SMART GRIDS

The Practical Implementation of a Modern Electrical Grid

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INTRODUCTION

The advancement of the human species within the last century has truly been an amazing feat. At the turn of the 20th century humans had just begun to develop a true understanding of the natural sciences; the fields of thermodynamics, fluid mechanics, chemistry and biology were growing in leaps and bounds. During this time of transition and discovery, one of the greatest single technologies in human history was developed to an implementable level; electricity. While the discovery of electricity can be traced back millennia to the ancient civilizations of the Egyptians and Greeks it wouldn't be until the two hundred years leading up to 1900 that electricity would receive proper scientific analysis, with the culmination manifesting itself as the implementation of electrical power. With the advent of widely available electricity, we witnessed a paradigm shift. Electricity held the potential to affect every aspect of traditional life at the time, and has played a role in every significant discovery we have had in the last 100 years. The development of the electric lamp loosened our reliance on oil lamp and wax candles, and easily provided clean, bright light at the flip of a switch (the original patent for Edison's carbon filament light bulb can be seen in Figure 1). With the availability of electricity came the implementation of electric motors for both consumer and industrial products. Soon began the development of electrical powered machines which would reduce human labour required for many civilian and industrial tasks. The dawn of the electric age signified the start of the greatest single period of advancement in human history, and this advancement still continues today thanks to the availability of consistent, dependable electricity.

