Asset Optimization and Economic Issues in the Smart Grid

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Abstract— Today's electrical grid is considered one of the greatest engineering accomplishments of all time. It was recognized in 2003 by the National Academy of Engineering as the preeminent engineering achievement of the twentieth century. Currently, the utility industry is facing a number of challenges that are bringing about the need to make major changes to the grid. These challenges include the need for greater energy security arising from increasing demand for energy worldwide and decreasing supply of fossil fuels to meet the demand, worldwide concern about global climate change, aging infrastructure and inefficiency in the existing grid. Additionally, consumers want to play a role in their own energy management and conservation. To address these challenges, the utility industry is in the early phases of migrating toward a "smart grid." The goal of the smart grid is to make the existing grid more efficient and less harmful to the environment, while continuing to provide safe, reliable, and affordable electricity to consumers. This paper discusses the current issues in regard to energy consumption, problems with the existing grid and the goals of the smart grid , information and communication technology (ICT) infrastructure, and communication technologies, standards, and protocols that are either already in use or are being considered for the smart grid , micro-grids, plug-in hybrid electric vehicles (PHEVs) and smart homes and the role they will play in the smart grid, existing smart grid deployments and pilot projects , the economic issues related to the smart grid and focuses on sensors for smart grid networks, and green networks.

Index Terms— smart grid, ICT , wireless Technologies, sensor, micro grid, smart home.

I. Introduction

The existing electricity grid is becoming less reliable as the infrastructure it is built upon continues to age, and because electricity and electronic devices now permeate every facet of our lives, the demands placed upon the grid are growing exponentially. American electricity consumption increased from about 118 kilowatt-hours a month in 1950 to nearly 1000 kilowatt-hours a month in 2010 [1] and world energy consumption is on track to increase by 44% from 2006 to 2030 [2].

The growth in worldwide energy consumption is due in large part to the availability of cheap energy that is provided by fossil fuels such as oil, coal, and natural gas, but these resources are becoming increasingly scarce. The supply of these fuels will not continue to meet the demand. Many oil and natural gas fields have peaked (or will in the near future) and their production will continue to decline, causing prices for this "peak-oil" to steadily increase. Estimates of when global oil production is likely to peak are between 0-20 years. The remaining oil and gas fields are either in politically unstable or environmentally sensitive areas [3]. Even if fossil fuels remain plentiful, a future based on fossil fuel consumption will threaten the environment by causing damaging climate change, the effects of which are still largely unknown. In order to reduce carbon emissions, the use of plug-in hybrid electric vehicles (PHEVs) and high-speed electric trains will need to replace gasoline and diesel powered vehicles, and homes and offices will need to be heated and cooled electrically rather than with coal, oil fired burners, or natural gas. This transition is expected to increase electricity demand globally by 76% by 2030[2].

This increased demand for electricity means the existing grid will need to be re-tooled and the utility industry's business model redesigned in order to continue to provide safe, secure, reliable, environmentally friendly, and affordable electricity service to consumers. The grid will have to transition from a mostly unidirectional, centralized, and hierarchical organization to a distributed, networked, and automated energy value chain [1]. The existing grid topology is an hierarchical pyramid, with a few large power plants (burning fossil fuels) at the top that generate electricity and send it over a long distance through the transmission system to smaller utilities, who in turn provide electricity to end-users, on-demand, through the distribution system. Figure 1 is an illustration of the structure of the existing grid [4].

End users are typically located far from where the electricity is generated. Because of this hierarchical structure, failures in the system cause a domino affect, where one failure can affect thousands or even millions of users, and power outages today are much more detrimental than in the past given our dependency on electricity in order to function as a society. Inefficiencies in the existing generation system cause a loss of nearly 8% of its capacity in the transmission lines, and it reserves nearly 20% of its capacity to meet peak demand. In other words, 20% of generation capacity is only used 5% of the time [4]. The existing grid is also a unidirectional system both in terms of delivery and communication. Figure 2 [5] illustrates the current level of asset utilization in today's grid.

