiple types of fuels. This allows flexibility and reduction in cost of the infrastructure required to get the fuel to the generator. The preferred fuel source differs in various parts of the world. However, the required quality of the selected fuel may be more important with certain new DG technologies.
- Newer distributed generators can run on fuels generated from biogasification. Biomass (e.g., wood, hog waste, agricultural byproducts) is a truly renewable source of fuel in most developing countries and especially in agricultural regions.

From the end-user perspective, distributed generation is also attractive for several reasons.

- Power is readily available and the power has improved quality and reliability over power produced from central generating stations.
- Depending on the nature of fuel used, electricity prices are often lower than power from central plants.
- Some DG technologies provide cogeneration possibilities, which allow site recovery of heat and / or hot water. This has the potential to raise energy efficiency to around 90%. In rural villages, the recovered heat can be used for hot water, space heating, industrial processes and even space cooling (adsorption air conditioners).

The above advantages of DG can be realized as a result of technical improvements in the development of small-scale electricity generators. The specific details are provided in a following section.

Comparison with Conventional Central Generation

The bulk of electric power now used worldwide is produced by central station power plants, most of them using large, fossil-fired combination or nuclear boilers to produce steam that drives steam turbine generators. A majority of these plants are greater than 100 MW making them relatively large in both physical size and facilities requirements, and often making site selection and procurement a real challenge. These large plants also need a significant infrastructure both to get fuel and supplies to the plant and for transmitting and distributing the power once it is generated. One can make a comparison of DG with central generation on two levels: (1) new installations, (2) incremental capacity additions.

For new installations the most direct comparison between DG and central generation is by efficiency. The plant efficiency of existing large central generation units could be in the 28-35% range depending on the age of the plant. This means that they convert between 28-35% of the energy in their fuel into useful electric power. By contrast, efficiencies of 40-50% are attributed to small fuel cells and to various new gas turbine and combined cycle units suitable for DG applications. Certain novel technologies, such as a fuel cell / gas turbine hybrid, is claimed to offer electrical efficiencies about 70%. Of course, these claims still need to be proven with full size pre-production and production units.

Perhaps one of the most important values provided by DG is the short time in which a system can be installed. As Figure 1 shows, the elapsed time for most DG projects is significantly less than that for coal and gas plants. Speed of implementation and the modular nature of this technology allow developing countries to efficiently invest in power generation as the population grows.

Typical large central plants must be over-designed to allow for future capacity and consequently they run most of their life in a very inefficient manner.

A transmission and distribution infrastructure represents a significant cost in initial capital and continuing operations and maintenance. A DG unit does not have this T&D burden because it is already at the site of electrical use. In addition the T&D infrastructure is often responsible for a good deal of the service reliability problems experienced by electrical users. By avoiding those costs and reliability problems, DG can provide better service at lower cost in many applications. The effect of the T&D infrastructure on the price of electricity to users along the system is illustrated in Figure 2. Purchase of electricity is less expensive the nearer you are to the source of generation. With DG, the electricity user is at the source of generation.

One of the fundamental factors considering the design of conventional T&D systems is that it costs more to upgrade most facilities to a high capacity than it does to build that capacity in the original construction. This factor contributes to generation and T&D infrastructure being built with considerable margin (50%) above existing load to allow for growth.

The very high cost per kW for upgrading a T&D system (Table 2) creates one of the best perceived opportunities for DG applications. Thus, planners often look at areas of the system where slow, continuing load growth has increased load to the point that local delivery facilities are considerably taxed as areas where DG can deliver significant savings. Note that in rural or developing countries the incremental T&D expansion cost is greatest due to the dispersion of the load.

Distributed Generation and Related Technologies

The newly developed DG systems typically range from 5kW to 5 MW, have a foot print size of between 0.01 and 59 kW / square meter, have capital costs ranging from $200 to $6000 / kW, and are capable of producing electricity in the 3-20¢ / kWh range. These characteristics are ideal for distributed power generation systems. Table 3 provides important technical parameters of distributed generation technologies that are now commercially available. This section offers a short description of the most promising DG technologies for application in developing countries.