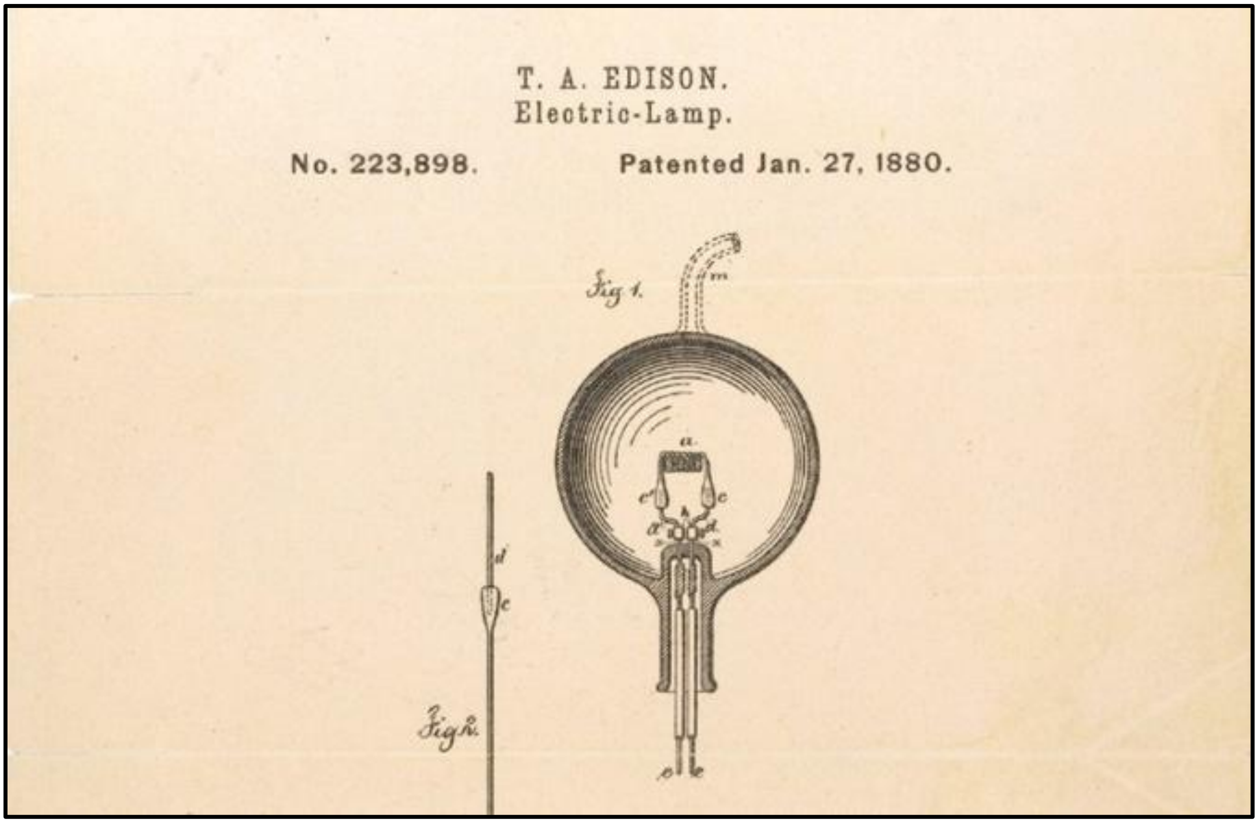

FIGURE 1: – THE ORIGINAL PATENT FOR EDISON'S CARBON FILAMENT INCANDESCENT LIGHTBULB (JOSEPHSON, 1959)

As we have discovered over the last 100 years, it is always possible to improve upon our current implemented technology. When the Wright brothers completed their historic first flight, would they have imagined that a mere 60 years later humans would be able to leave our planet and touch the surface of the moon? Like flight, the utilization of electricity was born into this world on the notion of a few determined individuals and became a continuously evolving entity. However, currently the world's electricity production and distribution philosophy is in dire need of a redesign. For example, in the United States, the majority of the electrical grid infrastructure dates back to the 1960's and 70's. Under current loading trends this aging grid is reaching the upper limits of its supply potential. This is reinforced by the ever increasing frequency of blackouts and power shortages experienced by US citizens. It is expected that energy demand in the United States and the world will triple by 2050 (Massoud, 2013), a feat which will be simply unobtainable with the current electrical system. To solve our energy supply problem, world power grids will have to be re-designed to account for the substantial increase in demand requirements our society will be placing upon them in the next few decades.

With the requirement for revitalization of our power grids understood as fact, it would seem narrow sighted to replace these aging systems with a larger capacity traditional power supply grids. With the advancement in micro processing, wireless data transmission, intelligent controls, mechanical, electrical and materials sciences, it would seem foolish to neglect these technologies in the implementation of a new age electrical supply grid. For this reason, the most promising future for modern electrical energy distribution lies with the smart grid; an electrical grid distribution design philosophy incorporating modern digital data logging, two way communication, parallel computing and modern transmission technology into one analogous system possible of adjusting electrical production and supply in real time to provide optimal power flow to all customers and simultaneously, reducing losses and inefficiencies associated with the traditional grid system.

HISTORY OF POWER PRODUCTION AND SUPPLY

With the advent of the incandescent light bulb in the 1880's, it became apparent that electricity had enormous potential for both the industrial, commercial and civilian markets. In 1879 with Thomas Edisons' patient on the carbon filament incandescent light bulb, electric lamps began to phase out oil fired ones as electric light offered a brighter, cleaner lower maintenance alternative (Josephson, 1959). However, these new electric lamps were useless without a stable source of electrical power. During the fledgling days of the electric lamp, most customers happened to be industrial clients wishing for an alternative to oil lamp light in factory applications. Many of the initial lighting installations incorporated miniature generating plants for the sole purpose of providing the operation with electricity for lighting. These early small scale "power plants" typically consisted of a DC generator (dynamo) powered by a coal fired steam engine (Granovetter & McGuire, 1998). While this system worked well for large industrial operations, electricity & electric light was gaining popularity with both government and the general public, and centralized distribution appeared more practical and profitable for wide scale electrical connectivity, especially to men like Thomas Edison.

During the early days of electricity, few were more involved in the development of electrical technology then Thomas Edison. Seeing the vast potential of electricity to change the lives of the people utilizing it, Edison spend his time and resources developing both electrical consumer products, but also the machines and systems required for power generation. Edison was a strong believer in DC current, and as such focused his attention and resources on the development of DC technology. Edison also believed that electrical energy should be considered a primary commodity to be regulated and sold to a customer base in the same fashion as coal or oil. With this philosophy in mind, Edison constructed the Pearl Street Station on Manhattan Island in New York as seen in Figure 2; the first centralized power generation and distribution facility in the United States (Josephson, 1959). Producing DC electricity via the use of a 175

Horsepower 700rpm steam engine and an Edison electric Dynamo, Pearl Street serviced 400 Electric Lamps for 85 customers in the downtown Manhattan area upon its completion in September 1882. In only 2 years this number increased to 500 customers servicing 10 000 lamps (Josephson, 1959)

FIGURE 2: EDISON'S ORIGINAL PEARL STREET STATION. (JOSEPHSON, 1959).

