Pearson BTEC Levels 5 Higher Nationals in Engineering (RQF)

Unit 44: Industrial Power, Electronics and Storage

Unit Workbook 4

in a series of 4 for this unit

Learning Outcome 4

Integrating Renewable Energy to the Grid

4 IMPACT OF RENEWABLE RESOURCES

Intro to Renewable Resources

4.1 Standalone and Grid Renewables

4.1.1 Standalone (Off-Grid) Renewable Energy Systems

For many people, powering their homes or small businesses using a small renewable energy system that is not connected to the electricity grid (called a stand-alone system) makes economic sense and appeals to their environmental values.

In remote locations, stand-alone systems can be more cost-effective than extending a power line to the electricity grid (the cost of which can range from £10,000 to £40,000 per mile). But these systems are also used by people who live near the grid and wish to obtain independence from the power provider or demonstrate a commitment to non-polluting energy sources.

Successful stand-alone systems generally take advantage of a combination of techniques and technologies to generate reliable power, reduce costs, and minimize inconvenience. Some of these strategies include using fossil fuel or renewable hybrid systems and reducing the amount of electricity consumed.

In addition to purchasing photovoltaic panels, a wind turbine, or a small hydropower system, some additional equipment (called "balance-of-system") to condition and safely transmit the electricity to the load that will use it is required. This equipment can include:

- Batteries
- Charge controller
- Power conditioning equipment
- Safety equipment
- Meters and instrumentation.

With stand-alone systems the amount of equipment needed depends on overall requirements. In the simplest systems, the current generated by the renewable system is connected directly to the equipment that it is powering (load). However, if power storage is required for use when the system isn't producing electricity, batteries and a charge controller are required.

A typical standalone AC system is shown in Figure 1.

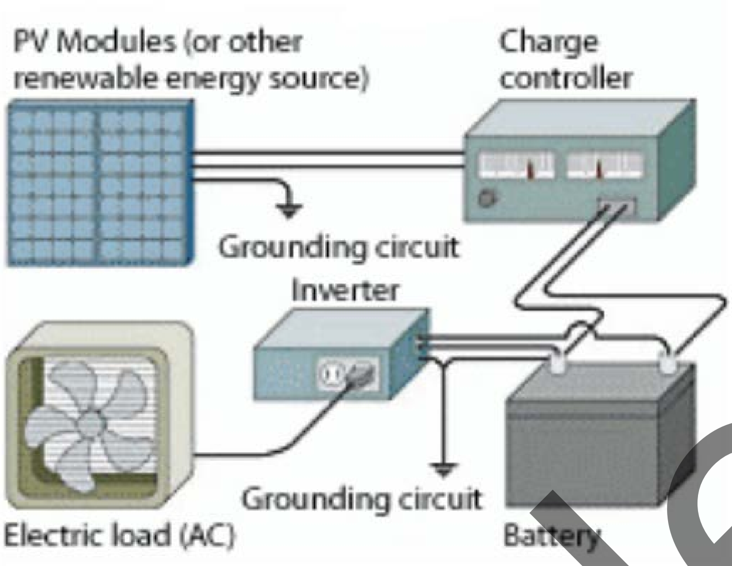

Figure 1 A typical standalone AC system

Depending on the needs, balance-of-system equipment for a stand-alone system could account for half of the total system costs. Typical balance-of-system equipment for a stand-alone system include batteries, charge controller, power conditioning equipment, safety equipment, and meters and instrumentation.

A grid-connected system requires balance-of-system equipment that allows safe transmission of electricity to system loads and to comply with the power provider's grid-connection requirements. Power conditioning equipment, safety equipment, and meters and instrumentation will be required.

4.1.1.1 Batteries for Stand-Alone Systems

Batteries store electricity for use during times that the system is not producing electricity (the resource is not available). Batteries are most effective when used in wind and photovoltaic systems (variations in micro-hydropower resources can be more seasonal in nature, so batteries may be less useful).

The "deep-cycle" (generally lead-acid) batteries typically used for small systems last 5 to 10 years and reclaim about 80% of the energy channelled into them. In addition, these batteries are designed to provide electricity over long periods and can repeatedly charge and discharge up to 80% of their capacity. Automotive batteries, which are shallow-cycle (and therefore prone to damage if they discharge more than 20% of their capacity), should not be used.

