Electrical Power and Energy: Needs, Supply Systems, Failures and Disaster Management and Rapid Recovery

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Abstract

Electrical power (rate of energy) and total energy with the supply network is similar to the human heart with the complex vein system, and electricity is needed all the time on earth for multiple operations. Electrical power and electrical energy are two important parameters to build the supply network, distribution systems with the storage facilities. Around the world, electricity is generated using coal (38%), natural gas (23%), hydro systems (16%), nuclear reactors (10%), wind (5%), oil (3%), solar (2%), biofuel (2%) and others (1%). In the United States of America, the amount of coal used is about 19% and natural gas is about 40%. There are many challenges related to electricity production, distributions based on the demand and storage. The electricity production is very much influenced by the available natural resources and the efficiency of the electricity generators. The electricity demand is very much influenced by the industrial activities, population and the natural weather conditions. Maintaining the power production plants and the distribution systems are also some of the major challenges. Also new technologies are being developed and integrated with the supply systems for production, maintenance and distribution. Around the world the electrical energy consumption is over 21 trillion kWh. In year 2020, U.S. electrical energy consumption was 4.0 trillion kWh, ranked second in the world. In the U.S. the electrical consumption has increased by 13 times (1300%) in the past 70 years. Also, in the U.S. the electricity production and distribution varies from state to state based on the rules and regulations. Recent studies have shown that about 16% or more of electricity failures in the U.S. are due to the severe weather conditions.

In recent years, natural disasters and human made disasters including cyber-attacks have become a major problem in power failures of critical operations such as water supplies, hospitals, transportation systems, oil supplies and charging electric cars and other vehicles. Hence there is a need for developing resilient power supply systems with alternative methods of electricity production from small scale to large scale taking into account both natural and human made disasters to minimize major disruptions in multiple operations and also the losses in the time and revenue.

Introduction

Scientists and inventors have worked on developing the principles of electricity since the 1600s. Benjamin Franklin, Thomas Edison, and Nikola Tesla made notable contributions to our understanding and use of electricity. Benjamin Franklin demonstrated that lightning is electricity. Thomas Edison invented the first long-lasting incandescent light bulb. The fundamental principles of electricity generation were discovered during the 1820s and early 1830s by the Michael Faraday. His basic method is still used today where electric current is generated by the movement of a loop of wire, or disc of copper between the poles of a magnet.

Before 1879, direct current (DC) electricity was used in arc lights for outdoor lighting. In the late 1800s, Nikola Tesla pioneered the generation, transmission, and use of alternating current (AC) electricity, which reduced the cost of transmitting electricity over long distances. Tesla's inventions brought electricity into homes to power indoor lighting and into factories to power industrial machines. Electricity has been generated in power stations since 1882. The invention of the steam turbine in 1883 to drive the electric generator started a strong increase of world electricity consumption.

Before electricity became widely available, about 120 years ago, candles, whale oil lamps, and kerosene lamps provided light; iceboxes kept food cold; and wood-burning or coal-burning stoves provided the heat. This can be considered as an alternative method combing with the new and alternative technologies during the future power failures.

Historically, electricity use for lighting ~~usually~~ accounted for the largest share of total annual commercial sector electricity use, but its share has declined over time mainly because of the increasing use of high efficiency lighting equipment. Conversely, the amount and share of electricity use for computers and office equipment has increased over time. Space cooling requirements are determined by weather, climate, and building design, and by heat produced by lighting equipment, computers, office equipment, miscellaneous appliances, and building occupants.

The industrial sector uses electricity to operate machine drives (motors), lights, computers and office equipment, and equipment for facility heating, cooling, and ventilation. Some industries, such as aluminum and steel manufacturing, use electricity for process heat, and other industries, such as food processors, use electricity for cooling, freezing, and refrigerating food. Many manufacturers, such as pulp and paper and lumber mills, generate their own electricity for direct use, mostly in combined heat and power systems, and some is sold. This reduces the amount of their electricity purchases and their net electricity consumption. Some industries have their own power generating and distribution systems make It more resilience to some of the disasters.

Battery is an electrochemical cell where chemical energy is converted to electrical energy. Historically, in 1800 Alessandro Volta initiated the battery and in 1836 Daniel Cell was developed. Batteries are used in multiple applications including charging all types of instruments, phones, construction tools and transportation vehicles. Battery is another source of alternative electrical power during the mjor power failures. Today battery sales are estimated to be over $48 trillion per year.

Electricity is a secondary energy source

Electricity is the flow of electrical power or charge. Electricity is both a basic part of nature and one of the most widely used forms of energy. The electricity that is used is a secondary energy source because it is produced by converting primary sources of energy such as coal, natural gas, nuclear energy, solar energy, and wind energy, into electrical power. Electricity is also referred to as an **energy carrier**, which means it can be converted to other forms of energy such as mechanical energy or heat. Primary energy sources are renewable or nonrenewable energy, but the electricity is neither renewable nor nonrenewable.

Lessons Learned

There have many major electricity power and energy losses around the world impacting not only countries and also the global operations. This includes the 2011 Tsunami and Earthquake in Japan, hurricanes Katrina (2005) and Ike (2008) in Gulf of Mexico and forest fires in California and Australia (2019) and many other places around the world. In year 2021 there was a winter storm in Texas and there were major power losses across Texas impacting millions of people and commercial operations. There is need for building redundancy power systems starting at local level to cities, counties, states and the county.

Hence there is need for preparedness (P), disaster response (DR) and rapid recovery (RR) for major (blackout) and minor (brownout) power outages to minimize the human, time and revenue losses with rapid recovery.

Objectives

The objectives of this study are to investigate the critical issues related to electrical power and energy needs, disaster protection and building resilience in disaster management. The specific objectives are as follows:

(a) Identify the critical parameters for the electrical power and energy production, supply systems and potential failures.

(b) Develop disaster management and rapid recovery plans to build the resilience.

In this study, the data was collected on the critical needs of electrical power and energy with the building of resilience to maintain the systems under critical events.