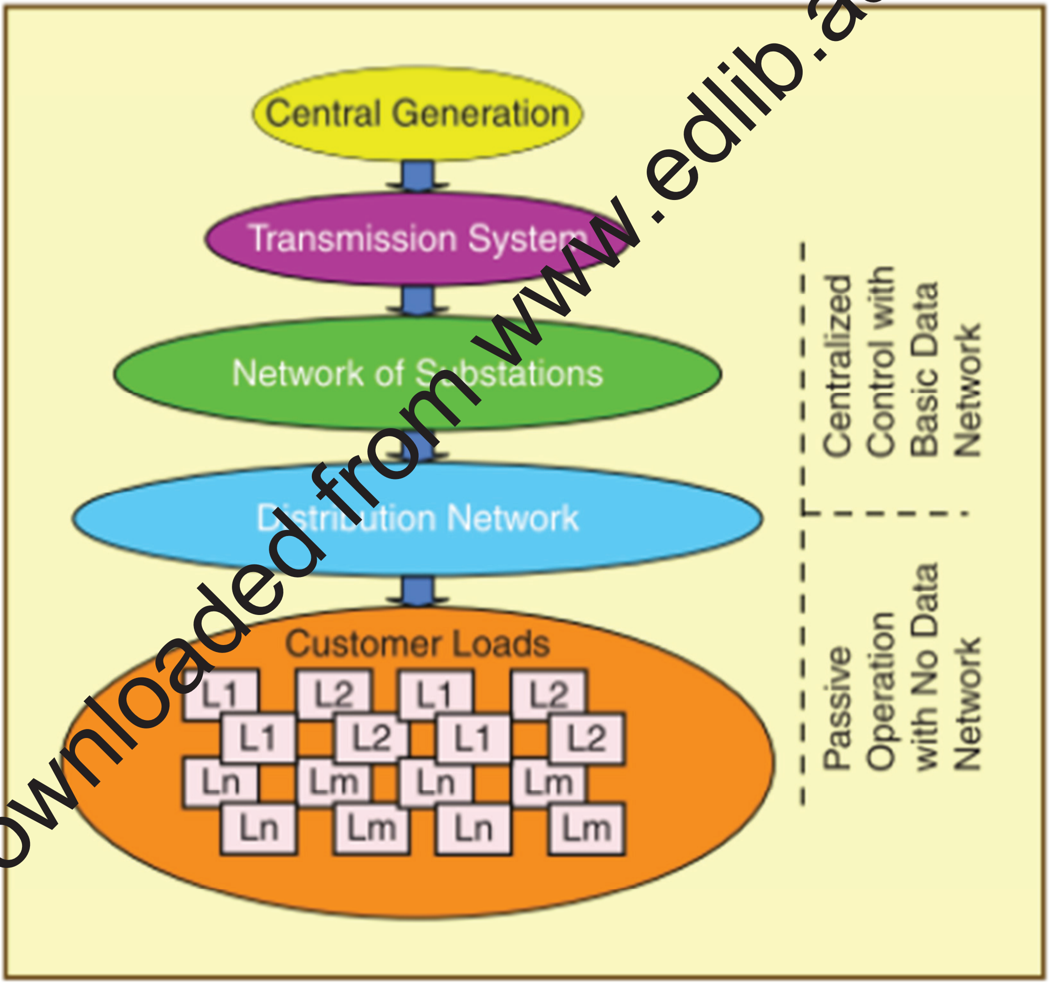

Figure 1: The Existing grid

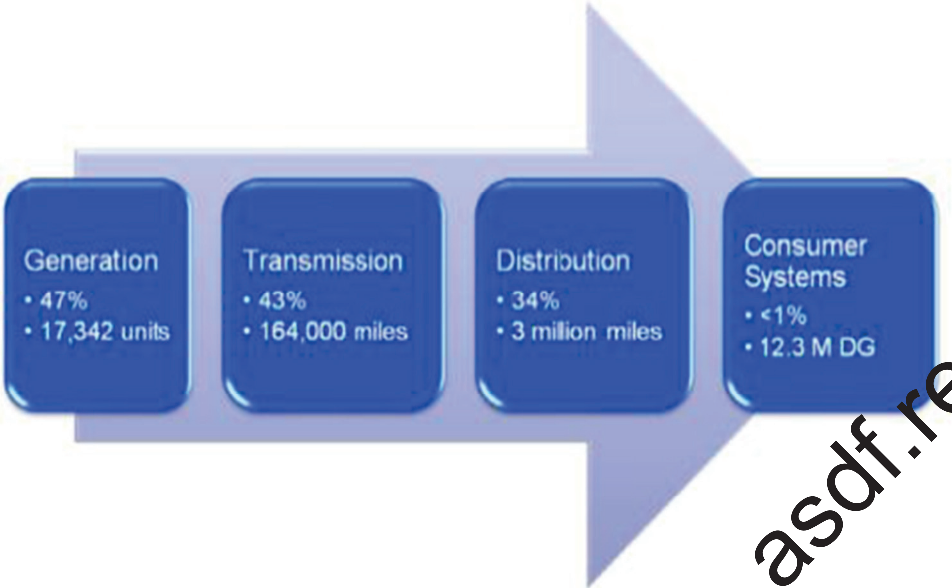

Figure 2. The current level of asset Utilization

The figures shown are the average utilization as a percentage of capacity. The figures indicate that there is room for improvement by increasing utilization of existing assets as opposed to building new ones. It should be noted that the most under-utilized area is the consumer systems asset class where millions of Distributed Generation (DG) resources are not connected to the grid [5].

The smart grid will require utilities to make more efficient use of assets in the generation, transmission and distribution systems, create a bi-directional flow of real-time information, and incorporate renewable generation resources such as wind, solar, and tidal sources, as well as plug-in hybrid electric vehicles (PHEVs) that will not only consume electricity, but also give back to the grid by acting as a distributed form of energy storage[3]. The supply of renewable sources of energy changes in response to changing conditions (wind speeds, cloud cover, PHEV battery capacity etc.), so a shift in the way electricity is provided to consumers will be necessary. Perhaps the most difficult transition that utilities will have to make is the transition from supplying electricity to consumers on-demand, to using demand-response (DR) to reduce peak demand. DR means the demand for electricity is managed in response to the available supply of resources. DR is needed in order to reduce peak demand, which is a major source of inefficiency in the existing grid, as mentioned earlier.

Reference [5] list three ways in which the smart grid differs from the existing grid:

a) Decentralized Supply and Control – Increased number of generation and storage resources from a few large, centralized power plants to many millions of decentralized resources, some of which will be owned by utilities, and others that won't.
b) Two-way Power Flow at the Distribution Level – Although the transmission system in the existing grid currently allows two-way flows, the distribution system does not. The smart-grid will allow consumers to sell energy back to the grid. Consumers who both consume and provide energy back to the grid are referred to as “prosumers.”
c) Two-way information flow – The transmission system uses SCADA to gather information, but SCADA has not been implemented in the distribution system, and no information is exchanged at all between consumers and grid operators [3].

Some of the principal characteristics of the smart grid are follows:

- Enable active participation by consumers;
- accommodate all generation and storage options;
- Enable new products, services, and markets;
- Provide power quality for a digital economy;
- Optimize asset utilization and operate efficiently
- Anticipate & respond to system disturbances (self-heal); and
- Operate resiliently against attack and natural disaster.