The cost of deep-cycle batteries depends on the type, capacity, climate conditions under which they will operate, frequency of maintenance, and chemicals used to store and release electricity. Wind or photovoltaic stand-alone system batteries need to be sized to store power sufficient to meet your needs during anticipated periods of cloudy weather or low wind. An inexpensive fossil fuel-powered back-up generator can be used to cover unanticipated or occasional slumps in the renewable resource.

For safety, batteries should be located in a space that is well ventilated and isolated from living areas and electronics, as they contain dangerous chemicals and emit hydrogen and oxygen gas while being charged. In addition, the space should provide protection from temperature extremes. Locate batteries in a space that has easy access for maintenance, repair, and replacement. Batteries can be recycled when they wear out.

4.1.1.2 Charge Controllers for Stand-Alone Systems

This device regulates rates of flow of electricity from the generation source to the battery and the load. The controller keeps the battery fully charged without over-charging it. When the load is drawing power, the controller allows the charge to flow from the generation source into the battery, the load, or both. When the controller senses that the battery is fully (or nearly fully) charged, it reduces or stops the flow of electricity from the generation source or diverts it to an auxiliary or "shunt" load (most commonly an electric water heater).

Many controllers will also sense when loads have taken too much energy from batteries and will stop the flow until sufficient charge is restored to the batteries. This last feature can greatly extend the battery's lifetime.

The cost of controllers generally depends on the ampere capacity at which the renewable system will operate, and the monitoring features required.

4.1.1.3 Power Conditioning Equipment

For both stand-alone and grid-connected systems, power conditioning equipment is required.

Most electrical appliances worldwide run on alternating current (AC) electricity. Virtually all the available renewable energy technologies, with the exception of some solar electric units, produce direct current (DC) electricity. To run standard AC appliances, the DC electricity must first be converted to AC electricity using inverters and related power conditioning equipment.

There are four basic elements to power conditioning:

1. Conversion (of constant DC power to oscillating AC power)
2. Frequency of the AC cycles (50 cycles per second in the UK)
3. Voltage consistency (extent to which the output voltage fluctuates)
4. Quality of the AC sine curve (whether the shape of the AC wave is jagged or smooth)

Simple electric devices, such as hair dryers and light bulbs, can run on fairly low-quality electricity. A consistent voltage and smooth sine curve are more important for sensitive electronic equipment, such as computers, that cannot tolerate much power distortion.

Inverters condition electricity so that it matches the requirements of the load. If you plan to tie your system to the electricity grid, you will need to purchase conditioning equipment that can match the voltage, phase, frequency, and sine wave profile of the electricity produced by your system to that flowing through the grid.

For connecting to the Grid in the UK see:

https://www.nationalgrid.com/uk/electricity/connections/applying-connection

Factors affect the cost of inverters:

- Application (utility-interconnected, stand-alone, or both)
- Quality of the electricity it needs to produce for stand-alone
- Voltage of the incoming current
- AC wattage required by your loads (for stand-alone systems only)
- Power required for the starting surge of some equipment
- Additional inverter features such as meters and indicator lights.

When an inverter is sized it pays to plan for any future additional loads that might be required. In the case of a grid-tied system in which you want to enlarge your renewable energy system, it is often cheaper to purchase an inverter with a larger input and output rating than you currently need than to replace it with a larger one later.

4.1.1.4 Safety Equipment

Safety features protect stand-alone and grid-connected small renewable energy systems from being damaged or harming people during events like lightening events, power surges, or malfunctioning equipment.

Safety disconnects: Automatic and manual safety disconnects protect the wiring and components of your small renewable energy system from power surges and other equipment malfunctions. They also ensure that your system can be shut down safely for maintenance and repair. In the case of grid-connected systems, safety disconnects ensure that your generating equipment is isolated from the grid, which is important for the safety of people working on the grid transmission and distribution systems.

Grounding equipment: This equipment provides a well-defined, low-resistance path from your system to the ground to protect your system against current surges from lightning strikes or equipment malfunctions. You will want to ground both your wind turbine or photovoltaics unit itself and your balance-of-system equipment. Be sure to include any exposed metal (such as equipment boxes) that might be touched by you or a service provider.