Electric Power and Energy

(i). Power

It is also the rate of energy needed and defied as follows:

Electric Power (EP) = Voltage (V) x Current (I) (Watts or Joules/second)

(ii). Energy

Electric Energy is defined as follows:

Electrical Energy (EE) = Voltage (V) x Current (I) x time (t) (Joules or Watts.hour)

Electricity is mostly generated at a power station by electromechanical generators, driven by heat engines heated by combustion (using coal, natural gas, oil and biofuel), geothermal or nuclear fission. Other generators are driven by the kinetic energy of flowing water and wind. There are many other technologies that are used to generate electricity such as photovoltaic solar panels. Around the world, electricity is generated using coal (38%), natural gas (23%), hydro systems (16%), nuclear reactors (10%), wind (5%), oil (3%), solar (2%) , biofuel (2%) and others (1%).

Power Needs

United States

The three major categories of energy for electricity generation are fossil fuels (coal, natural gas, and petroleum), nuclear energy, and renewable energy sources. Most electricity is generated with steam turbines using fossil fuels, nuclear, biomass, geothermal, and solar thermal energy. Other major electricity generation technologies include gas turbines, hydro turbines, wind turbines, and solar photovoltaics. Fossil fuels are the largest sources of energy for electricity generation. Natural gas was the largest source, about 40% of U.S. electricity generation in 2020. Natural gas is used in steam turbines and gas turbines to generate electricity. Nuclear energy was 20% of the electricity generation. Coal was the third-largest energy source for U.S. electricity generation in 2020, about 19%. Nearly all coal-fired power plants use steam turbines. A few coal-fired power plants convert coal to a gas for use in a gas turbine to generate electricity. Petroleum was the source of less than 1% of U.S. electricity generation in 2020. Residual fuel oil and petroleum coke are used in steam turbines. Distillate—or diesel—fuel oil is used in diesel-engine generators. Residual fuel oil and distillates can also be burned in gas turbines. Hydropower plants produced about 7.3% of total U.S. electricity generation and about 37% of electricity generation from renewable energy in 2020.1 Hydropower plants use flowing water to spin a turbine connected to a generator.

Wind energy was the source of about 8.4% of total U.S. electricity generation and about 43% of electricity generation from renewable energy in 2020. Wind turbines convert wind energy into electricity. Biomass was the source of about 1.4% of total U.S.

electricity generation in 2020. Biomass is burned directly in steam-electric power plants, or it can be converted to a gas that can be burned in steam generators, gas turbines, or internal combustion engine generators. Solar energy provided about 2.3% of total U.S. electricity in 2020. Photovoltaic (PV) and solar-thermal power are the two main types of solar electricity generation technologies. PV conversion produces electricity directly from sunlight in a photovoltaic cell. Most solar-thermal power systems use steam turbines to generate electricity.

Geothermal power plants produced about 0.5% of total U.S. electricity generation in 2020. Geothermal power plants use steam turbines to generate electricity.

The electricity consumption in the U.S. in 2020 was about 4.0 trillion kWh/year. It has increased about 13 times of the electricity consumption in year 1950 as shown in Figure 1. In the U.S.in 2020, residential consumptions amounted to 38.9% amount to about 1.56 trillion kWh. The commercial consumption was about 34.8% amounted to about 1.39 trillion KWh. The industrial consumption was about 25.1% amounted to about 1.1 trillion KWh. The transportation consumption was about 0.2% amounted to about 0.01 trillion KWh.

The annual growth in total U.S. electricity demand is projected to average about 1% from 2020 through 2050.

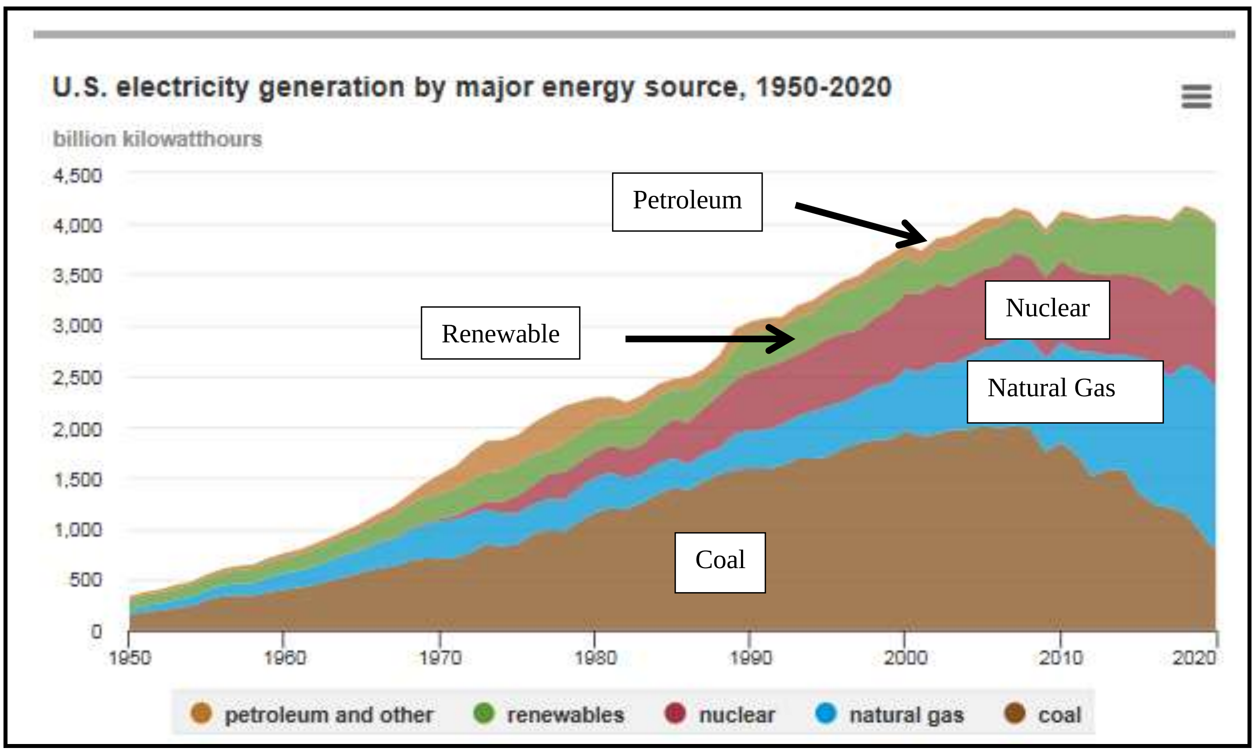

Figure 1 History of Energy Sources Used for Electricity Production in the United States

World

Electricity is used in more than 190 countries and 37 countries use 19 trillion kWh/year, which is 90% of the total world consumptions. The largest producer and user of electricity in the world is China and it is about 4.8 trillion kWh/year. The third largest producer of electricity is Japan and it about 1 trillion kWh/year. The fourth largest producer of electricity is Russia, and it is about 0.95 trillion kWh/year. The fifth largest producer is India, and it is 0.94 trillion kWh/year. In the top ten uses 3 countries are from the American continent, 4 from Asia and 3 from Europe. Out of the top 37 countries producing electricity 15 countries are from Europe, 14 countries are from Asia, 6 countries are from America 1 country are from Africa and Australia. Australia and South Africa produce 0.24 trillion kWh per year.

