Enhancing Smart Grid Technology to the Consumer Level

Varnika Sinha

Introduction: Energy and Its Fundamental Impact on Human Society

Energy is a vital human resource. Humans are constantly using energy. The human body requires energy derived from food to operate the necessary processes of life. Like the human body, machines also require energy. Machines rely on electricity to operate. In today's world, electricity is a necessary source of energy humans need. However, humans are destroying the earth in the process of collecting and utilizing this energy.

Often, consumers are unaware of how they are wasting electricity when using appliances. **Figure 1** shows the annual cost and the average amount of electricity consumed by the most common household appliances by consumers per year. Consumers typically use appliances at suboptimal times when electricity is in great demand. The primary time consumers use their appliances is during the evening, specifically from 6-8 pm (C. Lavertu, personal communication, August 26, 2016). During this time, the vast majority of electricity sent to consumer homes is generated by fossil fuels. The overexertion of fossil fuels is the primary cause of global warming (U.S. Department of Energy, 2016). Global warming is a huge problem. Climates are changing, and the balance of many ecosystems throughout the earth is becoming shattered.

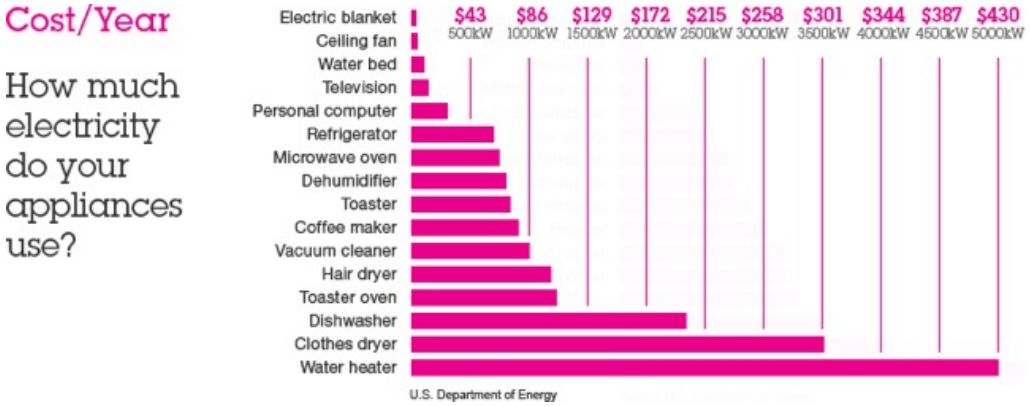

Figure 1: The graph above shows the cost (dollars) and the average electricity consumption (kWh) of the most common household appliances by consumers per year. Many consumers are unaware of the information displayed in the graph. (U.S. Department of Energy, 2016)

Renewable energy is promoted as a way to save the earth from the effects of global warming, but it is scarcely used in comparison to fossil fuels for generating electricity. Renewable energy is not integrated into many consumers' daily consumption of electricity (C. Lavertu, personal communication, August 26, 2016). Many consumers are unaware of how to use electricity wisely. This lack of awareness leads to overexertion of fossil fuels and minimization of renewable energy, both of which further the severity of global warming.

Electricity Generation

Energy Sources: When and How Much of Which Type

In order to fulfill a consumer's daily consumption, energy must be generated from a source that provides a potential of converting energy usable by humans. Planet Earth provides humans with many raw resources of energy that have the potential to be converted into usable energy. The primary types of electricity used by humans are thermal, nuclear, hydropower, photovoltaic, and wind (U.S. Department of Energy, 2016). **Figure 2** shows the percentage of each type of electricity used to generate electricity in the United States as of 2016.

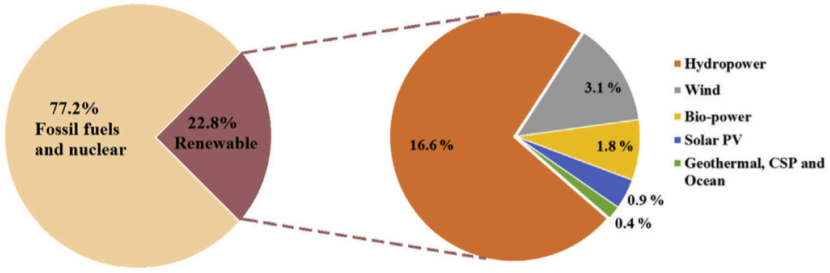

Figure 2: This chart displays the percent of each type of electricity used in the United States electricity generation. The pie chart on the left compares thermal energy to renewable energy, and the pie chart on the right compares the sources of renewable energy. (Ellabban and Abu-Rub, 2016)

Thermal energy is currently the most commonly used to produce the world's electricity. Thermal energy is defined as raw resources that produce steam to turn turbines to generate electricity (Pierce, 2015). According to the U.S. Department of Energy, in 2015, the United States generated about 4 trillion kilowatt-hours (kWh) of electricity. About 67% of the electricity generated was from fossil fuels. Fossil fuels are a sub category of thermal energy. The electrical generation of fossil fuels is the leading cause of global warming.