Surge protection: These devices also help protect your system in the event that it, or nearby power lines (in the case of grid-connected systems), are struck by lightning.

4.1.1.5 Meters and Instrumentation

Meters and other instruments allow monitoring of a small renewable energy system's battery voltage, the amount of power you are consuming, and the level at which your batteries are charged, for example.

If you are connecting your system to the electricity grid, you will need meters to keep track of the electricity your system produces and the electricity you use from the grid. Some power providers will allow you to use a single meter to record the excess electricity your system feeds back into the grid (the meter spins forward when you are drawing electricity, and backward when your system is producing it).

Power providers that don't allow such a net metering arrangement require that you install a second meter to measure the electricity your system feeds into the grid.

4.1.2 Standalone (Off-Grid) Renewable Energy Systems

When connecting a home energy system to the electric grid, it is necessary to consider equipment requirements as well as the power provider's requirements and agreements.

While renewable energy systems are capable of powering houses and small businesses without any connection to the electricity grid, many people prefer the advantages that grid-connection offers.

A grid-connected system allows you to power your home or small business with renewable energy during those periods (daily as well as seasonally) when the sun is shining, the water is running, or the wind is blowing. Any excess electricity you produce is fed back into the grid. When renewable resources are unavailable, electricity from the grid supplies your needs, eliminating the expense of electricity storage devices like batteries.

In addition, most power providers allow net metering; an arrangement where the excess electricity generated by grid-connected renewable energy systems "turns back" your electricity meter as it is fed back into the grid. If you use more electricity than your system feeds into the grid during a given month, you pay your power provider only for the difference between what you used and what you produced.

Some of the things you need to know when thinking about connecting your home energy system to the electric grid include:

1. Equipment required to connect your system to the grid
2. Grid-connection requirements from your power provider
3. National and / or local codes and requirements

4.1.2.1 Equipment Required for Grid-Connected Systems

Aside from the major small renewable energy system components, you will need to purchase some additional equipment (called "balance-of-system") in order to safely transmit electricity to your loads and comply with the power provider's grid-connection requirements. The following items are likely to be required:

1. Power conditioning equipment
2. Safety equipment
3. Meters and instrumentation.

Because grid-connection requirements vary, you or your system supplier/installer should contact your power provider to learn about its specific grid-connection requirements before purchasing any part of your renewable energy system.

4.1.2.2 Grid-Connection Requirements from Your Power Provider

Currently, requirements for connecting distributed generation systems (like home renewable energy or wind systems) to the electricity grid vary widely. But all power providers face a common set of issues in connecting small renewable energy systems to the grid, so regulations usually have to do with safety and power quality, contracts (which may require liability insurance), and metering and rates. You will need to contact your power provider directly to learn about its specific requirements.

4.1.2.3 Addressing Safety and Power Quality for Grid Connection

Power providers want to be sure that your system includes safety and power quality components. These components include switches to disconnect your system from the grid in the event of a power surge or power failure (so maintenance engineers and technicians are not electrocuted) and power conditioning equipment to ensure that your power exactly matches the voltage and frequency of the electricity flowing through the grid.

In an attempt to address safety and power quality issues, several organizations are developing national guidelines for equipment manufacture, operation, and installation (your supplier/installer, a local renewable energy organization, or your power provider will know which of the standards apply to your situation, and how to implement them):

4.1.2.4 Contractual Issues for Grid-Connected Systems

When connecting a small renewable energy system to the grid, you will probably need to sign an interconnection agreement with your power provider. In your agreement, power providers may require you to do the following:

Carry liability insurance: Liability insurance protects the power provider in the event of accidents resulting from the operation of your system.

Pay fees and other charges: You may be asked to pay permitting fees, engineering/inspection fees, metering charges (if a second meter is installed), and stand-by charges (to defray the power provider's cost of maintaining your system as a backup power supply).

Administration Charges: In addition to insurance and fees, you may find that your power provider requires a great deal of paperwork before you can move ahead with your system.