Power Failures

Reasons for Power Outages

Electrical power failures are due to natural, human or combination of disasters. Due to abnormal power demand (unbalanced voltage (V) or current (I)) there could be **permanent outage** for less than a day referred as **brownout** (partial system failure) and weeks resulting in **blackouts** (whole system failure).

(a). Natural Disasters

Major natural events listed below can knock down transmission lines, damage transformers and destroy substations and power generating stations. These factors must be taken into account based on the location when planning for preparedness for blackout power failures.

(1). Severe weather (hurricanes, tornadoes, flooding, lightening, rain, snow, ice, drought)

Heavy rains, high wind speed and also snow and ice storms can affect the electrical power stations, substations and also the transmission lines.

In the U.S. the major outages caused by severe weather occur at these rates:

- 8% by wind, including hurricanes, tropical storms and tornadoes
- 3% by lightning that can zap a transformer or fry wires
- 5% from snow and ice, leading to winter power outages

(2) Earthquakes

Earthquakes can affect the power stations and also the transmission lines without any warning. In Japan it even impacted nuclear power plants. Hence there is a need for isolating the power plants from earthquakes or locate the power plants outside the earthquake regions.

(3) Fires and Volcanic eruptions

Fires and volcanic eruptions can impact the power plants and transmission lines badly. Hence there is need for building fire protection systems (placing underground) or even locating the power plants outside the potential fire and volcanic activity regions.

(4) Fallen Trees

Electricity transmission lines placed through the jungles and along the roads with trees leading into houses and commercial building are vulnerable to damage from falling trees and branches. High winds and the load from heavy rains, snow or ice can cause trees to snap and bring down utility poles and wires. A random power outage can happen simply when an old or diseased tree topples over without warning.

(5) Animals

Wildlife can also be a factor that causes power outages with the transmission lines going through jungles. Birds, squirrels and other small animals can chew through transmission lines, knock down components while foraging for food or short-circuit connections while building nests. The warm wires and hum of flowing electricity also seems to attract some animals.

(b). Human made disasters

(1). Motor vehicle accidents near power lines

Motor vehicle accidents can be a cause of power outages at local levels. A car, bus or truck can skid out of control, hit a utility pole and bring down power lines and equipment. Driver impairment, a momentary lapse of attention or a patch of slippery pavement is all it takes to lead to this disaster. This kind of random power outage usually affects a relatively small area.

(2). Equipment failures

Like any kind of equipment, the components that bring power to customers can be faulty, break or wear out with age and exposure to the environments. Transformers can fail. Insulators can corrode and break. Insulation on cables can crack, and wires can snap. Power distributions needs a lot of complex equipment and electrical networks which can stop working properly causing power failures.

(3). High energy demand

Due to extreme weather conditions (very hot or very cold) there will be abnormal power demands. Due to abnormal power demand (unbalanced voltage (V) or current (I)) there could be **permanent outage** for days and weeks resulting in **blackouts** (whole system failure).

(4). Constructions

There are always constructions happening around the transmission towers and poles, power stations and underground. Construction equipment can knock down utility poles and cut the electrical power transmission lines. Excavators and landscapers can cut underground electrical lines. Based on the damages, it can result in **brownout** and **blackout.**

(5). Maintenance (Planned power outages)

In order to continue the electrical power and electrical energy supply maintaining the systems are very critical. Maintenance will involve checking, servicing and also replacing critical elements is the electrical power networks. This can result in temporary power outage for a short time up to one day resulting in **brownout**.

(6). Cyber attacks

All the control systems are computer based and connected to the internet platforms resulting in random cyber-attacks. Based on the type of cyber-attack and the type of supply system impacted such as power station, substations or distribution systems it can result in both **brownout** and **blackout.**

Cyber-attack is a human based disaster. With the advancement of technologies almost all operations are controlled using computers connected to the internet. The internet platform is connected to the world and once any computer opened it is connected to the world. **Philosophically, internet is considered as the battery charger** for all the connected computers. Internet platform will provide all the requested information with minimum time delay, transfer data and also control systems including the power grids and water supplies. All **the connectivity (electrical connection with computer language)** makes the system very **vulnerable to misuse** using the computer language, **known as cyber-attacks**. Cyber-attacks can result in minor to major losses of personnel information and also security of the operating systems impacting individuals, cities, businesses and entire country. Cyber-attacks happen rapidly and by knowing the problem **pre-planning with security filtering and blocking will help**. Virus attack will start slowly but can spread rapidly. Hence it is important to **develop comprehensive disaster management and rapid recovery plans** to minimize the losses. Cyber-attack will impact human mental balance. Unlike **contaminated** sites, cyber-attacks has no **rules and regulations**. For cyber-attack pre-planning based on past experience is important **for preparedness**. The **rapid recovery (RR)** due to **cyber-attack (loosing personal information to large operating systems) can take a lot of time and money.**

A cyberattack is a malicious and deliberate attempt by an individual or organization to breach the information system of another individual or organization. Usually, the attacker seeks some type of benefit from disrupting the victim's network. It can also endanger public health, contaminate the water, devastate natural resources, and disrupt the economy. **It will also affect the animals and birds.** In an increasingly technological era, the world has become more dependent **upon computer-controlled operations to maintain our high standard of living**. Also, cyber-attack can impact the security, manufacturing and transportation industries and all other businesses.

Impact of Electrical power outage

Being prepared is key when it comes to what to do when power goes out. Although the negative effects of a power outage are hard to fully calculate, what blackouts can mean for individuals or businesses can include any of the following:

- No lights or air conditioning

- A possible interruption of water and natural gas service
- A dangerous interruption in the running of life-sustaining medical devices
- No cell phone service because cell towers are out
- Damaged electronics
- Spoiled food in your refrigerator
- Inoperable traffic signals and limited travel
- Lost revenue for your business

The United States boasts one of the most robust electrical power systems in the world. Widespread or regular outages are rare. And random power outages are more often inconveniences than hardships.