The power generated at Pearl Street was all DC and produced at the load voltage of approximately 100 volts, depending on proximity to the generating station. At this time DC voltage transforming was not a practical option, which forced DC generation stations to provide power at the low supply voltage. Due to this requirement, transmission cables had to be of significant diameter to carry enough current to mitigate transmission losses, as DC degrades quite rapidly during transmission and as such generation stations were required to be in close proximity to the consumer. Implementation of DC power, with its simplicity and rapidly increasing uses, allowed for rapid mobilization and installation of electric lighting and power metering devices but would not be the solution to the large scale energization problem. While Edison spent his time focused on improving his DC generation and transmission systems, a rival philosophy was gaining recognition; Alternating Current electricity. With the help of Nikola Tesla, George Westinghouse developed the first successful AC generation and distribution system, a system which would rival Edison's DC philosophy and lead to what was known as the War of the Currents. This struggle for the dominant current ended with Westinghouse's AC generation and distribution system emerging victorious, and led to the wide scale implementation of AC power systems.

AC power is superior to DC power in several ways, but most significantly when versatility and transmission losses. As discovered by early AC pioneers such as Tesla, AC voltage is readily transformed to a multitude of different voltages and is easily stepped down with the use of a transformer. Because of this, AC electricity can be transmitted at very high voltage to its required destination, and locally transformed to a much lower voltage for domestic and commercial use. As high voltage transmission is possible with AC current, it is possible to use smaller transmission lines and equipment as compared to DC current, and rectification of the AC power is readily implementable for applications where DC power is required. High voltage AC current experiences significantly lower transmission losses then low voltage DC on the basis of I^2R losses, where the transmission loss is proportional to the square of the transmitted current times the resistance. For the same equivalent power load, a high voltage AC transmission line will carry significantly less current than a low voltage DC line, and thus produce significantly less transmission losses. For these reasons, AC was considered superior to DC electricity, and was chosen as the world standard for power generation and transmission.

Once the potential of electricity was realized by the general public, electrification became widespread through the population centers of North America. While development of electrical networks was most prominent in the largest of metropolitan areas, electricity production began to appear in more isolated areas, though most electrical production in these smaller population centers could be attributed to privately owned micro-plants producing electricity for one or more industrial processes or commercial operations. (Granovetter & McGuire, 1998). During the early days of electrification, electrical network construction and supply originated through venture capitalism. Electrical generating systems and associated networking was often implemented for supply to individual apartment complexes and housing communities, industrial operations and commercial ventures. Within the United States more than half of all electricity consumed until 1930 was generated via private industry as opposed to centralized operations (Granovetter & McGuire, 1998). As most of the supply of electricity was controlled by private industry, much of the development of the electrical grid was left to those supplying the electricity. As demand for power increased, many of these privately operated stations increased their supply area by increasing their supply range, effectively creating the groundwork for the first true North American electrical grid (Granovetter & McGuire, 1998).

As North America entered the end of the 1920’s and into the 1930’s, demand for electricity increased significantly as the development of electricity utilizing technologies became readily available to general public. Development of electricity generating technology had continued throughout this same time period; steam turbines utilized for generating electricity continued to grow in size and efficiency and by 1930 most of the small scale steam engine electrical generation plants had been replaced by large centralized plants owned and operated vastly by conglomerations of pioneering electricity supply companies (Kaplan, 2009). As this transition occurred, the grid connectivity between regions, counties, states and provinces increased as individual utilities wished to increase production productivity and load balancing through the transfer of available generated current to jurisdictions in need of supplemental peak power. Electrification and grid connectivity continued across the continent well through the 1960's and 1970's. By this time electrification of the vast majority of small communities throughout Canada and the United States had occurred, and the continued development of an improved high level electrical grid slowed to a halt (Massoud, 2013), as power requirements for population centers large and small appeared satisfied. As the population grew across North America, larger, more efficient and more numerous power stations were constructed to meet the growing demand of our electrified society.

WHERE WE ARE NOW: THE PROBLEMS WITH OUR AGING GRID.