4.1.2.5 Metering and Rate Arrangements for Grid-Connected Systems

With a grid-connected system, when your renewable energy system generates more electricity than you can use at that moment, the electricity goes onto the electric grid for your utility to use elsewhere. The Power Purchase Agreement (PPA) requires power providers to purchase excess power from grid-connected small renewable energy systems at a rate equal to what it costs the power provider to produce the power itself. Power providers generally implement this requirement through various metering arrangements. Here are the metering arrangements you are likely to encounter:

Net purchase and sale: Under this arrangement, two uni-directional meters are installed: one records electricity drawn from the grid, and the other records excess electricity generated and fed back into the grid. You pay retail rate for the electricity you use, and the power provider purchases your excess generation at its avoided cost (wholesale rate). There may be a significant difference between the retail rate you pay and the power provider's avoided cost.

Net metering: Net metering provides the greatest benefit to you as a consumer. Under this arrangement, a single, bi-directional meter is used to record both electricity you draw from the grid and the excess electricity your system feeds back into the grid. The meter spins forward as you draw electricity, and it spins backward as the excess is fed into the grid. If, at the end of the month, you've used more electricity than your system has produced, you pay retail price for that extra electricity. If you've produced more than you've used, the power provider generally pays you for the extra electricity at its avoided cost. The real benefit of net metering is that the power provider essentially pays you retail price for the electricity you feed back into the grid.

4.2 The Smart Grid

A smart grid is an electrical grid which includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficient resources. Electronic power conditioning and control of the production and distribution of electricity are important aspects of the smart grid.

4.2.1 Background

4.2.1.1 Historical development of the electricity grid

a) https://www.youtube.com/watch?v=LD6hWnnsCBE
b) https://www.youtube.com/watch?v=hVu844ZcCdU
c) https://www.youtube.com/watch?v=nbPmsBmo03Y
d) https://www.youtube.com/watch?v=iattHLRbE0Y
e) https://www.youtube.com/watch?v=N8jqbKd8hVg

4.2.2 Modernization opportunities

Since the early 21st century, opportunities to take advantage of improvements in electronic communication technology to resolve the limitations and costs of the electrical grid have become apparent. Technological limitations on metering no longer force peak power prices to be averaged out and passed on to all consumers equally. In parallel, growing concerns over environmental damage from fossil-fired power stations has led to a desire to use large amounts of renewable energy. Dominant forms such as wind power and solar power are highly variable, and so the need for more sophisticated control systems became apparent, to facilitate the connection of sources to the otherwise highly controllable grid. Power from photovoltaic cells (and to a lesser extent wind turbines) has also, significantly, called into question the imperative for large, centralised power stations. The rapidly falling costs point to a major change from the centralised grid topology to one that is highly distributed, with power being both generated and consumed right at the limits of the grid. Finally, growing concern over terrorist attack in some countries has led to calls for a more robust energy grid that is less dependent on centralised power stations that were perceived to be potential attack targets.

4.2.3 Definition of "smart grid"

The first official definition of Smart Grid was provided in the USA by the Energy Independence and Security Act of 2007 (EISA-2007);

… to support the modernization of the Nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth and to achieve each of the following, which together characterize a Smart Grid:

1. Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.
2. Dynamic optimization of grid operations and resources, with full cyber-security.
3. Deployment and integration of distributed resources and generation, including renewable resources.
4. Development and incorporation of demand response, demand-side resources, and energy-efficiency resources.
5. Deployment of 'smart' technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation.
6. Integration of 'smart' appliances and consumer devices.
7. Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal storage air conditioning.
8. Provision to consumers of timely information and control options.
9. Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.
10. Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services."

A common element to most definitions is the application of digital processing and communications to the power grid, making data flow and information management central to the smart grid. Various capabilities result from the deeply integrated use of digital technology with power grids. Integration of the new grid information is one of the key issues in the design of smart grids. Electric utilities now find themselves making three classes of transformations:

1. improvement of infrastructure;
2. addition of the digital layer, which is the essence of the smart grid; and
3. business process transformation, necessary to capitalize on the investments in smart technology.

Much of the work that has been going on in electric grid modernization, especially substation and distribution automation, is now included in the general concept of the smart grid.