Supply Systems

Electricity is generated at Power Stations by electromechanical generators (> 50 kV) driven by heat engines heated by combustion, geothermal power and nuclear fusion. Also, other generators are driven by kinetic energy (KE) of flowing water and wind. There are many other technologies that are used to generate electricity such as photo voltaic solar panels.

Electrical power and energy is transferred to substations and the by overhead lines and underground high voltage cables (Figure 2 and Figure 3). The entire supply system (heart of the body) must be working with the transmission lines (vein system of the body) to supply the electrical power and energy (blood flow in the body). Any minor failures can interrupt the electrical energy supply.

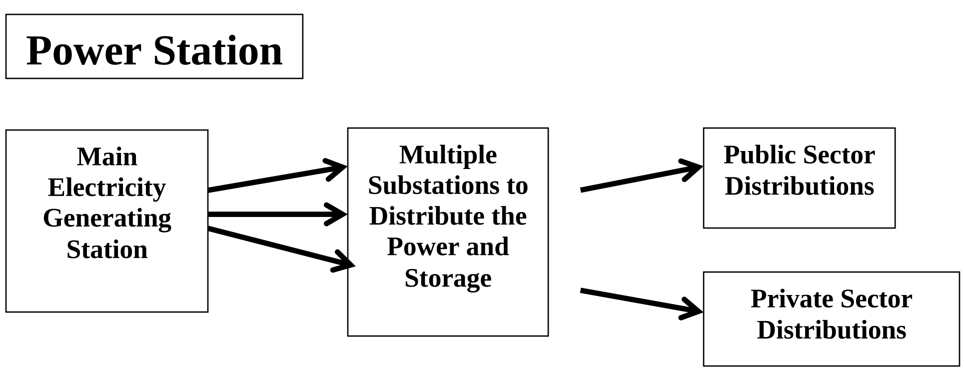

Figure 2 Flow Chart for the Electricity Supply Systems

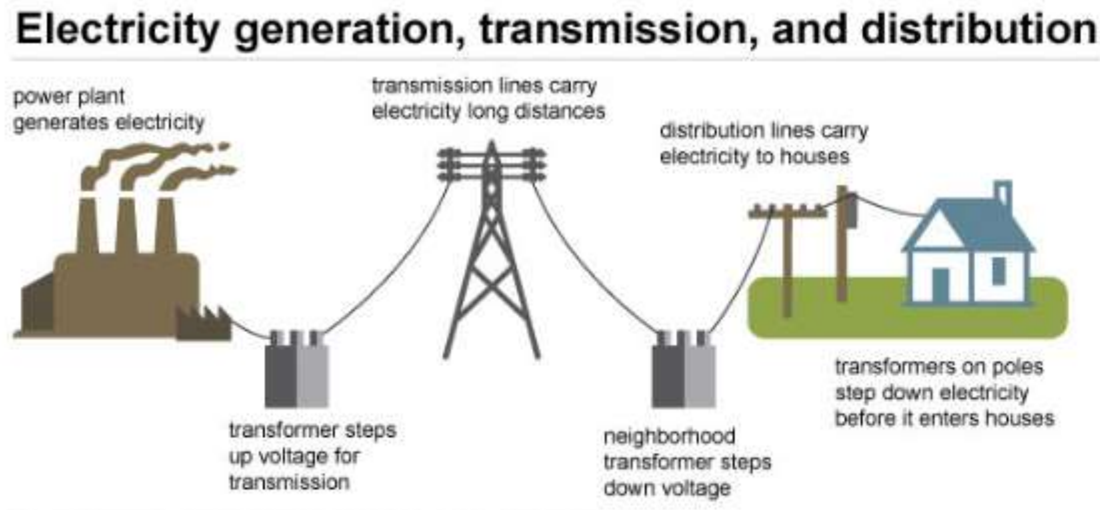

Figure 3 Actual Electricity Generation, Transmission and Distribution Layout

Critical parameters

(1). Need to develop **protection systems** (external and internal) for all types of disasters including flooding for the power stations and distribution systems.

(2). Identify the critical elements related to **maintaining and monitoring** of the power grids including the fuel supplies. Also protect against the **cyber-attacks**.

(3). Develop redundancy systems with **alternative power generators**, storage facilities and distribution systems

(4). For the affected humans develop a disaster response (DR) and rapid recovery (RR) processes for power failure without and with multiple disasters.

THC- Rapid Recovery Multi-Infrastructure Model

It is important to **integrate the multiple infrastructures** that depend on the power supply for rapid recovery. Also this will be a parallel process. Of the 5 items identified in Figure 4, items 1, 2, 3 and 4 are really critical for rapid recovery with the order of priorities.

