

DISTRIBUTED GENERATION SYSTEMS: A NEW PARADIGM FOR SUSTAINABLE ENERGY

Janet Marsden, *Member, IEEE*

Abstract — The great challenge for designing and developing sustainable alternative energy infrastructure is in essence the same as for maintaining our present infrastructure: How can we best solve the problems of delivering energy when and where it is needed? This involves rethinking supply and demand, load balancing, and energy sourcing paradigms with a view toward local production utilizing next generation technologies. Exploiting distributed generation means designing hybrid systems based on site-specific conditions; using new technologies to leverage traditional energy sources; and minimizing transmission and distribution costs – particularly the losses associated with long-distance transmission. Load balancing in particular becomes far more tractable when viewed as a local problem of matching energy supply and demand. Looking at modern network technologies as the models for creating a new generation of energy delivery systems provides insights into how local energy production systems can be scaled up to internetworked production systems that leverage alternative energy generation based on local and sustainable resources together with traditional large scale generation. As smart grid development advances, network theory and technology provides a new model for energy systems based on a multi-dimensional energy production network rather than the outmoded single-direction, source-to-consumption model we now have.

Index Terms — alternative energy, green technology, sustainable energy, distributed generation, complex systems.

I. INTRODUCTION

AS the US addresses the challenges of achieving energy sustainability in the 21st century, the recognition of the need to find alternatives to current practices has been stymied by the identification of many complexities: including matching supply and demand, the scale of current and projected needs, and the difficulty of replacing the present unidirectional system with far more complex hybrid systems utilizing disparate sources and supplies of energy. One of the major challenges is designing new systems that leverage existing infrastructure based on centralized generation to take advantage of alternative sources at a local level. The examination of past energy technology practices at historic sites can provide us with some lessons for new system designs that integrate centralized generation with local resources, and match distributed demand with local supply. The rationale for this

research is the need we are faced with to identify and utilize alternative energy resources.

Obviously, there are energy sources and practices from the past that we would not want to return to, such as using horses as beasts of burden or clearcutting forests for wood to burn. But our ancestors showed considerable ingenuity in utilizing local, sustainable energy sources; such as running mills and factories using hydraulic power from local rivers and creeks, and windmills to pump water and grind grain. Because they were faced with limitations of time and distance, past generations approached energy production as a decentralized problem based on local resources. The objective of energy sustainability can be approached today in the way it was in the past: as a site specific problem of achieving minimal or zero net demand. By applying modern technology and ecological knowledge, we can utilize local resources in a way that causes little or no environmental damage.

During the 20th century, local onsite power production was gradually abandoned in favor of ever larger and more centralized energy production. These massive centralized systems have become more and more difficult and expensive to manage effectively and sustainably. After first exploiting many hydropower resources through dams and impoundments in the early part of the century, and depleting most domestic supplies of petroleum in the mid-20th century, the US became increasingly dependent on foreign supplies of fossil fuels to move our vehicles and power our industries. As long as these resources were cheap and plentiful, it made sense to shift our means of production away from local resources. But now we are faced with the dilemma of declining production and supplies which are slated to become ever more scarce and expensive. It is time for us to reacquaint ourselves with local energy production, and educate ourselves about reducing our demand for offsite energy by meeting as much of the need as possible using onsite energy sources.

The great benefit of rediscovering these local energy resources is the potential to create facilities that meet all or a large part of their own energy needs without requiring long distance energy transmission. Local energy production reduces waste by lessening dependence on the infrastructure of large power plants and distribution systems which are notoriously inefficient. Pollution related to current energy production and usage can be reduced as well. For example, there are dozens if not hundreds of abandoned hydropower facilities all over the US that

formerly provided energy for agricultural production, manufacturing and transportation 50, 100 or more years ago. They were abandoned because of the development of centralized power production, mainly powered by fossil and nuclear fuels, but many of them could be viable again.

Understanding what types of energy were important and how those energy resources were used during the last 150 years can help us develop a truly sustainable approach to modern living that is far less dependent on foreign imports. Our ancestors were limited by distance and time. They were forced to use what was at hand. They were creative, inventive and successful. We can learn from their example and see our energy resources with a fresh eye by looking at these past approaches to solving energy challenges. In addition, this new approach represents the birth of a US energy industry that will provide thousands of local jobs that cannot be outsourced, because the systems that will be designed, installed and maintained will be generating power from local sources. Local power supplies also mean an improved manufacturing and industrial business environment.