Currently the power grid in North America is entering a very critical point. With much of the electrical generation and distribution infrastructure currently implemented throughout Canada and the United States dating as far back as the 1970's, the age of these systems is starting to become apparent. The population of North America increased 100 million people between the years of 1970 and 2010. This substantial increase in population has imparted significant modification of the 70's era electrical system and has transformed it into what it is today. With the significant level of modification the existing grid as experienced over the last 40 years, issues are beginning to arise with interruptions and fluctuations in sections of the power supply. The electrical grid in the United States is a prime example of an electrical system in dire need of upgrade. Currently only 0.17% of revenue generated from electrical sales in the US is reinvested for electrical research and development; only the pulp and paper industry in the US receives less capital investment. As such the current US electrical system was ranked 20th in the world in a 2011 study conducted by the World Economic Forum (Massoud, 2013).

As many of the electrical grids across the continent evolved as self-sufficient entities with grid interconnection arriving later, load balancing between electrical networks can be challenging at times. Due to the patchwork nature of the system and the large population influx over the last 40 years, certain sections of Canada and the United States are very close to the limits of their current electrical supply capacity. This is quite apparent as the number of blackouts and brownouts increases every year, due partly to the increase in intensity of global weather patterns as well as the inability of certain sections of the grid to match complete peak demand under extreme load conditions. On any given day in the United States, 50 000 customers are without power for 2 or more hours due to blackouts and brownouts (Massoud, 2013).

The production of electricity in North America is based primarily on fossil fuel fired operations; production facilities which produce a significant quantity of greenhouse gases and airborne pollutants. Renewables such as hydro, solar and wind do account for a substantial amount of electricity production but they are generally region dependant, and their variability can cause connectivity and distribution issues with the current grid. In Canada, Hydroelectricity accounts for 62% of electricity produced, while coal only produces 14%. However the production of electricity from coal in Canada accounts for approximately 15% of the country wide CO_2 emissions (Weis, Thibault, Partington, Gibson, & Anderson, 2012). Coal and natural gas electricity production accounts for more than 50% of all electricity produced in the United States, accounting for 2.6 Billion MWh_e in 2013 (Kaplan, 2009); an industry which annually produces 24% of all greenhouse gas emission in the United States (Lin & Chen, 2013). As most of the coal fired power plants in North America were built and commissioned in the 1960's and 1970's, many of these facilities are coming to the end of their lifecycles, and will soon be in need of replacement, or major refurbishment. Many of these old plants are no longer meeting emissions compliance and partial or complete shutdown may offer a more economical solution then retrofitting these aging facilities. Such is the case with Nanitcoke Power station in Nanticoke Ontario. Constructed in phases during much of the 1970's the operation was responsible for 4 GW peak generating potential, but with increasing environmental pressures half of the plant was decommissioned in 2010 in efforts to reduce the greenhouse gas emissions in Southern Ontario, with the remainder of the plant decommissioned in late 2013 (Weis, Thibault, Partington, Gibson, & Anderson, 2012).

FIGURE 3: NANTICOKE POWER GENERATING FACILITY IN NANTICOKE ONTARIO. ONCE THE LARGEST COAL FIRED PLANT IN NORTH AMERICA AT 4 GW PEAK CAPACITY, HAS BEEN DECOMMISSIONED AS OF DECEMBER 2013 (WEIS, THIBAULT, PARTINGTON, GIBSON, & ANDERSON, 2012).

Renewable energy may offer a solution to the current global concern of rising greenhouse gas emission levels. To achieve a noticeable change in the current greenhouse gas emission trends in North America, 20% of all electricity will have to be generated with renewable energy (Lin & Chen, 2013). Currently 12% of the electricity in North America is via renewables. While initiatives are in place in Canada and the US to promote investment in renewables, the current electrical grid is providing the largest road block in wide scale implementation of renewables. Renewable generating methods such as solar and wind have the largest potential for impact on the North American electrical market but their variability under changing environmental conditions has the potential to place excessive strain upon the current electrical grid. Spikes and drops in power production from renewables introduce unfavorable characteristics into the distribution grid, and without the proper protection along the grid, renewable power fluctuations have the potential to create brownout or blackouts in areas with a grid ill-suited for renewables. Until the infrastructure in much of North America is replaced and revitalized it will be unreasonable to assume condition dependant renewables will replace the continuous power of the fossil fuel fired generating facility.