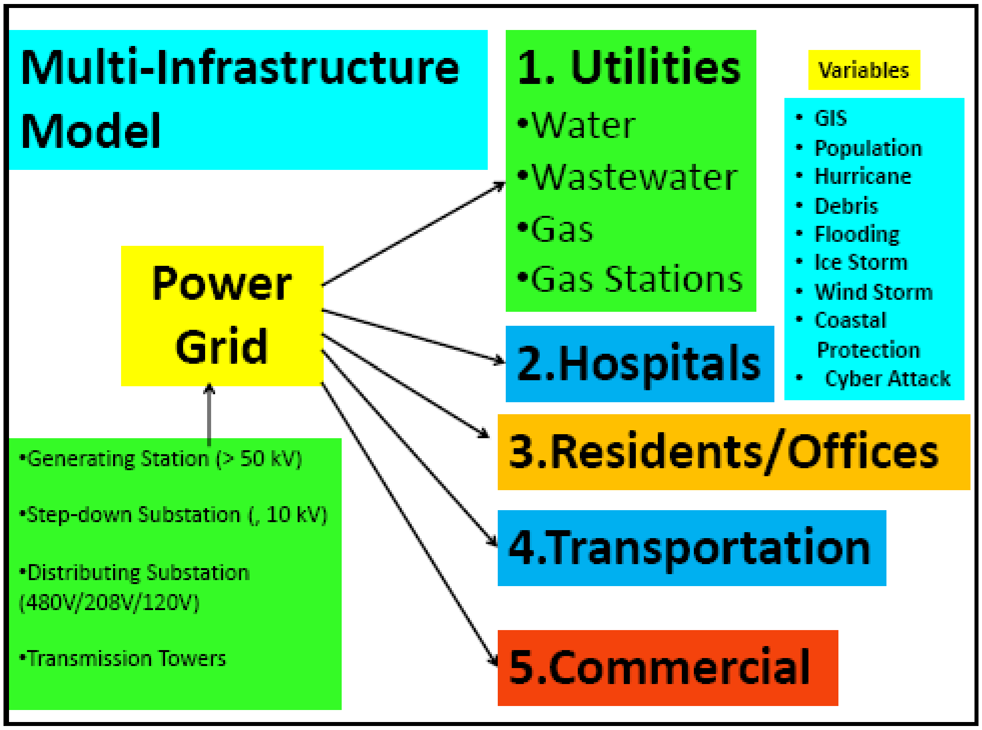

Figure 4 THC- Rapid Recovery Multi-Infrastructure Model

1. Utilities

For all operations water supplies are important. Power failure can result in affecting the water treatment plants, pumps and also the distribution systems. Also, wastewater and gas infrastructures must be in operation without any damages and losses due to power failures. Also, **gas stations** must be functional with their **own generators** during power failures to supply the needed gas for supporting the transportation and other operations including generators. This will **be ranked number 1 (No. 1)** in essential power supply.

2. Hospitals

Patients in the hospitals must be continuously treated and monitored using electrically powered instruments. Also, there will be new patients coming to the hospital based on the impact of the disasters. The hospital should have their **own generators**. This will **be ranked number 2 (No. 2)** in essential power supply.

3. Residents and Offices

Largest amounts of electrical energy are supplied to residents and offices. In order to minimize the time lost and regular operations power supplies must be restored to the residents and offices. Residents and offices must consider having their **own generators**. This will **be ranked number 3 (No. 3)** in essential power supply.

4. Transportation

Power failure can impact the traffic lights on streets, exits and tool roads creating major traffic problems. It can affect the airports. This can also impact the food and commercial transportation. This will **be ranked number 4 (No. 4)** in essential power supply.

5. Industries

Chemical plants, petroleum plants, medical supply manufacturing plants, cars and equipment manufacturing plant and many others can be impacted by power failures. This can impact many supply chain and related operations. Commercial manufactures and operators consider having **backup generators** to be used during power failures. This will **be ranked number 5 (No. 5)** in essential power supply.

Economic Impact of Power Failures

Even local power failures can impact the global activities and many economies due to interruption of critical supplies. Also, the manufacturing industries will be affected impacting the critical medical supplies, chemical supplies and also oil supplies. Power failures can impact the airports, ports and rail systems related to transportation of the critical supplies. Also, the power failures can impact the construction industries in many ways. The economical impact can vary across the regions, and the consequences can be largely dependent on a region's economic position.

2. Disaster Management and Rapid Recovery Plans (DMRRP)

In order to optimize the DMRRP, it is important to identify and quantify the major processes based on the type of power failure caused by natural or human based disasters. Also, the power failure can be characterized as **brownout** (short-term-1 day or less) or **blackout** (long-term - for days, weeks or months)

Models

It is important to develop models to quantify the (a) Preparedness, (b) Disaster response and (c) Rapid recovery for various disasters. Based on experiences it is being proposed to represent Disaster Management and Rapid Recovery as a 3- Phase Model as follows:

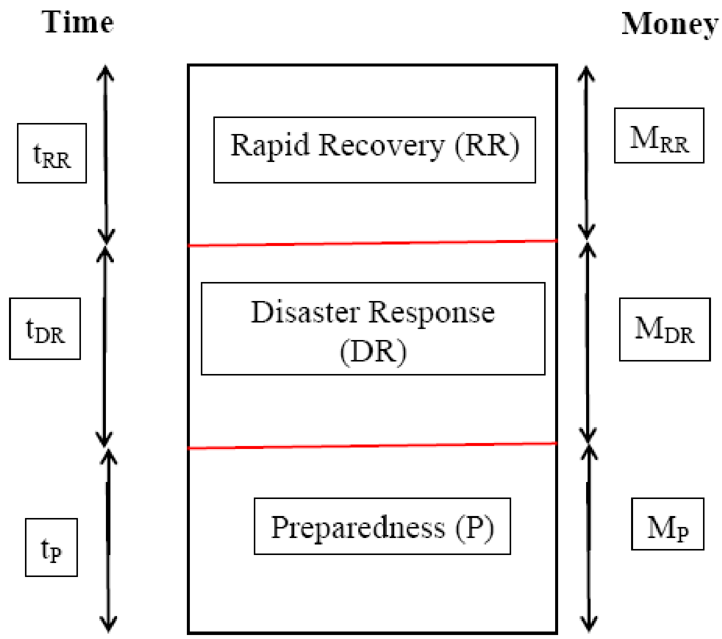

Figure 4. 3-Phase Representation of Disaster Management and Rapid Recovery

Both time (t) and money (M) are two most important parameters. Many factors will influence the **parameter M**, and will depend on the time (t), sources (Local, State, Federal), regulations and many other factors. The preparedness parameters tp and Mp will depend on the approaches selected to do the preparations including communications and evacuation.

(ii). Preparedness (P) and Critical Parameters (tp and Mp)

It is important to identify the critical parameters for preparedness for power failures related to **individuals, families, project teams, communities and commercial activities**.

OBJECTIVES

Overall objective of **preparedness (P)** includes **plans to minimize losses** of humans (H), animals (A), environment (E) and property damages. Also organize the **temporary removal of people** (Evacuation) and property (valuables) from threatened locations, and facilitate timely and effective rescue, relief and rehabilitation. The specific objectives are as follows:

(1). Building a networking team **with leaders** representing communities, schools, hospitals, nursing homes, cities, counties, state emergency managers, power utilities, groceries, department of transportation and industries.

(2). Identify the **potential single and multiple disasters** related to power failures with natural, human made and virus for the **area of interest**.

(3). Develop alternative plans (add gas cookers, gas lamps, gas-based generators) to **build resiliency** in the communities and also **training programs** for kids and adults.