This paper discusses the current issues in regard to energy consumption, problems with the existing grid and the goals of the smart grid in section 1. The definition and general description of the smart-grid as well as a description of the information and communication technology (ICT) infrastructure, and communication technologies, standards, and protocols that are either already in use or are being considered for the smart grid are discussed in section 2. Section 3 is a discussion of micro-grids, plug-in hybrid electric vehicles (PHEVs) and smart homes and the role they will play in the smart grid. In Section 4 a few of the existing smart grid deployments and pilot projects are covered Section 5 covers the economic issues related to the smart grid. In section six we discuss sensors applications for smart grid and the paper concludes in Section 7.

II. ICT Infrastructure, Standards, and Protocols

Smart-grid is defined as a system that uses two-way communication and information technologies, and computational intelligence in an integrated fashion across electricity generation, transmission, distribution, and consumption to achieve an electric system that is clean, secure, reliable, efficient, and sustainable[6]. The smart-grid will incorporate advanced information and communication technologies (ICT) along with automation, sensing, and metering technologies and energy management techniques in order to optimize the supply and demand of energy and improve asset utilization in the electrical system[7].

Communication of real-time data and the use of analytics and predictive modeling are crucial to the operation and management of the generation system within the smart-grid, therefore, IT will play a large role in the transition from the existing grid to a smart grid. System operators will need to use advanced system operation tools that provide real-time monitoring of all system components in order to optimize performance and avoid blackouts and integrate renewable energy sources that are variable in nature. Examples of these advanced tools include wide-area situational awareness (WASA), wide-area monitoring systems (WAMS), and wide-area adaptive protection, control and automation (WAAPCA)[8].

In the transmission system, smart-grid technologies include flexible AC transmission systems (FACTS) that enhanced the controllability of transmission networks and maximize power transfer capability. Dynamic line rating (DLR) are used to optimize existing transmission assets through the use of sensors that provide real-time information regarding the currant carrying capacity of a section of the network. Lastly, high voltage DC (HVCD) technologies assist in connecting wind and solar resources to the grid that are located large distances from load centers [8].

The distribution system has largely been the focus of smart-grid initiatives, since it is the least automated and provides the most opportunity for improvement. Advanced metering infrastructure (AMI) is used in the distribution system that enables the bi-directional flow of information and provides utilities and customers with real-time data on consumption and electricity pricing. AMI refers to smart meters and the technologies that are combined with them. Other technologies used in the distribution system include customer-side-systems, which include energy management systems, smart appliances, energy storage devices, in-home displays, building automation systems, energy dashboards, and energy applications for smart phones and tablets [8]. A three-layer smart grid conceptual model has been proposed by the Power

Engineering Society, as shown in figure 3 [7]. The layers include the energy and power systems layer, communications layer, and information technology layer. The ICT layers of this model account for approximately 70% of the smart grid infrastructure.

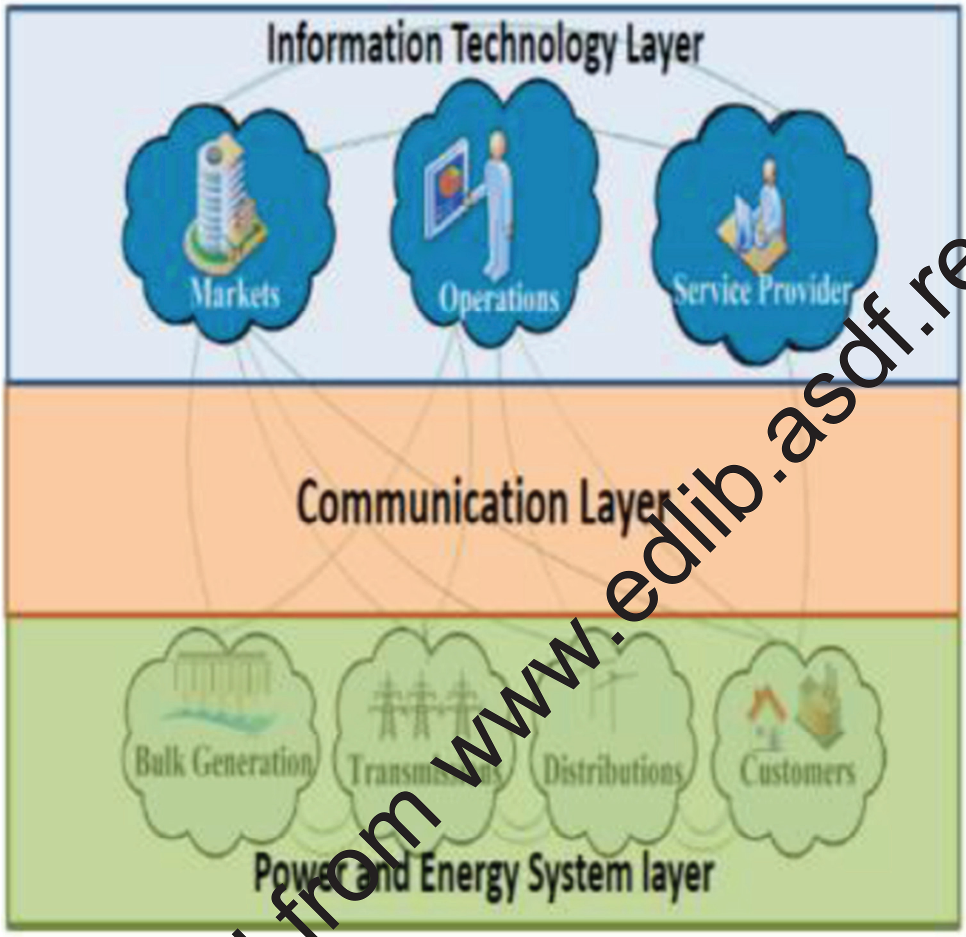

Figure 3. Smart Grid conceptual model

1) IT Layer

The IT layer of the smart grid is divided into two sub-layers; the Computing Platform and Operational Systems Layer (CPOS) and the Business Applications and Services (BAS) Layer. The CPOS layer consists of hardware in the form of servers that host all of the grid's operation systems. These systems include demand-side management and demand response, grid optimization, switching plans, outage and geographic information, transmission and distribution automation, communication networks analysis and management, self-healing and disturbance correction, dispatching and tracking, tagging power flow analysis, cyber-security protection, renewable energy integration, and protection and real-time Supervisory Control and Data Acquisition (SCADA) analysis[7].