SMART GRID

The introduction of the internet and ad hoc systems into the modern workplace resulted in a leap forward in the way that business could be carried out. By networking data transmissions together, process control was made easier, which allow for an increase in the flexibility of industrial system operation. These advances could result in anything from easy compensation during process upsets in chemical plants or refineries to the optimization of traffic flow patterns in response to shifting road conditions. While the advances in the utilization of these ad hoc networks has affected layers of modern industry, it has had a limited effect on the power grid. As of 2010, the North American distribution grid had information and communication systems in only one quarter of their network (Farhangi, 2010). To move the grid into the future, and prevent the service interruptions that plague the current system, the idea of a smart grid was formed.

A smart grid can be most easily defined as a collection of independent interwoven micro-grids. These grids must be able to integrate data from the consumers, the distributors and the producers of power. This information is used to effectively optimize the power grid economically and environmentally, all while becoming safer and more reliable. These smaller grids accomplish this goal by allowing the demand to be shared amongst a large number of smaller intelligent production and distribution systems, allowing for greater overall system flexibility. These subsystems are in constant communication, which allows for constant demand based optimization of power generation, which in turn will reduce the number of blackouts and brownouts. The constant system communication can also allow for the users to provide feedback, which can potentially allow them to set preferences for where they draw their energy from, giving users an easy way to choose greener power. Overall, these advantages should allow for the system to avoid service interruption, while opening a niche market for renewables and small scale power generation. In order for the system to properly carry out the functions described above, these micro-grids should consist of both traditional base load and unconventional condition based power systems tied together with advanced metering and distribution.

BASE LOAD POWER

The effects of smart grid technology on large generating stations will reduce the total emission of carbon dioxide and other pollutants in two ways. First, the use of smart controls will allow for power stations to continuously operate as close as possible to their point of optimum efficiency, minimizing the emissions per unit of power generated. Second, by replacing power stations such as the Sundance coal plant in Edmonton Alberta (Figure 4), which is the single greatest emitter of greenhouse gases in the country (Weis, Thibault, Partington, Gibson, & Anderson, 2012) with systems of distributed energy generation and storage will open up a window of opportunity for environmentally friendly technologies, such as wind and solar to gain a larger share of the market.

In its essence, the base load power generation is the most archaic portion of the smart grid. These stations will connect into the grid in much the same way that they currently do, and will consist of the same types of generators for which society currently draws its power. Primarily nuclear stations, hydro plants and fossil fuel fired generation stations, base load power will continue to provide a stable base in a smart grid system, although its function will be somewhat reduced. Given that residential and commercial power fluctuate significantly throughout the day, a system designed to provide more or less constant output is not ideal for their service. In a smart grid system, these residential loads will be increasingly met by a growth in the number of smaller scale energy systems, thereby reducing the demand required from the large base load stations (Qi & Ariyur, 2011). These condition based power sources will become increasingly important in the overall power market.

FIGURE 4: SUNDANCE COAL FIRED GENERATION STATION (WEIS, THIBAULT, PARTINGTON, GIBSON, & ANDERSON, 2012)

CONDITION BASED POWER

Condition based power refers to any source of energy that alters output due to changes in operating conditions. These energy sources would make up the difference between what the base load power is able to produce and what the individual users consume during all hours, but especially at peak usage times. In fact, the dichotomy between the peak usage hours and regular hours is so great in the current electrical grid that 20% of all generation was constructed to account for the peak demand, and essentially exists only to operate 5% of the time (Farhangi, 2010). The term ‘conditional’ could refer to environmentally based conditions such as wind and solar rates, or it could refer to operational conditions, such as rising peak power demand.

ENVIRONMENTAL CONDITION BASED POWER

A power source which is said to be environmental condition based refers to the fact that the source requires a particular set of physical conditions to exist in order for it to function. While the fuel for these plants is usually free, their inherent unpredictability makes them poor choices for use as base load generation station. The fastest growing sources of renewable, condition based energy come from the wind and solar sectors (Moslehi & Kumar, 2010), and each of these industries is set to play an important part in the energy system of the future. While they are both incredibly useful, they are very dissimilar, and each comes with their individual advantages and disadvantages.