(4). Preparedness plans should identify the **critical elements** to be purchased (water, food, medicine) and **filling the gas tanks in the vehicles** before the disaster. Also prepare the communities for **power failures**. Add gas-based systems to build the needed reslilency. Identify the amounts to be stored in your **food banks**. Have **multiple insurances** for health, cars and home (flooding, fire, broken windows).

(5). Develop alternative **evacuation plans**.

(6). **Minimize** the parameter **tp** and **optimize** the parameter **Mp** based on the alternative plans.

(7). Develop alternative **communication methods** for pre-warning before the power failure disasters and also for communicating during and after the disaster with and without the impact of **cyber attacks**.

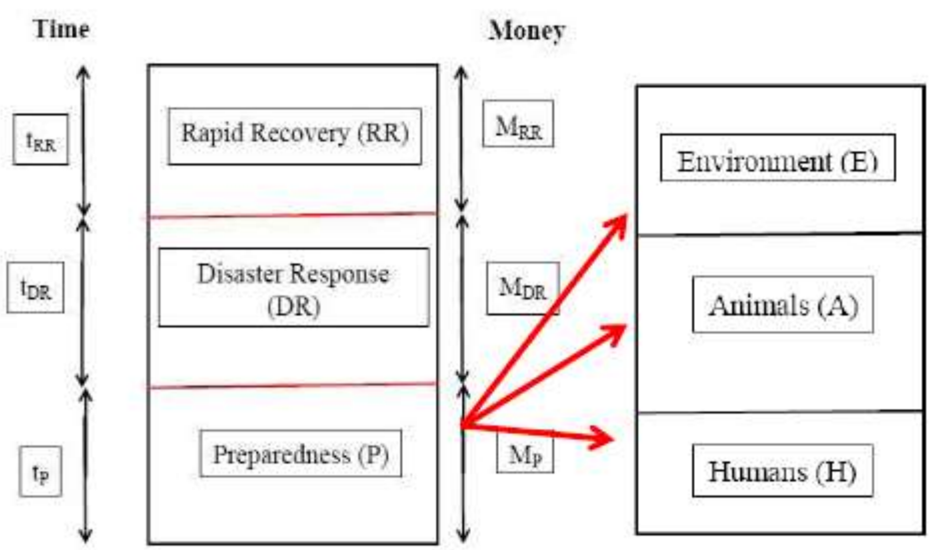

Figure 5. Parameters for Preparedness (P) (for you, family, team, city, country)

EVACUATION OBJECTIVES (Blackout only)

Overall objective for **evacuation** due to blackout includes **plans to temporarily**

move the humans (H), animals (A), and valuable properties (cars, computers, phones) and documents. Also must have charged batteries for multiple applications.The specific objectives are as follows:

(1). Identify the **types of potential power losses** with the other potential natural, human made and virus for the **location of interest**. Based on the blackout develop the evacuation plans.

(2). Determine the mode of **public transport** (trains, buses) or **private transport** (cars, vans) that can be used for evacuation.

(3). Identify **more than one safe location** to evacuate with the **family and pets** based on weather predictions and government guidelines to build the resiliency in the evacuation plan This will also help with **avoiding road blocks and traffic** to reach the safer place quickly. Be aware of **cyber-attacks.**

(4). Select the evacuation location (Government shelter, hotels, schools) with faster returning opportunity. Protect against **virus spread**. Attention to **sanitation issues**, **drinking water and food**.

(5). **Basic items** that need to be taken during the evacuation are as follows:

- Flashlight, battery-powered radio and extra batteries
- Prescriptions and other medicines
- First aid kit
- Important documents (birth certificates, passport, home insurance, bank accounts)
- Bottled water
- Food (canned, bagged)
- Clothing and bedding (sleeping bags, pillows)
- Masks
- Special equipment for infants or elderly or disabled family members
- "Comfort items," such as special toys for children
- **Computer hard drive and laptop with charge batteries**
- Pet food and other items for pets (litter boxes, leashes)
- Avoid glassware

(7). Check your home/office before leaving

- Turn off all the electrically powered equipment including the refrigerators.

(8). Develop plans for **quick return** and **potential repairs** for the house and job related construction sites and applying for loans and insurance.

This will be part of the **Disaster Response (DR) parameters t_{DR} and M_{DR}.**

(iii). Disaster Response (DR) and Critical Parameters (t_{DR} and M_{DR})

It is important to identify the major issues related to disaster response (DR) and rapid recovery (RR) with parameters, t_{DR}, t_{RR} M_{DR} and M_{RR}. The power loss disaster response and recovery are very much influenced by the losses, time to restore the power and debris removal due to multiple disasters.

Return from Evacuation

In order to accelerate the DR and RR, it is important to return home as soon as possible taking the safe pathway. There could be road blocks and damages that needs to be factored into the return plan.

Losses

The losses for both brownout and blackout can be divided into short-term and long-term losses. Losses will result in influencing the **parameters time and money.**

Short-term Losses

The timeline will be between 0.5 month and 1 month to recover and get the lost items (less than 1 month) for **you, family and team.**

- Road blocks
- Prescription medicine
- Damaged car or truck
- Insurance policies — homeowners, auto, life and any others
- Employment information
- Failure of refrigerators, air conditioners and heaters
- Traffic lights failure
- Closed restaurants and stores
- Lost phones, computers and charges
- Financial information such as bank accounts and credit cards

(iv). Rapid Recovery (RR) and Critical Parameters (t_{RR} and M_{RR})

It is important to identify the major issues related to power failure disaster responses to rapid recovery (RR) with parameters, t_{RR} and M_{RR}. The disaster response and recovery are very much influenced by the losses and debris removal.

Long-term Losses

The timeline will be **over one (1) month** to recover and get back most of the lost items for **you, family, team, community, city, country.**

- Power Loss and Grid Failures
- Debris
- Road blocks
- Deaths (humans, pets, animals)
- Property lost (house, buildings, highways)
- Damaged transport facilities (trains, buses, cars, 18 wheelers and others)
- Closed businesses, schools, Universities
- Closed Airports and Ports

3. MULTIPLE DISASTERS

There are multiple disasters happening around the world. Also, the current COVID-19 pandemic and cyber-attacks will add to the multiple disasters. Multiple disasters could be totally natural or human based or a combination. Multiple disasters will have two or more disasters at one time. For example, during power failure there can be hurricane, virus pandemic (human) and also cyber-attacks (human), fire (human), oil spill (human) and flooding (natural).