When fossils fuels are used at electrical generation plants, these plants take raw materials such as coal, natural gas, and petroleum as fuel to heat water at high temperatures. These high temperatures produce steam which turns turbines to generate electricity. Excess materials, products from the chemical reactions, exit the plant as emissions. These emissions release harmful chemicals in the air which are harmful to humans and the earth. **Figure 3** displays the greenhouse effect using carbon dioxide as an example for an emission. The greenhouse effect is the process where excess energy heats up the earth to eventually high temperatures not suitable for life. The greenhouse effect subsequently causes global warming.

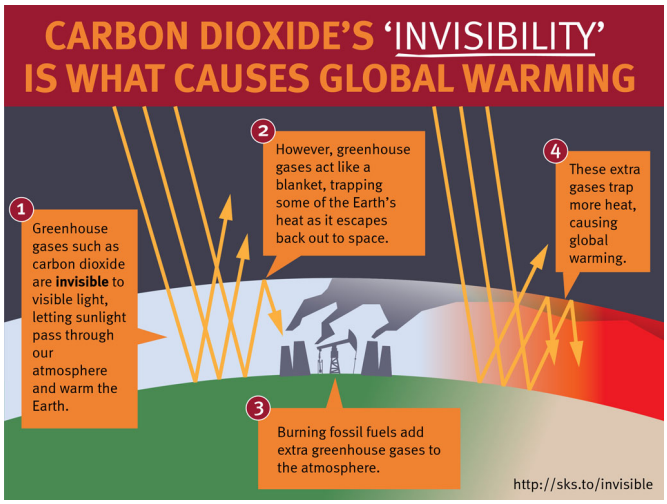

Figure 3: This figure selects carbon dioxide, one of the well-known emissions produced by fossil fuels, as an example to show how the greenhouse effect subsequently causes global warming. (Cook, 2013)

Renewable Energy Potential: Ways to Make Earth Cleaner

Renewable energy is a viable alternative to thermal energy. Renewable energy is a cleaner, more versatile, and more abundant resource than thermal energy. In fact, renewable energy is unlimited and can be found almost anywhere on Earth. However, it is less used than thermal energy. Renewable energy is underutilized in human electricity consumption (C. Lavertu, personal communication, November 23, 2016).

The main types of renewable energy are hydropower, photovoltaic (solar), and wind. These resources are constantly replenished on Earth. Harnessing renewable energy is much easier than harnessing thermal energy. These resources are also cleaner because they produce no harmful by products that would greatly affect the earth at large (Cook, 2013).

In **Figure 4**, a map of solar energy is shown. This map predicts the amount electricity harnessed kWh/m^2 if utilized. A lot of this energy is left unutilized simply because utility companies don't harness it. Solar energy is one of the most promising renewable energy sources (Pierce, 2016). Upon careful examination of **Figure 4**, solar energy has a lot of potential to be harnessed in developing countries. The most concentrated patches of solar energy are

around the equator, where coincidentally, there are a lot of developing countries. Developing countries have problems with generating sufficient electricity to fulfill the necessary requirement of using electricity (Ellabban and Abu-Rub, 2016). If this solar energy shown in **Figure 4** was utilized, the developing countries within this area would have no problems in generating sufficient electricity.

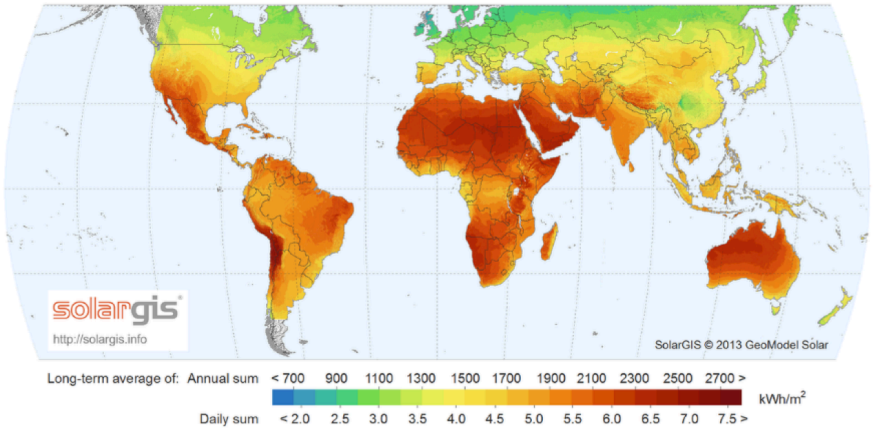

Figure 4: Map of predicted electricity generation if all solar energy was harnessed. (Solargis, 2016)