The BAS layer consists of software packages that are responsible for the following:

1. Utilities customer care and billing, consumer interface and web interface.
2. Business and home energy management, distribution mobile workforce management
3. Third party service providers, their party access for marketing and financial applications.

2) Communications Layer

The smart grid communication layer connects all of the sub-systems (generation, transmission, distribution, and consumptions) within the smart grid to the IT and energy and power systems layers, allowing for the bi-directional exchange of information between grid and ecosystem operators and consumers. The communications sub layer is further divided into three sub-layers in addition to the existing SCADA. The communication layer sub-layers include; Automatic Meter Reading (AMR) networks layer, Advanced Metering Infrastructure (AMI) networks layer, and Advanced Metering Infrastructure Plus (AMI+) networks layer [7]. Each of these sub-layers serves certain types of networks within the grid. The network types are described in the following paragraphs. Figure 4 illustrates the functions of each of the sub layers.

Figure 4. Smart grid software layer

Consumer Premises Networks (CPNs) are located on the customer's premises and facilitate communication between appliances and smart-grid equipment. These networks are served by the AMR sub-layer. The CPNs are also subdivided based on the consumer's consumption profile into Home Area Networks (HAN), Business Area Networks (BAN), and Industrial Area Networks (IAN) [7]. These networks can serve devices like smart appliances, EV charging outlets, and in-home displays for HANs, load control devices, renewable energy integration, power measurements, and demand side management. Data in these networks can be exchanged though real-time measurement parameters (RTMP), or power consumption data. RTMP is used for demand-response and demand-side management. It measures current, frequencies, voltage and power. The smart meter power consumption data profile is defined by IEEE standard 6010-6011 [9]. The possible communication technologies for CPNs include both wired and wireless networks such as Zigbee, Xbee, Wi-Fi, BACnet, Home Plug, 6-lowPAN, and SAEJ6847[7].

Neighborhood Area Networks (NANs) are part of both the AMI and AMR sub-layers. The function of a NAN is to gather information from devices in the CPNs via smart meters and send the data to the data center at the utility for processing. Devices served by NANs include concentrators, which collect data from meters in all neighborhoods, load control relays, and advanced smart meters. Communication technologies used by NANs include both wired and wireless networks such as Wi-Fi, WiMax, LTE, GPRS/EDGE, RF Mesh, FTTP/FTTH/Ethernet, and RF Radio point-to-multipoint [10].

Access Area Networks serve devices at the distribution level such as voltage regulators, renewable energy resources, re-closers, remotely operable switches, capacitors, line sag and maximum demand indicators, distance to fault relays, and line fault indicators. Access Area Networks use both wired and wireless communication technologies that include WiMax, GSM-CDMA, BPLC, 1G/LTE, and FTTP/FTTH/Ethernet.2 The Backhaul Network also serves devices at the distribution level. These include SCADA devices (RTU substations and IDE), Pressure, Temperature, and Oil level sensors, protection relays, and monitoring cameras. The communication technologies used by the Backhaul Network include WiMax, BPLC, LTE/LTE Public, FTTP/FTTH/Ethernet, Microwave, and Fiber[7].

Core and Office Networks are responsible for corporate communications in order to provide voice, data, planning, and Quality of Service. Network communication technologies used in these networks include GPRS, LTE, Leased Line Circuits, and FTTP/FTTH/Ethernet. External Access Networks use public access networks in order to provide access to the previously described networks to ecosystem operators. Figure 5 [7] provides a visual summary of the different networks and their associated communication technologies, as well as how they interface with one another.