In planning all these potential challenges, it is important to integrate the GIS (Geographical Information System) to identify the critical locations including hospitals, food supply and gas supply. It is also important to determine the resources available for preparedness (P), disaster response (DR) and rapid recovery (RR) plans.

Modelling of Multiple Disasters

It is important to understand the import parameter need for modelling multiple disasters. Base on the model, importance of various parameters can be identified for disaster management and rapid recovery planning

Monitoring

It is important to develop new technologies for **real time monitoring of the multiple disasters. To ensure the health and safety of the humans and animals**, real-time **monitoring of disasters (flooding, wind speeds, power grids), evacuations, hospital and other critical facilities** will be a good use in disaster response and rapid recovery. Real-time monitoring will also help in developing procedures to minimize the virus attacks and cyber-attacks. Real-time monitoring system must have alternative powering systems including batteries.

Disaster Management and Rapid Recovery Plans

During a multiple disaster (more than one), it is important to have a comprehensive disaster management and rapid recovery plans. Base on the disasters, following plans can be considered for implementation.

PLAN 1: Combine processes (mixture theory) for the disaster management plans for multiple disasters including power failures. For example, if there was a power failure (P) with flooding (F) in the same area the DMRRP can be a combined process (PLAN 1) by integrating both disasters to minimize the cost (M_{PF}) and time (t_{PF}) (Figure 6).

PLAN 2: Develop a **parallel process** (**similar to parallel electrical circuits**) for the disaster management and rapid recovery plan. This will be the approach with the cyber-attacks in place, because the power failure and flooding could be only partly overlapping the affected regions (Figure 7(a)). Hence the DMRRP can be a parallel process (PLAN 2) to minimize the costs (M_{PC} and M_{FC}) and time (t_{PC} and t_{FC}) as shown in Figure 7.