WIND

Wind energy has been growing globally at a breakneck pace for years. It has now reached a level of maturity great enough that it is no longer considered a fringe producer of power, but is a widely used power source, especially in European markets, such as Germany and Spain (Carrasco, et al., 2006). In fact, it is expected that wind power will contribute an astounding 20% of the power generation of Europe by the year 2020 (Liserre, Sauter, & Hung, 2010), and is expected to reach that mark in the United States by the year 2030 (Moslehi & Kumar, 2010). This rapid rise in the feasibility of wind energy from being a little used technology to a major player in the global market is due in part to the introduction of smart technologies such as variable speed turbines which allow for the power output to remain at the desired frequencies over large ranges of wind speeds (Carrasco, et al., 2006).

These turbines are capable of producing huge quantities of energy, and large systems such as the Jiuquan wind power farm (Figure 5), with a capacity of over 10 GW (Xu, et al., 2009) would be able to produce equal amounts of power as large conventional generation stations. Unfortunately, this large potential for power generation comes with several caveats. First, it is semi-random by nature, meaning these stations require there to be wind to operate, and given that there is no fool proof way to predict the future wind speeds, the generation provided can be wildly unreliable. Furthermore, there is no link between the fluctuations of wind speeds that matches with the changes in human power consumption, whether that be over the period of a day or a year (Moslehi & Kumar, 2010). This means that even if the wind is strong enough to allow the generators to operate at full capacity, it might be doing so at a time where no one needs the power. Finally, the large sources of wind energy are frequently found far away from major population centers, which will introduce large transmission losses into the system (Moslehi & Kumar, 2010).

FIGURE 5: JIUQUAN WIND FARM (YUANYUAN, 2012)

To combat this, inventive and efficient methods of energy storage will need to be implemented. Which gives rise to the concept of a hybrid energy system. Like in a car, the hybrid system will allow the excess energy produced from one source be converted into another for use at a later time. Systems such as battery capacitors, flywheels (Liserre, Sauter, & Hung, 2010) and pumped water storage (Moslehi & Kumar, 2010) have been considered for this purpose, but the concept of storage is not as simple as in a car. Certain productive aspects of the power grid (like diesel engines) are not able to handle fast stop/start cycles, meaning the total capacity of the storage systems must be carefully controlled with respect to the power output so as to minimize the damage caused by system cycling.

SOLAR

Similar to wind energy, solar power has experienced huge gains in recent years; with the solar electric sector growing by 20%-25% per year since the 1990's. Increased efficiency, as well as new manufacturing techniques that allow for panels to be constructed efficiently have allowed the cost of solar electric energy to be reduced, driving growth (Carrasco, et al., 2006). While photovoltaic (PV) cells produce DC power, they must run through inverters in order to meet the DC requirements of the modern electrical grid, which will invariably introduce power losses. In addition to the PV resources, solar energy can be collected through mirror arrays and focused to produce large quantities of solar heat. This heat can be used to boil water to very high temperatures, allowing it to be used in conventional Rankine cycle production.

Solar plants face many of the same problems as wind farms. Many of the major solar resources are located far away from population centers, meaning that there may be large transmission losses from energy transit. A good example of this is the Ivanpah generation station (Figure 6), which is located in the Mojave Desert. Unlike wind however, solar power does match up well with some aspects of consumer demand; yearly peak solar output sees a direct correlation with the demand load created from the use of air conditioners (Moslehi & Kumar, 2010). In addition, during periods of high production and low demand, the energy could be re-routed to the same power storage systems that are used by wind energy, which will allow these peaks and troughs in supply to be flattened out. While energy storage may help locations which experience fluctuating periods of solar radiation, it will do little for regions which experience relatively little sunshine. In the cases where these areas of low solar irradiation also have low or unreliable wind speeds, the smart grid must rely on other technologies to produce the necessary condition based generation.

FIGURE 6: IVANPAH GENERATION STATION (ZIPP, 2013)

OPERATIONAL CONDITION BASED GENERATION

When there are few natural sources of energy present in a location, the smart grid must turn to existing technologies for its power. While conventional base load power will be able to provide a large portion of the needed energy for these locations, these plants are rigid in their output, with a greatly limited ability to respond to changes in demand. For this purpose, smaller scale generators are currently used, and with some modification, could work well in a smart grid system. Since they lack the large thermal mass associated with boilers, Brayton cycle generators are particularly excellent at meeting these variations in demand, being able to go from idle to full operation in a relatively short period of time. Also, since they lack a full boiler and condenser system, they require a smaller physical footprint, and don't have to be close to a waterbody. While the system typically requires the use of a combustible fuel, simply moving from a coal based system to one that uses natural gas will greatly improve the emissions generated by the facility. When the use of a cleaner fuel is combined with the intelligent control of a smart grid, which allows the plant to operate as close as possible to its point of maximum efficiency, the system will allow for significant environmental savings over the older coal based plants.