Household Power

After electricity is generated at electrical generation plants, the electricity is transferred through a system similar as displayed in **Figure 6**. Because there are third parties involved between the path electricity takes to get from generation plants to the consumers' homes, it is often difficult for consumers to understand how much electricity they are using. They are unaware of how much electricity is generated because they are not directly interacting with their electric supply (McNally, 2013).

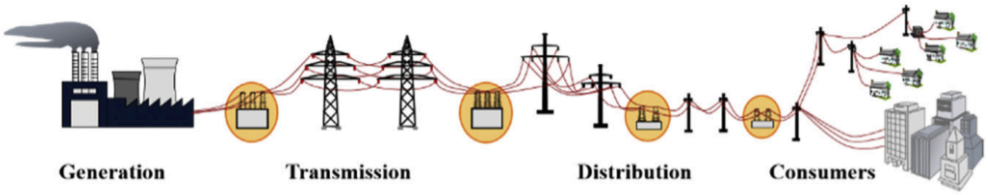

Figure 6: The figure above shows the path electricity takes from the generation plant to consumers' homes. (Ellabban and Abu-Rub, 2016)

To travel from generation plants to consumers' home, electricity must be converted into high voltages in order to travel quickly on the transmission lines. Electricity when generated is around 110 volts to 120 volts in the United States, but when it must be transferred it increases to 10,000 volts. The increase in voltage helps transfer huge amounts of electricity in short bursts of time. When electricity reaches the consumers home, it returns to the 110-120 volt range for the consumer to use safely (McNally, 2013).

Electricity flows in two ways, direct current (DC) and alternating current (AC). Direct current is when electricity is flowing in only one direction. When traveling from generation plants to consumers' homes, electricity is in DC, but when it reaches consumers' homes it converts to AC. Alternating current is when electricity is flowing in both directions. AC is safer for the consumer to handle because current is flowing in both ways, causing its charge to cancel out and prevent consumers from being shocked when handling their appliances. But, because the charges cancel out in AC, electricity consumption becomes harder to monitor. **Figure 7** displays how AC flows in households (McNally, 2013).

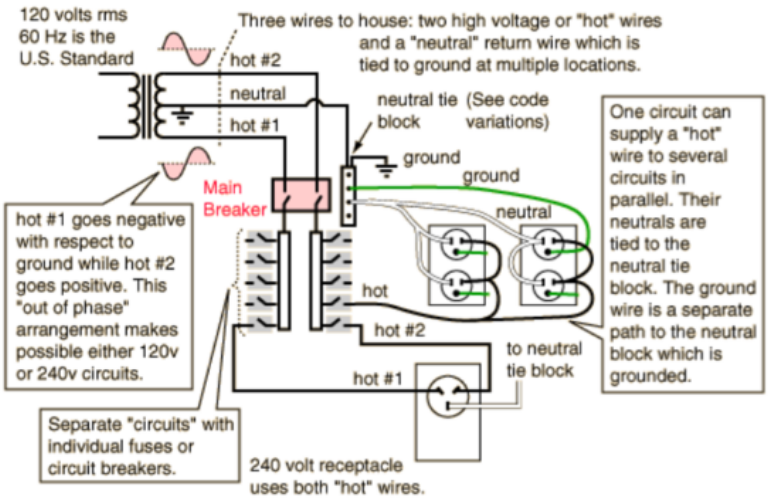

Figure 7: The figure above shows how electricity flows inside a consumer's house.

In order for electricity to be monitored, AC must split into DC. This split is possible because, as shown in **Figure 7**, AC wires have two DC wires. They consist of a ground wire that lets electricity into the household, a power wire that lets electricity out, and a neutral wire to neutralize the current. This system makes electricity monitoring possible (McNally, 2013).

The Current Power Grid

The current electric system is more than 100 years old and is in desperate need of modernization. The grid must change with expanding consumer expectations, increasing environmental regulation, and new technology (C. Lavertu, personal communications, November 23, 2016). Utility companies must find ways to improve service and meet their consumers' energy needs in a smart way (SGCC, 2016). Renewable energy must be implemented in order to effectively improve the grid. Smart grid can help solve these energy (C. Lavertu, personal communications, August 26, 2016).