4.2.4 Early technological innovations

Smart grid technologies emerged from earlier attempts at using electronic control, metering, and monitoring. In the 1980s, automatic meter reading was used for monitoring loads from large customers and evolved into the Advanced Metering Infrastructure of the 1990s, whose meters could store how electricity was used at different times of the day. Smart meters add continuous communications so that monitoring can be done in real time, and can be used as a gateway to demand response-aware devices and "smart sockets" in the home. Early forms of such demand side management technologies were dynamic demand aware devices that passively sensed the load on the grid by monitoring changes in the power supply frequency. Devices such as industrial and domestic air conditioners, refrigerators and heaters adjusted their duty cycle to avoid activation during times the grid was suffering a peak condition. Beginning in 2000, Italy's Telegestore Project was the first to network large numbers (27 million) of homes using smart meters connected via low bandwidth power line communication. Some experiments used the term Broadband over Power Lines (BPL), while others used wireless technologies such as mesh networking promoted for more reliable connections to disparate devices in the home as well as supporting metering of other utilities such as gas and water.

Monitoring and synchronization of wide area networks were revolutionized in the early 1990s when the Bonneville Power Administration expanded its smart grid research with prototype sensors that are capable of very rapid analysis of anomalies in electricity quality over very large geographic areas. The culmination of this work was the first operational Wide Area Measurement System (WAMS) in 2000. Other countries are rapidly integrating this technology — China started having a comprehensive national WAMS system when the past 5-year economic plan completed in 2012.

The earliest deployments of smart grids include the Italian system Telegestore (2005), the mesh network of Austin, Texas (since 2003), and the smart grid in Boulder, Colorado (2008).

4.2.4.1 Features of the smart grid

The smart grid represents the full suite of current and proposed responses to the challenges of electricity supply. Because of the diverse range of factors there are numerous competing taxonomies and no agreement on a universal definition. Nevertheless, one possible categorization is given here.

4.2.4.1.1 Reliability

The smart grid makes use of technologies such as state estimation, that improve fault detection and allow self-healing of the network without the intervention of technicians. This will ensure more reliable supply of electricity, and reduced vulnerability to natural disasters or attack.

Although multiple routes are touted as a feature of the smart grid, the old grid also featured multiple routes. Initial power lines in the grid were built using a radial model, later connectivity was guaranteed via multiple routes, referred to as a network structure. However, this created a new problem: if the current flow or related effects across the network exceed the limits of any particular network element, it could fail, and the current would be shunted to other network elements, which eventually may fail also, causing a domino effect. See power outage. A technique to prevent this is load shedding by rolling blackout or voltage reduction (brownout).

4.2.4.1.2 Flexibility in network topology

Next-generation transmission and distribution infrastructure will be better able to handle possible bidirectional energy flows, allowing for distributed generation such as from photovoltaic panels on building roofs, but also the use of fuel cells, charging to/from the batteries of electric cars, wind turbines, pumped hydroelectric power, and other sources.

Classic grids were designed for one-way flow of electricity, but if a local sub-network generates more power than it is consuming, the reverse flow can raise safety and reliability issues. A smart grid aims to manage these situations.

4.2.4.1.3 Efficiency

Numerous contributions to overall improvement of the efficiency of energy infrastructure are anticipated from the deployment of smart grid technology, in particular including demand-side management, for example turning off air conditioners during short-term spikes in electricity price, reducing the voltage when possible on distribution lines through Voltage/VAR Optimization (VVO), eliminating truck-rolls for meter reading, and reducing truck-rolls by improved outage management using data from Advanced Metering Infrastructure systems. The overall effect is less redundancy in transmission and distribution lines, and greater utilization of generators, leading to lower power prices.

Load adjustment/Load balancing

The total load connected to the power grid can vary significantly over time. Although the total load is the sum of many individual choices of the clients, the overall load is not a stable, slow varying, increment of the load if a popular television program starts and millions of televisions will draw current instantly. Traditionally, to respond to a rapid increase in power consumption, faster than the start-up time of a large generator, some spare generators are put on a dissipative standby mode. A smart grid may warn all individual television sets, or another larger customer, to reduce the load temporarily (to allow time to start up a larger generator) or continuously (in the case of limited resources). Using mathematical prediction algorithms, it is possible to predict how many standby generators need to be used, to reach a certain failure rate. In the traditional grid, the failure rate can only be reduced at the cost of more standby generators. In a smart grid, the load reduction by even a small portion of the clients may eliminate the problem.