II. DISTRIBUTED GENERATION AND SUSTAINABILITY

According to the US Department of Energy (USDoE), transmission and distribution losses associated with the delivery of electricity for residential, commercial, and industrial consumption accounts for 7% of gross generation, or 246 B kilowatt hours in 2009 (Fig.8.1 [1]). This figure alone makes a strong case for local energy production to minimize these losses. However, transportation represents 29% (Fig. 2.1a [2]) of US total energy consumption, and virtually all of this consumption is petroleum based (Fig.2.1b [3]). As we make the transition to electric vehicles, their fueling will become part of the electricity generation infrastructure, thereby adding significantly to the transmission and distribution costs of centralized generation.

The US Green Building Council, the developers of the Leadership in Energy and Environmental Design (LEED) program, although they are steadily improving, have not reached the level of understanding buildings as energy production systems, and facilities management as systems design and management [4].

What opportunities are available? How can we utilize our resources more efficiently? For distributed generation, the first consideration is identifying major local energy resources.

A. Hydropower

According to the US Environmental Protection Agency (US EPA) water resources are concentrated in the eastern half of the US (mainly east of the Mississippi) and around the Great Lakes [5]. There are also considerable water resources in the Pacific Northwest [5]. Despite the many advantages of hydropower, there have been very few new US hydropower projects in the last 20 years, plus many hydropower plants have been unable to renew their licenses due to issues such as environmental impacts on fisheries, and increased demand for recreational access.

However, utilizing 21st century hydropower technology can make tremendous new hydropower capacity available. The

World Energy Council estimates 2000GW per year from ocean waves alone, with little environmental impact [6]. Next generation kinetic energy turbines such as the Wave Energy Converter developed by Oceanlinx of Australia are modular, scalable and can be deployed in arrays to serve residential, commercial, industrial, municipal or even regional needs [6]. These generators do not require dams or impoundments because they utilize the kinetic energy of water motion, either waves or flow. Permitting is simplified and streamlined because shoreline or benthic construction is not required. Floating arrays can be tethered or moored and can take advantage of existing retaining walls, docks, piers, bridge abutments, or similar structures. Haulout of individual units for maintenance or replacement is also relatively easy. Aesthetically, these units are low profile and do not obstruct viewsheds. In addition to their potential for rivers, lakes and streams, they offer new near offshore power production potential for the Great Lakes, the Gulf of Mexico, the Eastern Seaboard, and the Pacific coast regions. They can be scaled up or down in size to fit the volumes and flow characteristics of the waterways where they will be installed. Installed as integral components of storm water management systems, they can also take advantage of storm events for energy generation.

B. Wind Power

Based on US DoE estimates [7], the mid-section of the US, where there is little hydropower potential, is the best place for wind production. Just as the best places for hydropower production are not the only places where hydropower can be developed, other locations besides the Midwest have potential for wind production. However, the focus for the Midwest region should be on wind development. Although large, horizontal axis wind turbines in large-scale wind farms have been the model for centralized wind energy production, for distributed generation, smaller vertical axis windmills make more sense. They are less expensive, safer, and easier to install, especially for residential and commercial applications. With the ability to accept wind from any direction without needing reorientation, they may be slightly less cost effective on a large scale, but are safer and more reliable in terms of regular supply for distributed generation aimed at net zero demand. In addition, wind power is an important component of a balanced supply system because wind supply complements solar production in the diurnal and seasonal cycles. Finally, large horizontal axis wind farms are not feasible for urban settings, but vertical axis wind generators installed on tall buildings can take advantage of the well-documented urban heat island effect and the height of existing urban infrastructure, thereby minimizing installation costs.

C. Solar Power

Although the sun is available everywhere, according to US DoE estimates the greatest potential for solar photovoltaics (PV) exists in the US southwest [8]. New technologies such as PV coatings makes solar energy a good source for distributed electricity generation even in areas where cloud cover makes solar a less than ideal energy source. PV coatings offer tremendous potential in urban locations where tall buildings have many square feet of roof and south-facing facades. As an

integrated component of a building's energy systems, solar can take advantage of the lofty construction that already exists in urban areas. The many tall buildings and flat roofs in cities are ideal locations for solar PV installations utilizing high tech PV sheaths. The coatings can transform any building surface exposed to the sun into an electricity generation location. Light colored or white PV coatings offer further benefit by minimizing the heat island effect to minimize cooling costs while generating electricity.