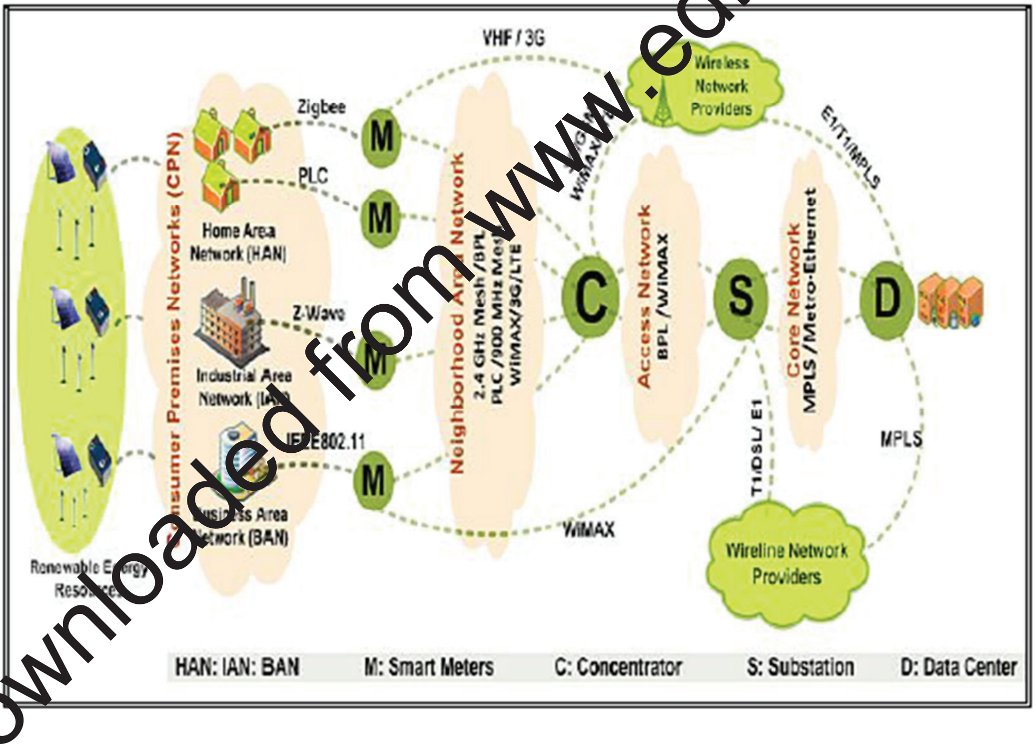

Figure 5. Available Networks options for smart grid

III. Micro-Grids, PHEVS, and Smart Homes

The transition to a smart-grid is expected to be an evolutionary process where utility companies slowly incorporate more and more smart-grid technologies into their existing infrastructure. Much like the evolution of the Internet, the smart-grid could become an interconnected network of smaller networks, called micro-grids. Micro-grids provide decentralized generation and storage that is more efficient and located closer to the customer's premises. Utility micro-grids, along with a Distribution Management

System (DMS) will enable large numbers of DG to contribute resources and assist in demand response to reduce peak load and improve reliability when the grid needs their support [5]. The Department of Energy describes micro-grids as:

“A micro grid, a local energy network, offers integration of distributed energy resources with local electric loads, which can operate in parallel with the grid or in an intentional island mode to provide a customized level of high reliability and resilience to grid disturbances. This advanced, integrated distribution system addresses the need for application in locations with electric supply and/or delivery constraints, in remote sites, and for protection of critical loads and economically sensitive development [5].”

In addition to utility micro-grids, community micro-grids are emerging whose purpose is to optimize local assets in order to best serve a community. They are self-contained power systems that operate in a small geographical area and are controlled locally [4]. They incorporate renewable resources along with traditional local generation. These micro-grids operate alongside the main grid most of the time, but can seamlessly move into “island mode” when necessary. The community micro-grid’s intelligence can determine if conditions require the transition into island mode in order for the community to be best served.

Once the conditions return to normal, the community micro-grid will connect back to the main grid seamlessly. The military has relied on micro-grids for some time as a way to generate its own power, leaving it to rely on local utilities strictly for supplemental power and other services. Figure 6 illustrates a typical micro-grid design [11].

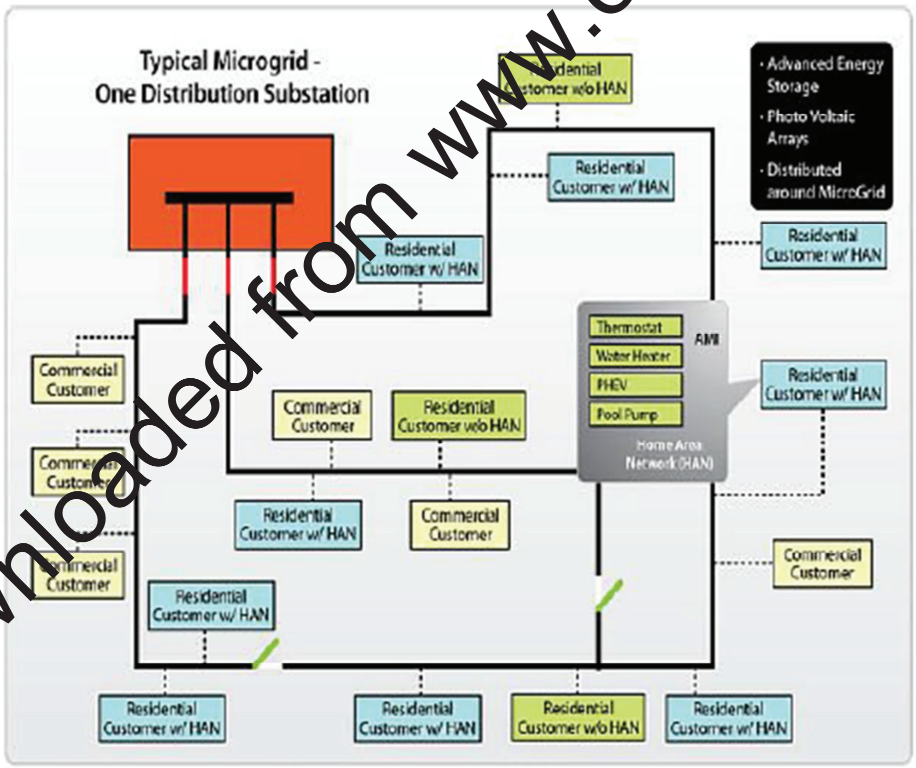

Figure 6. A typical Micro grid design

As the smart grid evolution progresses, micro-grids will begin to aggregate distributed generators into “virtual power plants,” allowing distributed generation to be entered into the main grid and sold on the market by individuals. Micro-grids are still a contentious issue for some utilities who question their true value. The research to date seems to discredit this notion. Micro-grids can assist in solving problems that on a large scale seem impossible, but become more manageable within smaller areas. Some of the suggested benefits of micro-grids are:

1. Easy renewable energy integration
2. Reduced losses in transmission
3. Lower carbon emissions
4. Local control and ownership
5. Use of island mode when blackouts occur
6. Cheaper and faster to build than large power plants.
7. Ability to incorporate storage from batteries or other devices
8. Micro-grids can contribute unused energy back to the main grid
9. Postponement of construction of new centralized power plants

Government regulation may be needed in order to require the use of micro-grids for the purpose of asset optimization in the smart grid. Further research is needed in this area to examine unintended consequences and to determine if the implementation of micro-grids will be cost effective for consumers.