Peak curtailment/levelling and time of use pricing

To reduce demand during the high cost peak usage periods, communications and metering technologies inform smart devices in the home and business when energy demand is high and track how much electricity is used and when it is used. It also gives utility companies the ability to reduce consumption by communicating to devices directly in order to prevent system overloads. Examples would be a utility reducing the usage of a group of electric vehicle-charging stations or shifting temperature set points of air conditioners in a city. To motivate them to cut back use and perform what is called peak curtailment or peak levelling, prices of electricity are increased during high demand periods, and decreased during low demand periods. It is thought that consumers and businesses will tend to consume less during high demand periods if it is possible for consumers and consumer devices to be aware of the high price premium for using electricity at peak periods. This could mean making trade-offs such as cycling on/off air conditioners or running dishwashers at 9 pm instead of 5 pm. When businesses and consumers see a direct economic benefit of using energy at off-peak times, the theory is that they will include energy cost of operation into their consumer device and building construction decisions and hence become more energy efficient.

According to proponents of smart grid plans, this will reduce the amount of spinning reserve that atomic utilities have to keep on stand-by, as the load curve will level itself through a combination of "invisible hand" free-market capitalism and central control of a large number of devices by power management services that pay consumers a portion of the peak power saved by turning their device off.

4.2.4.1.4 Sustainability

The improved flexibility of the smart grid permits greater penetration of highly variable renewable energy sources such as solar power and wind power, even without the addition of energy storage. Current network infrastructure is not built to allow for many distributed feed-in points, and typically even if some feed-in is allowed at the local (distribution) level, the transmission-level infrastructure cannot accommodate it. Rapid fluctuations in distributed generation, such as due to cloudy or gusty weather, present significant challenges to power engineers who need to ensure stable power levels through varying the output of the more controllable generators such as gas turbines and hydroelectric generators. Smart grid technology is a necessary condition for very large amounts of renewable electricity on the grid for this reason.

4.2.4.1.5 Market-enabling

The smart grid allows for systematic communication between suppliers (their energy price) and consumers (their willingness-to-pay), and permits both the suppliers and the consumers to be more flexible and sophisticated in their operational strategies. Only the critical loads will need to pay the peak energy prices, and consumers will be able to be more strategic in when they use energy. Generators with greater flexibility will be able to sell energy strategically for maximum profit, whereas inflexible generators such as base-load steam turbines and wind turbines will receive a varying tariff based on the level of demand and the status of the other generators currently operating. The overall effect is a signal that awards energy efficiency, and energy consumption that is sensitive to the time-varying limitations of the supply. At the domestic level, appliances with a degree of energy storage or thermal mass (such as refrigerators, heat banks, and heat pumps) will be well placed to 'play' the market and seek to minimise energy cost by adapting demand to the lower-cost energy support periods. This is an extension of the dual-tariff energy pricing mentioned above.

4.2.4.1.6 Demand response support

Demand response support allows generators and loads to interact in an automated fashion in real time, coordinating demand to flatten spikes. Eliminating the fraction of demand that occurs in these spikes eliminates the cost of adding reserve generators, cuts wear and tear and extends the life of equipment and allows users to cut their energy bills by telling low priority devices to use energy only when it is cheapest.

Currently, power grid systems have varying degrees of communication within control systems for their high-value assets, such as in generating plants, transmission lines, substations and major energy users. In general information flows one way, from the users and the loads they control back to the utilities. The utilities attempt to meet the demand and succeed or fail to varying degrees (brownouts, rolling blackout, uncontrolled blackout). The total amount of power demand by the users can have a very wide probability distribution which requires spare generating plants in standby mode to respond to the rapidly changing power usage. This one-way flow of information is expensive; the last 10% of generating capacity may be required as little as 1% of the time, and brownouts and outages can be costly to consumers. Demand response can be provided by commercial, residential loads, and industrial loads. Latency of the data flow is a major concern, with some early smart meter architectures allowing actually as long as 24 hours delay in receiving the data, preventing any possible reaction by either supplying or demanding devices.