D. Geothermal Energy

The use of geothermal energy is often overlooked, but is an important part of a comprehensive distributed energy strategy. Every energy conversion results in energy losses, so matching energy types to needs is sound energy strategy. There are two types of geothermal energy, active (volcanic) and ground source. The more limited type is the volcanic type that has been utilized extensively in places like Reykjavik, Iceland for heating and electricity generation. There are considerable geothermal resources of this type in the US southwest [9]. The other type is groundsource geothermal, which simply takes advantage of the constant temperature of around 55°F that exists underground from a depth of 3-5 feet. Groundsource geothermal energy is ideal for heating and cooling applications. The geothermal constant is available virtually everywhere in the US and offers energy savings by providing a baseline temperature that can be supplemented with a heat pump to regulate indoor temperatures with minimal cooling or heating energy. Large scale systems such as Cornell University's Lake Source Cooling project [10] demonstrate the principle on a grander scale, but houses and buildings have been built with basements for centuries for this reason. Exploiting this temperature base for buildings to minimize heating and cooling costs is simple, cost effective and basic good facility management. Minimizing building heating and cooling costs represents a significant opportunity for energy conservation.

E. Biofuels and Waste-to-energy Production

The final step in our tour of distributed energy generation is closing the loop to examine our most underutilized energy resource in the US, i.e. waste products. Data from the US DoE [11] indicates that various biological wastes such as crop residues are valuable as inputs to biofuel production. Although biofuel production from agricultural crop residues, meat and dairy processing wastes and other waste products have not been widely exploited in the US, other countries have developed significant energy generation infrastructure based on waste-to-energy technologies. For example, Brazil has become largely energy self-sufficient through the development of ethanol production from sugar cane processing waste. Japan has developed extensive recycling systems that include energy production through urban and agricultural waste incineration. In the US, the transition from landfilling waste at great cost in terms of lost agricultural production, pollution and future clean up, to energy production, is a logical and important step in developing distributed generation, preserving valuable agricultural land, and minimizing pollution.

III. DISTRIBUTED GENERATION AND THE SMART GRID

There are several issues associated with distributed generation. These include load balancing and the related topic of energy storage. In our present system, the transmission and distribution of electrical power is one-directional; electricity moves from the producer to the consumer. The challenge with this is that there is a time value of energy. It is needed when and where it is consumed at the moment of consumption. Excess production cannot be readily stored, energy must be produced on demand. This means that generation must have a peak capacity that far exceeds normal demand. Need is met through the use of production scaffolding based on cost and demand. Nuclear and hydropower are generally used for baseline supply because they are reliable, predictable and fairly low-cost. When additional power is needed, additional plants are brought on line based on their cost, which is dependent on fuel type and cost. Fossil fuels are generally more expensive, with oil more expensive than natural gas and coal cheapest. As demand increases, more expensive plants are brought online, with the most expensive to run being saved for peak energy demand, which usually occurs in the summer time for cooling. These most costly plants to run are called 'peakers'. When demand slackens, the peakers are shut down until they are needed again.

In a distributed generation paradigm, how will peak demand be met? First, by designing building systems to achieve zero net energy demand [12], a process that is underway in several locations, including in the US, but mostly in Europe, Japan and Scandinavian countries. Second, by designing and installing systems that are able to stockpile excess energy locally for use at a time when it is needed. In the past, for home or business owners going off the grid, this meant stacks of deep cycle marine batteries in the basement. Nowadays, a flywheel or water pumping system is a better alternative that allows for one or more days of power to be stored [13] for future use. Making on-site energy storage an integral part of the distributed generation paradigm, and designing hybrid systems based on balancing local needs and resources can minimize spikes in demand, reducing the need for expensive peaker plants. By identifying site-specific demands, and matching those to site-specific energy resources, significant load balancing requirements can be met by well-designed energy systems at the local level.

A. Integrating Distributed Generation and Transportation

As the transportation industry begins to produce all-electric vehicles, there are two implications of this automotive technology that are relevant to how we should think about the design of electricity generation. The first is next generation battery technology, and the second is how the design of electric vehicles should inform our design of electrical generation systems in general.

B. From the Smart Grid to the Wireless Grid

the transition of, smart grid Potentially, the aim of the transition to As the To make all this work as one seamless system, smart telecommunications applications afford dynamic access, updates and information. Advanced telemetry linked by sensor networks offers sophisticated load balancing, and easy communication with facility management systems.