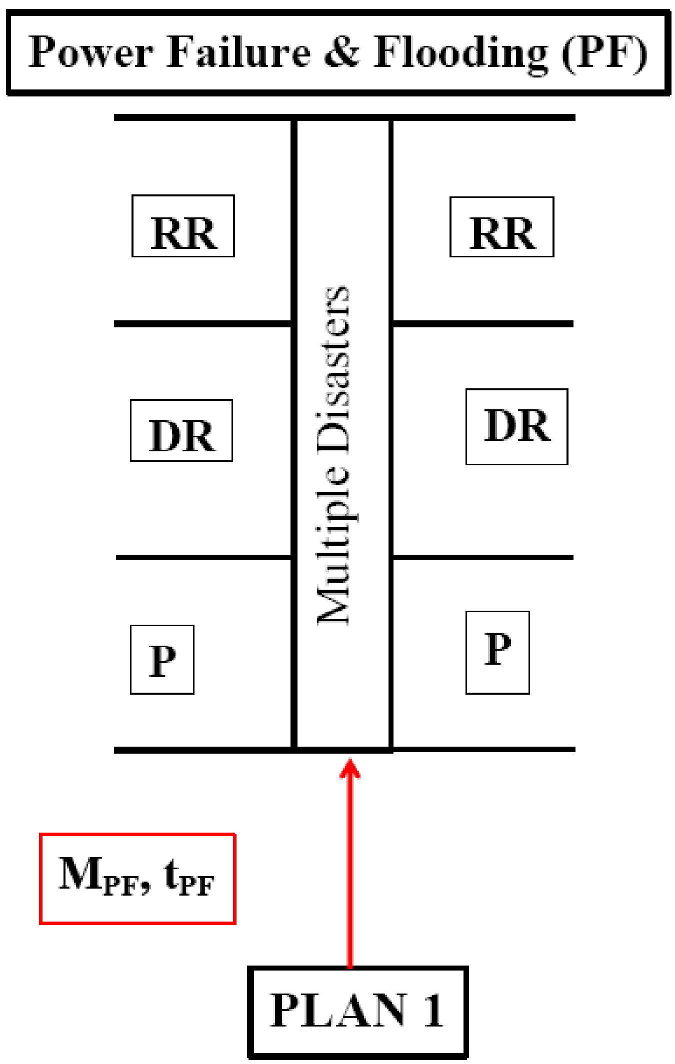

Figure 6. Multiple Disaster Plan 1 Combined Process

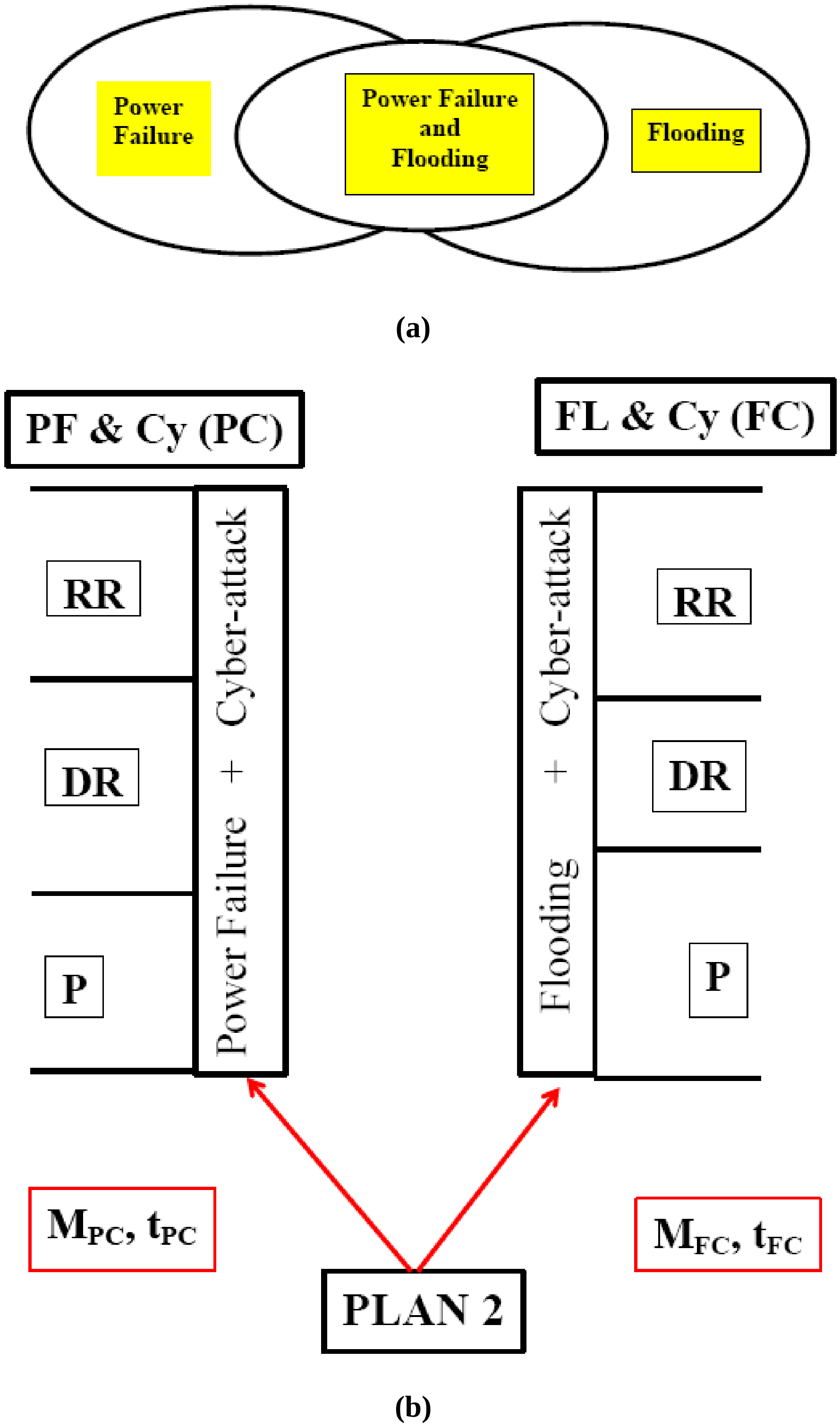

Figure 7. Multiple Disaster Plan 2 Parallel Process (a) Affected Regions and (b) DMRRP with the Cyber Attack

Preparedness (P)

Based on the potential disasters, PLAN 1 or PLAN 2 must be selected for the preparedness (P) process. There will be **almost no warning for power failure** and hence **preplanning and preparedness with adequate training will be important.** Power failure and flooding with and without cyber-attacks may result in **shut down of schools, businesses, airports** and **grocery stores** which have to be taken into account for when developing the preparedness (P) with PLAN 2. Based on the power failure region with and without flooding, people can be evacuated to different regions. Also, **resilience communication methods** have to be developed taking the power failure into account. This will help with the disaster response (DR) and rapid recovery (RR).

Disaster Response (DR)

Based on the power loss and flooding disaster regions with and without overlapping, PLAN 1 or PLAN 2 must be selected. This will also be related to the **available evacuation places with electric power. Also, ways and methods to open the business, schools and stores with the needed protection systems must be considered.**

Rapid Recovery (RR)

Based on the disasters, PLAN 1 or PLAN 2 must be selected. PLAN 2 will be very much impacted by the **scale of the flooding and power failure** on the population and daily operations. Also, comprehensive plans have to be developed for **rapidly recover after the multiple disasters including power failure**. The rapid recovery time and cost must be minimized. With the COVID-19 virus, the disposal of debris could become an issue and must be planned alternative methods during the preparedness (P).

4. New Technologies

(a) **Real-Time Monitoring**: Recent advances in sensor technology and communication have catalyzed progress in remote monitoring capabilities using **batteries**. Monitoring is only effective if the collected information can be stored and interpreted real-time. These advances have led to improved statistical and mechanistic modeling in monitoring.

(b) **Drones:** The earliest recorded use of an unmanned aerial vehicle (UAV) for warfighting occurred on July 1849. Since then, technology has evolved to make very efficient light weight aircrafts with cameras for monitoring before and after disasters.

(c) **Smart Cement**: Highly sensing smart cement has been recently developed for real-time monitoring. Smart cement is a chemo-thermo-piezoresisitive cement and a 3D sensor that could detect loadings on buildings, gas and water leaks, flood rising levels, seismic activities and fire (Vipulanandan 2021)

(d) **Flooding Protection**: There is an urgent need to developing simple and innovative methods to protect houses and streets from flooding. The flooding is greatly affected by the rate of run-off of the rainwater which has to be controlled by collecting.

(e) **Modeling:** It is important to quantify the 3-Phase DMRRP model parameters (losses, money and time). Also developing new models and also using Artificial Neural Network (ANN) for Artificial Intelligent (AI) to do the predictions related to losses and debris.

CONCLUSIONS

Based on the experiences from the worst hurricane (Hurricane Harvey with flooding) and worst winter storm (Uri with electrical power loss) in the State of Texas history with power failure, flooding and cyber-attacks Disaster Management and Rapid Recovery Plans (DMRRP) were developed Also data was collected on electric power and energy uses around the world and also evaluated new technologies and following conclusions are advanced:

1. Electrical power is equal to current x voltage (Watts). Electric power is also equal to the rate of electrical energy used (Joules/second). Electricity use and payments are quantified based on the total electrical energy used.
2. Electrical energy usage/production in the U.S. is 4.0 trillion kWh/year, 19% of the electrical energy produce annually around the world. In the U.S. the secondary energy electricity is produced using fossil fuel (60%), nuclear energy (20%) and renewable energy (20%).
3. Power failure is one of the major disasters and must be integrated in all the Disaster Management and Rapid Recovery Plans (DMRRP).
4. It is important to have alternative electrical power generators as backup to support some of the critical activities.
5. During multiple disasters like power failure with flooding and cyber-attack consider PLAN 1 (combining all activates in the same region) or parallel process (disasters distributed in multiple regions), PLAN 2, for the DMRRP with and without cyber-attacks.
6. Real-time monitoring is critical for minimizing urban areas impacted by the multiple disaster due to power failure, flooding and cyber-attacks.
7. Educate the communities regarding preparedness, minimize losses and rapid recovery.
8. Minimize the drinking water infrastructure damages. Build redundancy in the power grids to minimize losses.
9. Improve debris removal and minimize the delay. Also consider the effects of power loss and cyber-attacks in the debris removal and also disposal.
10. Consider adopting new technologies for real-time monitoring using drones, smart cement, flood protection and debris removal.
11. Evaluate the adaptation of the new 3-phase model with prediction models and Artificial Neural Network (ANN) in Artificial Intelligent (AI) for alternative

approach methods with losses, money and time predictions related to preparedness, disaster response and rapid recovery.

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