4.2.4.1.7 Platform for advanced services

As with other industries, use of robust two-way communications, advanced sensors, and distributed computing technology will improve the efficiency, reliability and safety of power delivery and use. It also opens up the potential for entirely new services or improvements on existing ones, such as fire monitoring and alarms that can shut off power, make phone calls to emergency services, etc.

Provision megabits, control power with kilobits, sell the rest

The amount of data required to perform monitoring and switching one's appliances off automatically is very small compared with that already reaching even remote homes to support voice, security, Internet and TV services. Many smart grid bandwidth upgrades are paid for by over-provisioning to also support consumer services and subsidising the communications with energy-related services or subsidizing the energy-related services, such as higher rates during peak hours, with communications. This is particularly true where governments run both sets of services as a public monopoly. Because power and communications companies are generally separate commercial enterprises in North America and Europe, it has required considerable government and large-vendor effort to encourage various enterprises to cooperate. Some, like Cisco, see opportunity in providing devices to consumers very similar to those they have long been providing to industry. Others are data integrators rather than vendors of equipment. While the AC power control standards suggest power-line networking would be the primary means of communication among smart grid and home devices, the bits may not reach the home via Broadband over Power Lines (BPL) initially but by fixed wireless.

4.2.4.2 Technology

The bulk of smart grid technologies are already used in other applications such as manufacturing and telecommunications and are being adapted for use in grid operations.

Integrated communications: Areas for improvement include: substation automation, demand response, distribution automation, supervisory control and data acquisition (SCADA), energy management systems, wireless mesh networks and other technologies, power-line carrier communications, and fibre-optics. Integrated communications will allow for real-time control, information and data exchange to optimize system reliability, asset utilization, and security.

Sensing and measurement: core duties are evaluating congestion and grid stability, monitoring equipment health, energy theft prevention, and control strategies support. Technologies include: advanced microprocessor meters (smart meter) and meter reading equipment, wide-area monitoring systems, dynamic line rating (typically based on online readings by Distributed temperature sensing combined with Real time thermal rating (RTTR) systems), electromagnetic signature measurement/analysis, time-of-use and real-time pricing tools, advanced switches and cables, backscatter radio technology, and Digital protective relays.

Smart meters.

Phasor measurement units. Many in the power systems engineering community believe that the Northeast blackout of 2003 could have been contained to a much smaller area if a wide area phasor measurement network had been in place.

Distributed power flow control: power flow control devices clamp onto existing transmission lines to control the flow of power within. Transmission lines enabled with such devices support greater use of renewable energy by providing more consistent, real-time control over how that energy is routed within the grid. This technology enables the grid to more effectively store intermittent energy from renewables for later use.

Smart power generation using advanced components: smart power generation is a concept of matching electricity generation with demand using multiple identical generators which can start, stop and operate efficiently at chosen load, independently of the others, making them suitable for base load and peaking power generation. Matching supply and demand, called load balancing, is essential for a stable and reliable supply of electricity. Short-term deviations in the balance lead to frequency variations and a prolonged mismatch results in blackouts. Operators of power transmission systems are charged with the balancing task, matching the power output of all the generators to the load of their electrical grid. The load balancing task has become much more challenging as increasingly intermittent and variable generators such as wind turbines and solar cells are added to the grid, forcing other producers to adapt their output much more frequently than has been required in the past.

Power system automation enables rapid diagnosis of and precise solutions to specific grid disruptions or outages. These technologies rely on and contribute to each of the other four key areas. Three technology categories for advanced control methods are: distributed intelligent agents (control systems), analytical tools (software algorithms and high-speed computers), and operational applications (SCADA, substation automation, demand response, etc.). Using artificial intelligence programming techniques, Fujian power grid in China created a wide area protection system that is rapidly able to accurately calculate a control strategy and execute it. The Voltage Stability Monitoring & Control (VSMC) software uses a sensitivity-based successive linear programming method to reliably determine the optimal control solution.