Plug-in hybrid electric vehicles (PHEVs) will also play an important role in the smart-grid. PHEVs are part of the vehicle-to-grid (V2G) system, which is an auxiliary distributed storage system that exploits the capacity of vehicle batteries[12]. More and more of these vehicles will be used as the need to reduce carbon emissions and the price of gasoline increases. PHEVs will put an added burden on the grid as people will need to charge them. But PHEVs will also be able to store energy and assist with load shaving. Consumers will be able to sell the power stored in their vehicle's back to the grid if/when they choose. This will help grid operators deal with peak demand for energy. When electricity prices go up during times of peak demand, consumers, through smart-grid technologies, will be notified of rising prices and can profit from selling their PHEVs stored energy back to the main grid based on time-of-use pricing, which is discussed later. PHEVs already come equipped with Time–of–Use (TOU) recharching controllers. The electric vehicle charging infrastructure within the distribution system of the smart-grid handles billing and other needs related to smart charging PHEVs during periods of low energy demand [8].

Another important piece of the smart-grid puzzle is what's been called a “smart home.” Consumers who use smart homes are able to manage their energy demand by installing advanced devices. These devices include two-way communicating thermostats and meters as well as other automation devices including programmable outlet controllers and smart appliances. Smart homes will contribute to demand response by lowering peak demand in the smart-grid. Reference [13] states an analysis by the appliance industry estimates that virtually the entire projected growth in peak demand expected for 2030 in the U.S. Could be avoided with full implementation of smart appliances. The appliance industry points out that new energy efficiency measures will have little impact on reducing peak demand and they are already beginning to affect the performance of some appliances. The Pacific Northwest Laboratory and Whirlpool conducted a demonstration project (that is discussed in detail in the next section) using a smart clothes dryer that could detect variations in frequencies on the grid that indicated an impending power outage and respond by turning off the dryer's heating elements for up to ten minutes while the dryer continued to run. The resulting analysis led the appliance industry and the energy-efficiency advocacy community to jointly request that demand-response capable appliances by included in the new ENERGY STAR program. Grid-connected refrigerators also offer significant energy savings as they can be programmed to defrost at non-peak times of day. The savings of having 100 million homes with connected refrigerators is estimated at 50 billion Watt [13]. Likewise, a connected dishwasher can be programmed to run in the middle of the night, even if it was loaded in the early evening. Smart homes allow consumers to manage their consumption based on the dynamic pricing that is later. Lastly, smart homes can assist in the main grid in restoring power after an outage by waiting a sufficient amount of time before restarting. In many cases after a power outage, all the devices restart simultaneously as soon as power is restored and cause another failure as a result.

IV. Smart Grid Projects

The Pacific Northwest project conducted by Clallum Public Utility District was one of the first to introduce an incentive program to encourage consumer's involvement in the plan for developing a smart-grid. Volunteer households were given free computers that received electricity rates every five minutes, along with thermostats, water heaters, and clothes dryers that were provided by Whirlpool. The devices could be programmed to inform households on current quantity of power they were using and at what cost, allowing the households to adjust their consumption accordingly. In addition, the computers allowed Clallum to remotely shut down the heating elements of the clothes dryers as described before in order to balance the load on the system. Each household was given a small amount of money at the beginning of the project and were allowed to keep whatever was left over at the end. The households were also given some instructional training on how to use the software. The 116 households that participated kept their demand below the utility's capacity at all times during the experiment, and saved an average of 10% on their power bills. This project was a good start, but replicating it on a large scale isn't likely as the participants were guaranteed that their bills wouldn't go up, and a single government laboratory ensured that the equipment was kept working during the entire duration of the project.

The Pecan Street Project is a research and development organization within the University of Texas at Austin that is carrying out a number of smart grid demonstration projects around the U.S. that emphasize customer participation. One of the projects in particular, the Mueller project, involves 1,000 homes that are equipped with energy management systems and incorporates most of the advanced smart-grid technologies. The project is analyzing new dynamic pricing models and studying the incorporation of DG, PHEVs, photovoltaic solar, and energy storage, as well as evaluating different smart-grid standards for interoperability. The expectation is that the results from this demonstration project can be extended to other smart-grid projects worldwide and under various conditions [14]. The Pecan Street Project rewards consumer participation by giving rebates for home efficiency measures and providing assistance financing efficient air conditioners as well as solar PV cells and solar water heaters. The Pecan Street Project is a model of the effectiveness of collaboration between utilities and policy makers as it also encourages green workforce development, promotes alternatives to automobile travel and the creation of energy business incubators [1].

V. Economic Issues

In order for the smart-grid to function effectively and efficiently, the electric utility industry's business model will require an overhaul. The electricity industry's business model was built on the notion that costs go down as supply goes up, therefore, the industry is largely responsible for consumer's lax attitudes toward energy consumption. The industry's strategy has historically been to sell more, and charge less.1 Now the utilities are faced with the need to change their business model to go from selling as much power as they can as cheaply as they can to both selling and conserving electricity. This paradigm shift will be extremely difficult since there are many different stakeholders involved with heterogeneous needs and goals and there are tremendous economic and regulatory issues to address. Reference [1] provides a very detailed discussion of the economic and regulatory issues surrounding the smart-grid in his book.