SYSTEM SECURITY

By relaying data from the consumer of power back to the producers and distributers, it has been shown that smart grids are able to simultaneously optimize energy flow and ensure the stability of the power grid. By de-centralizing the grid into many interwoven micro-grids, many of the security issues that revolved around the physical safety of individual power stations, the loss of which would debilitate the electrical system is greatly reduced. While it prevents many of the old issues, this modernization of the electrical grid brings with it with a significant amount of risk. The emergence of cyber-terrorism in recent years has had an enormous effect on digital systems. Since a smart grid relies on controlling systems based on the effective transmission of information between the user, distributor and producer, it opens up whole new avenues of risk. Cyber-attacks could target the software which controls the grid, which could cause widespread blackouts, damage to consumer electronics, or even loss of control of the smart grid infrastructure (Khurana, Hadley, Lu, & Frincke, 2010). This last possibility could allow outside attacks to influence equipment which is under the control of the smart grid, such as home and business automation, or virtually any aspect of the power distribution system. Ultimately, these attacks could result in unfathomable damage to the power utility infrastructure, as well as loss of life (Khurana, Hadley, Lu, & Frincke, 2010). To prevent these terrible acts from occurring, there needs to be a thick layer of digital security placed on these vital systems. There are several measures that will be able to increase the security of the smart grid to new levels.

First, the data could be segmented according to individual attributes. Segmentation refers to the separation of different types of information from one another through the use of firewalls, which would prevent unwanted intrusions which have been introduced into one system from branching out and harming others (Flick & Morehouse, 2011). Encryption could also be used to this effect, where access to various layers of data is restricted in order to control which users access which information. Code command signing, which refers to the need to input validation information in order for a piece of software to be integrated into a system (Flick & Morehouse, 2011). This would prevent intrusions by making it difficult for hackers to install their own malicious code into otherwise healthy systems. Finally, honeypots could be used to trap and identify hackers. Honeypots are seemingly vulnerable systems which appear to be productive, and would seem to carry the sort of information that an intrusion would be designed to apprehend. In fact, these systems are fully isolated from the main system, and can be set to send alerts when attacked, or even to deliver false information which will send the intruders to several areas which all present themselves in a similar fashion (Flick & Morehouse, 2011). Honeypots are commonly used in industry to allow companies to understand the types, frequencies and sources of intrusions that they are facing. This in turn allows them to be prepared when these systems attack their actual data.

Ultimately, the security threats posed to smart grids will present risk, but in order for the system to work properly, there must be an underlying trust that it will function properly, and that the information it carries is secure. In a modern age which has seen countless intrusions from governments and malicious third parties into nearly every aspect of our lives, this trust may be dubious at best, but it is the pillar on which the smart grid stands.

SMART METERING AND THE OPTIMAL POWER FLOW PROBLEM

The largest advantage the implementation of a smart grid has over the traditional grid comes from the two way communication proposed with the smart grid system. Under traditional grid loading scenarios, fluctuations in power consumption of a given area must be properly predicted from historical trend data in efforts to keep power supplied from the generating stations balanced with the demand, and as such many power generating authorities require large stand-by generating capacity in the form of natural gas fired turbines. If power consumption predictions are inaccurate, the resulting supply imbalance can result in shortages causing brownouts and potential blackouts, or on the other hand, surplus power which must be sold at a lower cost or distributed elsewhere. These imbalances are a significant source of inefficiency, and these transient periods account for many of the system failures occurring in the North American grid (Ipakchi & Albuyeh, 2009). With the implementation of a two-way communication network between the supplier and the individual demand, the principles of control theory can be implemented to increase the response time of the electrical system as a whole, and provide real time usage data to the supplier which will reduce the chances of demand saturation.