<u>Microturbines</u>

Microturbines operate on the same principles as traditional gas turbines. Air is drawn into the compressor where it is pressurized and forced into the cold side of the recuperator. Here, exhaust heat is used to preheat the air before it enters the combustion chamber. The combustion chamber then mixes the heated air with fuel and burns it. This mixture expands through the turbine, which drives the compressor and generator (typically at high speeds such as 70,000 to 120,000 RPM). Since the generator is mounted on the same shaft as the turbine, it rotates at the same speed. The combusted air is then exhausted through the recuperator before being discharged at the exhaust outlet.

The generator thus produces high frequency AC power that is converted to 50/60Hz by power electronics. Typical power ratings range from 25 – 500 kW although multiple units may be directly interconnected to provide up to 10 MW. Typical capital costs are in the 500-1000 $/kW range and electrical efficiencies range from 27-32%. Utilising the exhaust heat can improve the overall efficiency up to 80%. Footprint size is in the 60 kW/m^2 area, operating costs (i.e., cost to produce electricity) are estimated between 6 and 8 ¢ / kWh and NOx emissions are around 0.1 lb / BTU. Typically, micro-turbines use natural gas as fuel, but other fuels such as diesel, propane, and kerosene are possible. Flare gas from well heads has even been used as a source of fuel. However, the quality of the fuel (particulates, etc.) must be controlled due to the narrow paths within the turbine.

Fuel Cells

Fuel cells are electric batteries able to convert hydrogen and oxygen into electricity, heat and water. Fuel cells are similar to batteries in that they both use an electrochemical process to produce a DC current. Both batteries and fuel cells consist of two electrodes separated by an electrolyte. Unlike batteries, fuel cells electrochemically convert the energy in a hydrogen-rich fuel directly into electricity and operate as long as the fuel stream lasts.

Fuel cells are characterized by the type of electrolyte used; examples include alkaline, proton exchange membrane, phosphoric acid, molten carbonate and solid oxide. Depending on the electrolyte the fuel cell operates between 80 and 1000°C, ignoring this produced heat fuel cell efficiency can range between 35-65%. Utilizing the produced heat can raise the efficiency to over 80%. Target capital costs (assuming large volume manufacturing) range from 800-1300 $ / kW and footprint size ranges from 1-3 kW/m^2. Operating costs are estimated at between 8-10 ¢ / kWh and emissions of NOx gasses are extremely low at 0.003-0.03 lb / BTU.

Fuel cells are typically aimed at single installation sites (i.e., one bank of fuel cells) that require between 50 and 1000 kW, e.g., high rise office buildings, hospitals, schools, hotels, restaurants, etc. However, new small fuel cell developers (e.g., Plug Power and Ballard) who were previously aiming at the transportation markets see residential generation at about 5-10 kW power rating as a lucrative market

Wind Power

Windmills or wind energy converters convert wind power to electrical power. Typical systems range from 30 kW for individual units to 1.5 MW for wind farms of multiple units. Hub-heights are around 80 meters, and rotor diameters are 65 m. Rotor construction is either variable blade angle (pitch regulation) or non-variable, conversion from mechanical to electrical energy is via either synchronous or induction generators. Synchronous generators are usually equipped with pulse width modulated converters, control of these converters is essential for regulating the behaviour of the windmill on the electric grid. Windmills are often installed in groups, or wind farms, and are seldom used in isolation. Techniques for using HVDC links to connect wind farms to transmission grids are being investigated. A disadvantage of wind power is its irregularity; this further complicates connection to power grids.

Typical costs are around 1000 $ / kW, and electrical efficiencies around 25%. However, it must be noted that efficiency should not be compared with fuel cell or micro-turbine efficiency due to the renewable fuel source. Footprint sizes are in the order of 0.01 kW/m^2 and operating costs between 4 and 12 ¢ / kWh.

Solar Power

Conversion of solar energy to electrical energy has been technically possible since the late 1930's. The main difficulty is the high cost of photovoltaic systems, 6000 $ / kW is typical. Additionally the power output is directly proportional to the surface area of the cells and footprint sizes are hence relatively large (0.02 kW/m^2). As with windmills the electrical efficiency is relatively low (6-20%) but should not be compared with non-renewable systems. Operating costs are estimated at 18 – 20 ¢ / kWh.