The first issue facing grid operators is the way in which they charge customers for power. It is widely known that the most costly elements of producing and delivering electricity are the costs of the fuel required to make it, and the costs of building power plants. In order to provide the continuous balance necessary in the existing grid, human operators make decisions as to which power plants will need to be turned on during the day as demand increases. Some power plants costs more than others to operate, therefore, the cost of producing and delivering electricity changes by the hour or even by the minute throughout the day. At night, electricity is cheapest (2 to 3 cents/kWh) because the cheapest plants are running, but as people wake up and start turning on the lights, etc. additional plants are turned on and the costs increase (6 to 7 cents/kWh). During times of peak demand, when the most least efficient plants have to be turned on, costs are much higher (8 to 20 cents/kWh).1 Dumb meters don't account for this variation in costs, rather, they simply add up the number of kWh used by a customer over a month and charge a set rate for each kWh regardless of when it was used or how much cost the utility incurred to make it. Smart meters, on the other hand, track a customer's consumption hour-by-hour, allowing utilities to charge different prices for electricity used at different parts of the day. This is called time-based pricing. The use of smart meters and time-based pricing is beneficial for both the electric utilities and consumers. Utilities benefit in that they can set time-based prices and bill them and offer more pricing options. Also, smart meters allow appliances to be programmed to respond to price signals or user commands and adjust their use accordingly, as in the Pacific Northwest project described earlier. Lastly, smart meters “make it easier to integrate small-scale generators and storage on a customer's premises” in that they can keep track of self-generated power and decide when to store electricity to be used later.1 The smart meters, along with the systems that allow them to communicate price signals and record hourly use are collectively called Advanced Metering Infrastructure (AMI). AMI provides some core smart-grid functionality and is currently being used on a small scale, but it is just the beginning of the capability that fully enabled smart-grid technologies will provide in the form of sophisticated customer controls. Having large numbers of consumers who can adjust their demand when grid operators signal rising electricity prices is how peak loads are reduced via demand-response.

There are three types of time-based electricity pricing. First, real time prices (RTP) are set based on hourly wholesale prices with a mark-up. Real-time pricing can vary dramatically as much as 300% [1] so utilities tend to favor one of the other two pricing structures. TOU rates are calculated in a stair-step manner based on the daily patterns. For example, prices are highest in the middle of the day, lowest in the middle of the night, and mid-range during the morning and early evening. This pricing structure has been most commonly used by utilities since it doesn't require real-time communications with customers. TOU rates take into account consumption at different parts of the day, but they don't address the times when demand on one day is higher than another, as in when the temperatures are much higher or lower from one day to the next. Critical peak pricing (CPP) gives utilities the option of increasing rates substantially for just a few days during heat waves or extremely cold weather conditions when there is a spike in demand. Customers are notified in advance of the price increase so that they can plan to adjust their consumption. All of these pricing structures are designed to be profit neutral for utilities, but provide valuable benefits for customers and are very effective at reducing peak power demand. For example, TOU rates reduce peak demand by about 5% and CPP rates bring about a 20% reduction [1].

Pricing is one issue facing the utility industry, but implementing a smart-grid will require a complete overhaul of the industry's business model. It places the industry's current business models into two categories; the vertically integrated regulated utility and the disintegrated structure with retail choice. He then examines the likely path the two models will take within the constraints of three elements of a triad that include structure, regulation and competition, and business model, and describes two forces that have played a role in the triad. Structure refers to which parts of the industry a firm owns. Regulation and competition refers to how the industry is regulated, and business model deals with the business practices that meet regulatory requirements while maximizing profits. The two forces include vertical integration, which is “the savings that occur when a single utility owns all stages of the electric production and delivery process,” and the benefits of competition within the electric utility industry.

The vertically integrated regulated utility owns the generation, transmission, and distribution and is regulated by the government. The idea behind vertical integration is that by interconnecting all power sources, costs are minimized and value is maximized because it is cheaper to serve the needs of a large group than to serve customers individually. Reference [1] believes vertically integrated regulated utilities will transition into “energy service utilities” Energy service utilities will keep their vertically integrated regulated structure, while incorporating dynamic pricing and distributed generation resources, and smart-grid technologies.

The other scenario [1] describes is that the benefits of vertical integration become weaker and competition increases as a result of increasing implementation of smart-grid technologies. In this scenario, the utilities will stay out of the business of generating power and limit themselves to running a smart transmission and/or distribution system that integrates, sets prices for, and balances all types of generation, storage, and demand-response. These utilities are called “Smart Integrators[1].”

VI. Smart Grid and Sensors

Another critical component of the smart grid is the use of sensors that provide reliable communication of information within the grid. Wireless sensor networks (WSNs) are being introduced into the smart grid that will enhance the operation of all three sub-systems; generation, transmission, and distribution. The use of online sensing technologies provides the ability to monitor, diagnose, and protect the power system, which in turn reduces the impact of failures that result from natural disasters, equipment failure, etc. These sensors are the basis for maintaining safe, reliable, and efficient electrical service for consumers and businesses via the smart grid. Online sensing technologies will replace the wired communications systems that have been used in the existing grid for electrical system monitoring and diagnostics. These systems are expensive to install and maintain as they require extensive cabling infrastructure, so their implementation has been limited in the existing grid. In the existing grid, remote system monitoring and diagnostics are largely non-existent because of their high costs. Reference [15] states that at present, utilities have no monitoring whatsoever of most of their critical system equipment, such as motors that are less than 200 hp[1]. But the costs of widespread power outages to consumers and businesses are too high for this situation to continue. In order to maintain safe and reliable service, utilities must improve on their ability to monitor their critical equipment and do a better job of coordinating protection devices. WSNs offer a low-cost solution and can provide monitoring of all system components, identifying faults and isolating them before they spread and cause widespread power system failures. Because of their low-cost, wireless sensors are the preferred tools for providing quicker reaction to changing conditions within a smart grid. . Reference [15] posits that the advantages of WSNs in the smart grid over traditional wired communication networks include rapid deployment, low cost, flexibility, and aggregated intelligence via parallel processing. Another application of WSNs are wireless automatic meter reading (WAMR). WAMR allows utilities to reduce costs by eliminating the need for human meter readers, and by deploying WSNs that provide two-way communication between utilities and consumers, utilities can offer the dynamic, time-based pricing schemes discussed earlier.