Implementation of two way communication between electricity supplier and the customer will require the installation of smart meters in the place of an electrical grid's traditional power meters. The defining factor which sets the smart meter apart from a traditional meter is its connection to the central generating authority via network communication. Typically the smart meter network consists of several levels of control between the customer meter and the central producer. A fully functional two-way smart grid system will process usage data at each point of sale. Depending on the complexity of the system the data is then fed back into computing equipment installed in the transformers and bus bars, or to the central processing unit in the power generating station (Lin & Chen, 2013).While simple two way meter systems are much less complex then smart systems which integrate intermediate computing in individual transformers and bus bars, the additional processing power available from these intermediate systems allow for significantly increased network processing power through the utilization of parallel computing between intermediate transformer processor stations and the central processing unit.

Implementation of two-way communication between the demand and the electrical supplier offers the potential for sophisticated controls software, such as optimal power flow simulation algorithms. In typical smart grid systems data collected from smart meters throughout the supply jurisdiction provide live raw data content for the purpose of analysis via optimal power flow simulation. The optimal power flow simulation offers real time system control potential for an electrical system through computation of physically collected data and uses it to adjust to real time usage as well as predict changes in grid loading (Lin & Chen, 2013). A properly balanced optimal power flow simulation algorithm will take into account all electrical demand points, as well as static and dynamic generating stations such as fossil fuel fired and renewable plants respectively. By incorporating all relevant supply and demand data with known limits of the distribution network such as line load limits, bus voltage limits, and transformer characteristics, the optimal power flow simulation is able to produce real time power consumption trends, and calculate significantly more accurate predictions of required power during transient periods. By implementing real time consumption data with the use of optimal power flow algorithms, it is possible for the smart grid to balance the grid at an unprecedented level. By having continuous live data supplied from all points of the grid, the smart systems controlled by the optimal power flow algorithms will be able to balance multiple supply and load points simultaneously. This process is significantly improved if parallel computing is utilized between the remote processing potential of the smart meter processors and the centralized processing units installed in the power stations. By splitting the data required for processing between multiple processors and computing simultaneously, complicated algorithms can be calculated significantly more quickly which results in a much more accurate representation of the current state of the smart grid power system (Lin & Chen, 2013).

By utilizing a two-way communication network and a sophisticated system of optimal power flow controls significant energy savings may be possible. The optimal power flow solution offers energy savings via two methods; reduction in transient wastage, and increased utilization of renewables. By incorporating smart grid technology and optimal power flow controls, power generating authorities will have access to much more accurate and up to date consumption data. Access to data such as this will allow for a reduction in the safety factor associated with transient power production during peak hours of consumption. By confidently reducing the quantity of electricity produced during these times, significant economic and environmental savings can be achieved. Implementation of smart grid networks and optimal power flow simulation will also increase the accessibility of renewable energy to the domestic electrical grid. The variability in power generated by renewable resources inhibits their usefulness within a traditional grid setting, as fluctuations within a traditional grid are much more difficult to control, and many times renewables are disconnected from the grid during transient production periods rather than introducing the potential for supply fluctuations and possible system overload or failure. With the use of a smart grid with optimal power flow simulation, grid system power balancing of renewable resources becomes significantly easier than implementation in the traditional grid (Lin & Chen, 2013). This ease of implementation comes from the ability to actively monitor power generated at each renewable terminal simultaneously to the demand from the rest of the grid, and actively balance the generated current load between 1 or all customers simultaneously. Having the ability to provide this level of grid balance will allow for wide spread implementation of renewables, effectively reducing North America's reliance on fossil fuel fired power stations for base and peak loading.

CONCLUSION

The current electrical system is in dire need of an overhaul. Low levels of reinvestment into the power grid has resulted in ballooning yearly costs associated with repairing the damages caused by service interruptions. Additionally, as social and political turmoil has caused growing concern over the safety of the modern electrical grid, a system with reduced vulnerabilities is highly desired. These pressures on the current system will naturally result in a new method of power production and distribution. By adapting the smart grid as the new electrical distribution network, the current issues can be alleviated with the added benefit of creating a niche market for emerging renewable technologies. By switching to a smart grid, many of the concerns related to physical damages to the equipment are alleviated, although care must be taken to avoid the potentially catastrophic effects that could result from an infiltration into the smart grid networks. Through the use of modern industrial networking technologies, smart grids will allow the power generation and distribution system to perform at the level expected of a modern day utility.

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