Typical applications of photovoltaic cells include small installations of < 10 kW on building rooftops or remote systems that can not be connected to the electricity grid. There are, however, programs to test larger capacity systems, e.g., 1 MW EU Joule program in Spain. When connected to the grid, the connection is usually made through an inverter and the grid accepts all power from the photovoltaic system. Energy storage is often required for periods when there is no wind. The cost of the energy storage component could be significant.

Reciprocating Engines

Use of diesel and petrol engines to provide standby power for commercial and small industrial customers is not new. Recently engines operating on natural gas have been developed. Typical efficiencies range from 33 to 36% and capacities from 50 kW to 6 MW. Costs are in the 200-350 $ / kW range and footprint sizes are in the order of 50 kW/m^2. Operating costs are estimated at 6 – 9 ¢ / kWh and NOx emissions are around 0.3 lb / BTU. Disadvantages of combustion engines are pollution (both emissions and noise) and relatively high maintenance and operation costs. Previously these systems were connected to the electricity grid for standby power only, studies show that conversion to peak shaving or base loads require new designs and power conversion systems than conventionally used for emergency power generators. These newer systems are now coming onto the market from several suppliers.

Hydroelectric Power

Small hydroelectric plants are fairly common, being actively manufactured and installed in more than 100 countries. The smaller size plants include microhydro (<100 kW) and minihydro (100 kW to 1 MW). Typically plants less than 100 kW use an induction generator to generate the electricity. Plants larger than 100 kW can use either induction or synchronous generators depending on design and cost analysis. Many of these smaller plants do not include a dam, but they are run by a flowing river or stream. They are then dependent on the variation of water flow in the river than those with a storage reservoir.

Hybrid Power

The term hybrid power is used to describe any power system with more than one type of generator. Hybrid power systems usually consist of a conventional generator powered by a diesel or gas engine / turbine and a renewable energy source such as solar, wind, or hydroelectric. Batteries are often included in conventional hybrid systems.

There are several of these systems in use today for village electrification. The hybrid sources can be installed on a microgrid or in a single site. For example, a single residence may have several photovoltaic modules added to an existing genset to reduce the noise and inconvenience of having the generator running all the time. The advantage of a hybrid system is that one can exploit the strong points of multiple technologies and design a system that is close to optimal in both performance and cost. The main disadvantage is the capital cost usually resulting form the high cost of solar and the maintenance cost of batteries.

Microgrids

Microgrids are small electrical distribution systems that connect multiple customers to multiple sources of generation and storage. Microgrids are typically characterized by multipurpose electrical power service to communities with populations ranging up to 500 households with overall energy demand ranging up to several thousand kWh per day. The primary advantage of the microgrid is that reliability is greatly improved by having multiple sources of generation connected to the user. The primary drawback of course is the cost of the distribution or interconnection system and the need for control and dispatch on a system level.

Other Enabling Technologies

It is not enough to develop a DG system that only produces electric power. A fully automated DG system that requires little or no human intervention is ideal. Technologies bundled into the DG system, therefore, should include interfaces for connection to local supervisory control and data acquisition (SCADA), distributed control systems (DCS) and or Internet / Intranet systems. Other technologies that are necessary for a complete DG system may include developments in:

- Metering
- Protection and control
- Remote monitoring and fault diagnosis
- Automated dispatch and control
- Site optimization of electrical / thermal outputs.

Examples of Distributed Generation Systems

There are examples of distributed generation systems in dozens of developing countries. These systems use all of the generation technology options listed above. Although the primary source of power is reciprocating engines fueled by diesel fuel or natural gas, renewable energy sources (e.g., solar, wind, hydroelectric) have surged because of advances in technology and reduction in costs. For example, the explosive growth of photovoltaics in the developing world has driven down PV costs, as manufacturers take advantage of the economies of mass production.

An excellent example of the focus on distributed generation is in South Africa. Approximately 20% of South Africa's rural population is not expected to get utility grid electricity for at least the next 20 years. The South African government recognizes the importance of distributed generation and renewable energy technologies and has approved the use of photovoltaic systems for the electrification of 2000 clinics and 16,800 schools. Photovoltaic systems are eventually expected to electrify an estimated 2.5 million homes and 100,000 small businesses in a comprehensive South African grid electrification program. [6]

Other examples of distributed generation show the emphasis by governments to provide electric power to remote communities.