WSNs will only be successful if they are able to provide reliable and efficient communication, and there are challenges that have to be addressed. Interference exists within electrical environments that pose a threat to the ability of wireless sensors to operate effectively and reliably. Quality of service is also a concern given the many different applications that WSNs are expected to provide. Each application will have different QoS requirements, and because the bandwidth and latency of each wireless link will differ depending on conditions specific to its location, QoS requirements will be difficult to meet. Error rates are another issue in wireless communications. Link asymmetry, when one node can communicate to another, but not vice versa[1], is also a problem with WSNs, especially at long distances or low power transmissions. A link quality metric is needed in order to predict the quality of wireless links under different conditions and maintain safety and reliability. But because of the harsh environments within electrical systems, link quality is constantly changing, making it difficult to determine the value of link quality at any given time. Reference [19] suggests two areas of research to consider when designing wireless networks for electrical systems which include wireless channel modeling and link quality characterization. Channel modeling allows designers to predict the performance of the communication network for a specific propagation environment, channel modulation, and frequency band.

Growing concern about global climate change and rising energy prices is producing much research and discussion about green networks and sustainability. The U.S. Environmental Protection Agency describes sustainability as being based on a single principle, “Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations[16]. The use of WSNs in the smart grid will add to the already large amount of traffic that exists in the Information and Communications Technology infrastructure, and will require an approach that maximizes energy efficiency within the wireless sensor networks in order to maintain a sustainable communications network within the smart grid. The amount of greenhouse gases caused by ICT is estimated to be 2% of the global greenhouse gas emissions and will continue to increase as more wireless technologies are added [17].

In order to minimize the carbon footprint associated with WSNs used in the smart grid, energy-efficiency measures must be taken at all layers of the ICT protocol stack, while maintaining acceptable error rates and Quality of Service. Assuming the WSNs will operate as WANs similar to the existing cellular telephone networks, there are several proposals for reducing energy consumption in mobile networks. One technique for reducing energy consumption in mobile networks is aimed at mobile base stations, which at present are very inefficient in their use of energy, since even when there is little or no traffic they still continue to consume 90% of their peak energy.17 Coordinated multipoint communication (CoMP) is a technique that allows dynamic coordination of base stations so that redundant base stations can be turned off when there is little or no traffic. CoMP extends the service area of BS while maintaining QoS levels and data rates[18].

Cell shaping is another technique that can increase efficiency in mobile wireless networks. Two cell shaping schemes are the basic switching off and cell breathing schemes. Figure (7) illustrates the use of cell shaping, which is a way of adapting the shape of a particular cell to traffic distribution so that the maximum number of BS are turned off without affecting network performance[17].

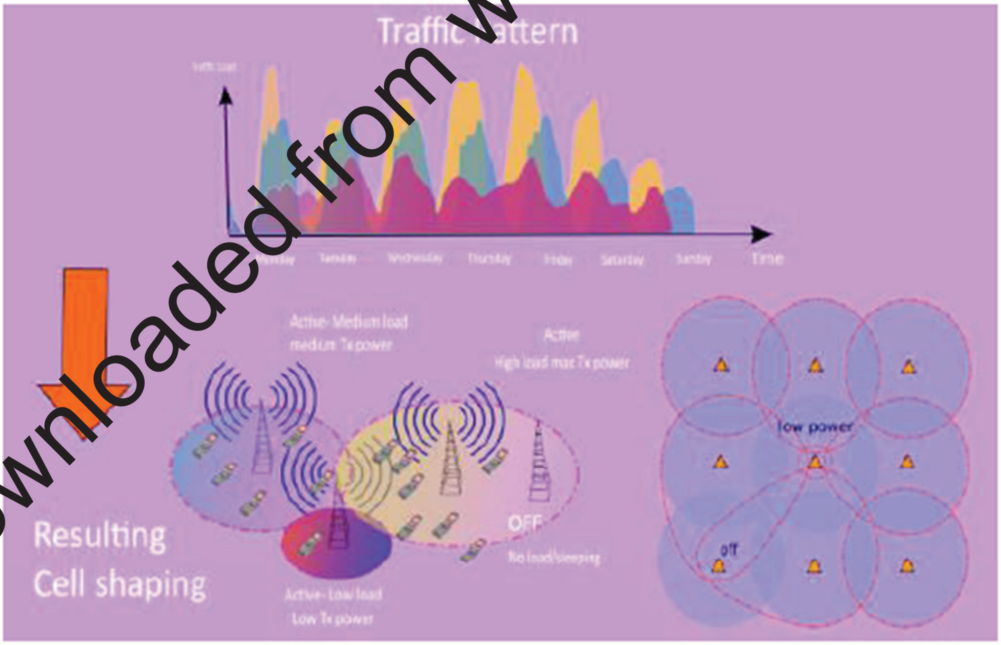

Figure 7. Cell shaping technique for traffic distribution

WSNs may also operate as WLANs. The main energy consumers in wireless LANs are the access points (APs), therefore the focus for reducing energy consumption is on increasing AP efficiency by reducing the number of idle APs in the network and providing network resources on-demand so that APs, network switches, and controllers can be turned off when they aren't needed [19]. In [15], the SEAR (Survey, Evaluate, Adapt, Repeat) strategy is proposed as a resource on demand strategy for high density WLANs. This approach offers most efficiency gains in highly redundant, centralized WLANs with overlapping APs, but only provide modest, if any, advantages in single layer wireless networks. SEAR operates from a centralized WLANs central controller, and is policy based, allowing administrators to set policies that maximize efficiency while maintaining specific network performance requirements.

VII. Conclusion

The issues and challenges surrounding the implementation of a smart-grid are many, although advancements are rapidly being made. There are technology issues regarding interoperability between various parts of the grid and the devices connected to it as well as competing standards and protocols. There are privacy concerns regarding the use of smart-meters that gather large amounts of information about individual households and businesses. The utility industry's business model must change its focus from encouraging mass consumption to energy efficiency. Regulatory policies will have to be put in places that ensure privacy and fair access. But one thing is certain; the smart-grid is a necessity in the face of shrinking supplies of fossil fuels and increased climate change. The smart-grid benefits will far outweigh its costs. Work must continue and collaboration between utilities, policy makers, and the IT community will be needed.

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