Implementation of Smart Grid Technology

Recent technological advances in the energy grid and home meters now allow consumers to waste less and control the energy they consume (SGCC, 2016). Specifically, smart grid technology helps the utility industry in determining when and how much of which type of electricity to use.

Smart grid is the evolution of the current electrical grid, utilizing modern technology to optimize the conservation and delivery of power. This technology promises to increase the efficiency of the current system by around 9% by 2030, annually saving more than 400 billion kilowatt-hours. With this technology, consumers can save up to $42 billion in a single year (SGCC, 2016).

Many factors are involved in the electrical market and power pricing. **Figure 5** displays the components of an ideal smart grid. Electricity is more expensive during higher demand times, generally at hours between noon and evening during the middle of the week. During these specific times, high demand causes electricity rates to go up exponentially. This spike in electricity rates is because of the lack of electricity generation capability and availability. The current system relies on building and maintaining expensive power plants which sit idle most of the time. Smart grid allows direct communication with power equipment to reduce the demand during peak periods, lowering the need for costly power plants (SGCC, 2016).

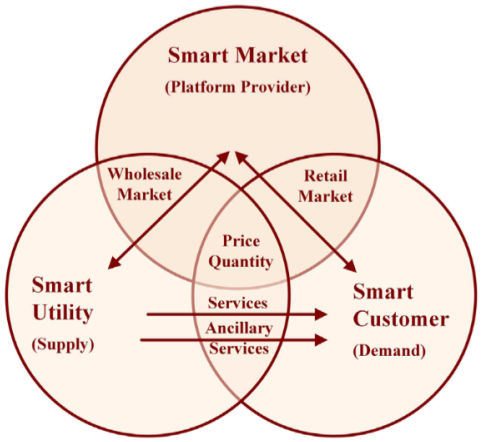

Figure 5: This Venn diagram displays how an ideal smart grid operates based on three pillars: smart market, smart utility, and smart costumer. Smart utility represents the efficient supply of energy, whereas smart customer represents the educated and aware consumer utilizing the supply of energy. Smart market controls these groups to provide the optimal price and quantity overall. (Ellabban and Abu-Rub, 2016)

Smart grid ensures that renewable power sources like wind farms and solar plants can be integrated into the grid (C. Lavertu, personal communications, November 23, 2016). Smart grid can enable the gird to rely more heavily on clean renewable energy. This implementation, in turn, will cut the environmental damage done by fossil fuels (SGCC, 2016).

Smart Grid provides potential benefits based on the opportunities for eliminating energy waste, lowering electricity costs, reducing environmental impacts, and improving power

efficiency, safety, reliability, and quality (SGCC, 2016). Smart grid helps guarantee America's future by getting energy usage under control now. According to the U.S. Department of Energy, the "Environmental Defense Fund does not advocate merely any smart grid; they advocate a smart grid done right"

Consumers: Awareness and Education of Electricity Consumption

Smart grid's energy management also helps families spend their money more wisely. The implementation of smart grid technology could result in $600 of savings for the average household each year. This implementation gives consumers control over their power bill by making electricity possible to monitor and adjust their energy consumption (SGCC, 2016).

Smart grid also tracks when and how much the consumer uses electricity at home and helps the consumer identify ways to waste less energy. This method puts more money into the consumer's pocket and creates a cleaner planet. Real-time pricing information helps consumers reduce their electricity costs 10% on average and their peak consumption by 15% (Shannon, 2015). Ellabban and Abu-Rub suggest that if consumers are given the ability to monitor their energy use more frequently in greater detail, many may make energy saving changes, such as turning off unneeded appliances.

Engineering Plan

Engineering Problem:

Consumers are unaware of wasting electricity when using appliances. This misuse causes consumers not to use electricity wisely and leads to overreliance of fossil fuels and minimizes the use of renewable energy which, in turn, furthers global warming.

Engineering Goal:

The goal of this project is to engineer a device that can display the amount of electricity consumed by the consumer per appliance while ensuring the consumer is receiving accurate data to help the consumer use electricity smartly.

Procedure

Development

The sensor included an Arduino board that is programmed to measure the voltage through its inboard voltmeter and receives a measurement from the attached split core transducer to measure current. The code calculated power based on the readings for voltage and current. After generating a value for power, the Arduino sent the data collected to an app through the Intel Edison, a WiShield and Bluetooth.

Design Criteria

1. Safety
2. User Friendly App
3. Read electricity usage accurately
4. High data sending speed
5. Availability/Accessibility

Testing

The prototype's sensor was tested against the accuracy and precision of commercial digital clamp meters. The prototype's success was measured on how well the sensor and the app communicate to each other.

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