- In India, the government plans to electrify 100,000 villages with renewable energy and install solar powered telephones in every one of the nations 500,000 villages.
- Mexico plans to electrify 60,000 villages using photovoltaics by the year 2000.
- In Zaire, several major hospitals depend on photovoltaic solar energy.
- In Mongolia, the government plans the distribution of 240 small wind / photovoltaic systems for household use as the first phase in a larger implementation plan.
- In Nepal, 1500 photovoltaic systems have been installed and are currently supplying village homes.
- Villages on islands in the Caribbean and Mediterranean are looking at distributed generation to provide the power required to desalinated drinking water for drinking.

An extensive database on distributed power for village applications is located on the Renewables for Sustainable Village Power (RSVP) World Wide Web site at http://www.revp.nrel.gov. The information contained at this site is updated to maintain its usefulness and to help develop and foster village power projects throughout the world. The database contains more than 140 international village power projects from more than 20 countries. It is searchable by technology, application, sector (e.g., residential, commercial), and geographical region.

Management of Distributed Generation Systems

The management of distributed generation systems will depend on the nature of the application, the dispersion of the generation sources, the type of generation used, and whether the sources are attached in a microgrid or individually to only the end-user.

Small scale distributed generation systems are mainly designed to operate independently. For example, most wind turbine operation systems will stop power production automatically as soon as frequency or voltage of the grid is below or above certain thresholds. The nature of the management system will greatly depend on whether the generators are dispatchable or non-dispatchable. Dispatchable units such as gensets, fuel cells, and microturbines, can be controlled by a central intelligence and relied on to generate according to the needs of the power system. Non-dispatchable technologies generate not as a function of power system needs, but rather as a function of intermittent availability of their energy source. Most renewable energy systems (e.g., wind and solar) are non-dispatchable.

The fact that non-dispatchable technologies cannot be controlled or dispatched by central control has made them historically less popular and less understood than other technologies. However, with the advent of "hybrid" systems the time that the renewable power generation is unavailable is replaced by dispatchable generation. This seems to offer the most promise when considering the multiple needs of environment, system performance, and overall cost.

One of the primary elements in a distributed generation management system is the dispatch strategy: the aspect of control strategy that pertains to the sources and destinations of energy flows. Existing systems models offer limited choices of component configuration and of dispatch strategy, and therefore have limited ability to determine optimal systems designs. However, an idealized predictive dispatch strategy based on assumed knowledge of future loads and power availability is being developed through analytical modeling. Such advanced modeling tools are currently being developed by the University of Massachusetts and NREL. With these models, various types of generation, energy storage, and load characteristics can be analyzed to determine the optimal system and dispatch methodology.

Key Considerations in Comparing Distributed and Central Generation

The results of any DG evaluation study are dependent on both the actual situation, including location, layout, type of demands, economic factors and on the scope of the planning methods available. Several "rules of thumb" are useful in determining when DG will be economically attractive over central generation. [5]

- The cost of delivering energy to an area, in one for or another, is a major factor in the total cost of electricity, and often the determiner of which option "wins" in the planning for a developing region.
- The larger the scale (greater the number of customer sites), the more economically viable various infrastructure-intensive solution, like tradition electric systems or DG in combinations with a significant distribution system, will be relative to other options.
- The higher the load density, the more economically viable various infrastructure-intensive solutions, like traditional electric systems or DG in combination with a significant distribution system will be relative to other options.
- Assumptions about the level and change over time in the cost of fuel can make a tremendous deference in the computed cost of a fossil fuel operation.
- "Traditional" types of electric system alternatives tend to have a economic advantage when the location is close to existing electrical facilities; the situation involves a large customer base; or per capita consumption is high.
- Dispersed DG tends to have the economic advantage only when customer locations are very remote or expensive to reach; the number of customers is quite small and they are far apart; and / or per capita usage is very low.

Conclusion

Without energy, there can be little economic development, clean water, refrigerated foods and medicines, no telephones, radios, televisions, or the most basic forms of sustainability. Many rural areas are too remote or too poor to support energy systems that are connected to the electricity grid. Many developing countries face population growth that far exceeds planned rates of grid connection, so that many will either remain without energy, or be forced to migrate to urban areas where the infrastructure is already over burdened.