4.3 Smart Homes.

a) https://www.engadget.com/2017/07/24/uk-smart-flexible-grid/
b) https://www.gov.uk/government/news/plan-launched-to-bring-smart-energy-technology-into-homes-and-businesses
c) https://www.engadget.com/2016/10/28/tesla-unveils-its-solar-roof-and-powerwall-2/
d) https://www.loxone.com/enen/how-can-smart-home-technology-create-an-energy-management-system-at-home/

4.4 Communication Technologies

a) https://www.youtube.com/watch?v=Rih7QdPk-Z8
b) https://www.youtube.com/watch?v=zB4-mBQPd7k
c) https://www.youtube.com/watch?v=WQWJzgbdq1E
d) https://www.youtube.com/watch?v=j0ZQc3tJCwQ
e) https://www.youtube.com/watch?v=Tsy19Iapmd4
f) Benefits of Information Communications Technology to Energy Infrastructure (Other Resources A4)
g) Emerging Interdependence of the Electric Power Grid and ICT (Other Resources A4)
h) http://www.elp.com/articles/powergrid_international/print/volume-17/issue-11/features/the-role-communications-smart-grid.html

4.5 Power System Safety and Security

http://magazine.ieee-pes.org/january-february-2012/smart-grid-safe-secure-self-healing/

The existing power delivery system is vulnerable to both natural disasters and intentional attack. A successful terrorist attempt to disrupt the power delivery system could have adverse effects on national security, the economy, and the lives of every citizen. Secure and reliable operation of the electric system is fundamental to national and international economic systems, security, and quality of life.

This is not new: A quote in 1990 from the US Office of Technology Assessment (OTA) … “Terrorists could emulate acts of sabotage in several other countries and destroy critical [power system] components, incapacitating large segments of a transmission network for months. Some of these components are vulnerable to saboteurs with explosives or just high-powered rifles.”

The report also documented the potential costs of widespread outages, estimating them to be in the range of 1 to 5 US dollars per kWh of disrupted service, depending on the length of the outage, the types of customers affected, and a variety of other factors. In the New York City blackout of 1977, for example, damage from looting and arson alone totalled about US$155 million—roughly half of its total cost.

During the 20 years since the OTA report, the situation has become even more complex. Accounting for all critical assets includes thousands of transformers, line reactors, series capacitors, and transmission lines. Protecting all these diverse and widely dispersed assets is impractical. Moreover, cyber, communication, and control layers add new benefits only if they are designed correctly and securely.

4.5.1 Electricity Infrastructure: Increasing Interdependencies

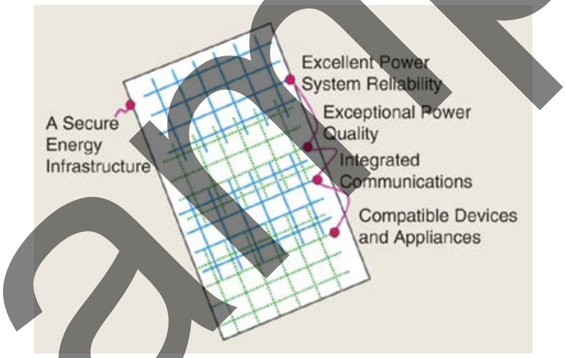

Figure 2 . A complex set of interconnected webs

Energy, telecommunications, transportation, and financial infrastructures are becoming increasingly interconnected, thus posing new challenges for their secure, reliable, and efficient operation. All of these infrastructures are complex networks—geographically dispersed, nonlinear, and interacting both among themselves and with their human owners, operators, and users (see Figure 2).

Virtually every crucial economic and social function depends on the secure and reliable operation of these infrastructures. Indeed, they have provided much of the high standard of living that the more developed countries enjoy. With increased benefit, however, has come increased risk. As these infrastructures have grown more complex in order to handle increasing demands, they have become increasingly interdependent. The Internet, computer networks, and our digital economy have all increased the demand for reliable and disturbance-free electricity; banking and finance depend on the robustness of electric power, cable, and wireless telecommunications infrastructure. Transportation systems, including military and commercial aircraft and land and sea vessels, depend on communication and energy networks. Links between the power grid and telecommunications systems as well as between electrical power lines and oil,