Developing countries are expected to account for over half of the increase in global energy consumption during the next 30 years. The demands of industry and a growing population put tremendous pressure on leaders to raise the standard of living in villages. New distributed generation technologies, using small scale generators near to the end-user of electricity, may offer a lower cost, environmentally kind alternative to traditional central power plants and associated transmission and distribution infrastructure.

Distributed generation could be a reasonable alternative for electric power needs in remote or sparsely populated situations such as villages in developing countries. In rural areas where electric service points are far apart, even a power distribution system of modest capacity will cost a great deal. By contrast, DG placed at just a few sites, as needed, can be less than half the total cost of more traditional power systems. Fuel delivery may be a problem in developing countries, but where it is truly burdensome, power generation from renewable resources may be justifiable.

References

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Table 1 Total Installed Annual MW for Prime Power Applications (Stand-by Power Applications not Included). [2]

	Site Size	1996	2000	2005	2010
Market Worldwide	0.3 - 5 MW	10,267	12,092	14,942	18,592
	< 0.3 MW	2,080	2,433	2,960	3,602
North American Market	0.3 - 5 MW	1,180	1,301	1,468	1,658
	< 0.3 MW	79	96	122	156

Table 2 Incremental T&D Expansion Cost in $ / kW of New Peak Load for Several Electric Utility Systems. [5]

Utility	Low	High
United States - Northeast	166	925
United States - Southeast	45	729
United States - Central Plains	82	336
United States - West Coast	64	610
Central America - Urban System	51	300
Central America - Rural System	51	920
South America - Urban System	129	438
Caribbean	65	518
Europe - North Central Urban System	290	846
Southeast Asia - Urban System	29	400
Southeast Asia - Rural System	40	2000

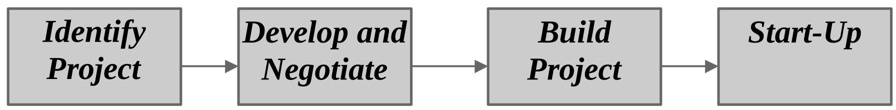
Table 3 Distributed Generation Technology Options.

	Engine Generator	**Gas Turbine Generator**	**Microturbine Generator**	**Photo-voltaics**	**Wind Turbine**	**Fuel Cells**
Dispatchable	Yes	Yes	Yes	--	--	Yes
Fuel	Diesel or Gas	Gas	Multiple Gas or Liquids	Sun	Wind	Gas
Efficiency, % (1)	35	29-42	27-32	6-19	25	40-57
Energy Density, kW/m2	50	59	59	0.02	0.01	1 - 3
Capital Cost, $/kW	200-350	450-870	500-1000 (500 in 2001)	6600	1000	3000 (1000 expected when fully commercialized)
O&M Cost, $/kWh (2)	0.01	0.005-0.0065	0.005-0.0065	0.001-0.004	0.01	0.0017
Electrical Energy Cost, $/kWh (3)	0.07-0.09	0.06-0.08	0.06-0.08	0.18-0.20	0.03-0.04	0.06-0.08
Energy Storage Required	No	No	No	Yes	Yes	No
NOx (lb/BTU)						
• **Nat Gas**	0.3	0.01	0.01	N/A	N/A	0.003-0.02
• **Oil**	3.7	0.17	0.17	N/A	N/A	--
Heat Rates, Mills BTU/kWh	10-15	5-10	5-10	N/A	N/A	5-10
Expected Operating Life, Hrs.	40,000	40,000	40,000	--	--	10,000-40,000
Technology Status	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial in 2001

Notes:

1. Efficiencies of renewable energy technologies should not be compared directly with those of fossil fuel technologies since the fuel is limited.
2. O&M costs exclude cost of fuel. There are no fuel costs for wind systems or photovoltaics.
3. Natural gas fuel is used for calculating energy costs except for wind and solar power.

Figure 1 Development time for various power plant projects. [3]



<u>Total Elapsed Time</u>

- Coal IPP 5-7 years
- Large Gas IPP 3-5 years
- Distributed Generation 6-18 months

Figure 2 Electric power costs less if bought from the system closer to the generating plant. Prices shown correspond to price per kWh paid by a user of electricity at the site shown. [4]