Effect of Natural and Man-made Disasters on Distribution System

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Table of Contents

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Executive Summary

Electricity is the backbone of modern society. It is ubiquitous in the daily lives of global citizens and all critical infrastructure systems depend on the reliable delivery of electricity. The security of electric supply has become a major concern world- wide, given modern society's strong dependence on its adequate delivery. Not only does the functioning of industry, transportation, and communication and computer systems depend on a continuous energy supply, but our complete style of living collapses when energy fails. Natural hazards can affect the electricity supply and result in power outages which can trigger accidents, bring economic activity to a halt and hinder emergency response until electricity supply is restored to critical services.

This study aims to elucidate how the characteristics of different natural and manmade disasters influence the power distribution system. For this purpose, forensic analysis of different natural disasters including COVID-19 and manmade disasters was carried out.

The study highlighted that how different natural hazards affect the power distribution system in different ways.Earthquakes cause inertial damage to heavy equipment (such as generators and transformers) and brittle items (for example ceramics), and ground failure and soil liquefaction can be devastating to electric infrastructure assets. Bangladesh is located near the boundaries of the active seismic Indian plate & Eurasian plate and Indian plate & Burma plate. Active faults such as those in the north and east of Bangladesh can also be destructive. A fault line at Madhabpur near Dhaka can cause an earthquake of 7.5 on the Richter scale. So, the risk of a major earthquake is ever growing.

Flooding can cause severe damage to distribution lines, poles and substation equipment and lead to interruptions in service continuity and widespread outages. Flooding becomes a problem for substations when the amount of water reaching the drainage network exceeds its capacity. Eighteen electric power substations were flooded in 1988 in Bangladesh. Severe flooding in 2007 washed away electricity poles in some parts of Bangladesh which caused disruption of electric supply Transformer load tap changers, voltage regulating relays are adversely affected by flood water.

The power distribution system of Bangladesh was significantly affected by the recent cyclones. Bangladesh experienced the worst ever blackout in 2007 after the severe tropical storm SIDR. All major power plants tripped and failed for varying durations. It took two days to restore the full generation. Despite restoration of power generation in most of the power plants, electricity supply was hampered as the power lines and poles were severely damaged.

COVID-19 is a burning question in recent times and the world is suffering from it. Not only the health sector but also other emergency services are also affected by it. Bangladesh's power

distribution system was severely affected by it. Regular billing could not be done due to meter readers not being able to visit consumer premises in the lockdown. That's why it was impossible to take actual reading. As a result, a large number of complaints were filed by the consumers about overbilling, consumers were aggrieved and the face of the organizations were tarnished. Most of the consumers were confined in their homes, many losing income, furthermore banks operated at a reduced capacity, as a result the bill collections of the electricity supply organizations took a massive hit in the COVID-19 crisis. They faced huge revenue loss.

Among man-made disasters cyber-attack is the most common disaster. As power systems rely more heavily on computerized communications and control, system security has become increasingly dependent on protecting the integrity of the associated information systems. Part of the problem is that existing control systems, which were originally designed for use with proprietary, standalone communication networks, were later connected to the Internet (because of its productivity advantages and lower costs), but without adding the technology needed to make them secure.

Clearly, there is no single answer to protect our electricity infrastructure from major natural or man-made disasters. Given past events and learning from them, we must learn how to make our systems more resilient and robust in the face of future uncertain and critical threats, while developing new technologies and management features. A reliable electric power supply following disasters is too important to be left to the same old approaches of the past. This issue will become more relevant in the future, as uncertainty increases, and with the possibility of global warming causing even more challenging weather- created disasters.

CHAPTER 1: INTRODUCTION

1.1 Background of the Study

Power sector of Bangladesh: Bangladesh has one national grid with an installed capacity of 23,548 MW as of June 2020. Bangladesh's energy sector is booming. Recently Bangladesh started construction of the 2.4-gigawatt (GW) Rooppur Nuclear Power Plant expected to go into operation in 2023. According to the Bangladesh Power Development Board in July 2020, 97 percent of the population had access to electricity. However per capita energy consumption (512 KWh as of June 2020) in Bangladesh is considered low. [1]

Electricity is the major source of power for most of the country's economic activities. Bangladesh's total installed electricity generation capacity (including captive power and renewable energy) is 23,548 megawatts (MW) as of 2020. Upto june 2020, total length of the distribution line is 5,82,000 km. [1]

The largest energy consumers in Bangladesh are industries and the residential sector, followed by the commercial and agricultural sectors. As of June 2020, total number of consumers is 37.9 Million. [1]

Problems in Bangladesh's electric power sector include high system losses, delays in completion of new plants, low plant efficiency, erratic power supply, electricity theft, blackouts, and shortages of funds for power plant maintenance. As of June 2020, total distribution Loss is 8.73%. [1]

Power distribution system: Electricity generated at bulk power plants is moved using high-voltage transmission lines. At the other end of a transmission line, another substation uses step-down transformers to reduce transmission voltages and links the transmission line with the electricity distribution system. The distribution system runs at lower voltages (down to 230V) and delivers electricity to individual customers. It includes distribution lines and distribution substations, which use transformers to gradually step down the voltage before it reaches the end customers. Medium and low voltage distribution circuits are often used as an economical way of connecting distribution lines with transmission lines. They include substations which step down the voltage from transmission lines and send it to distribution substations located in towns and neighborhoods. Some consumers who require higher voltages than the domestic power supply, such as large industrial facilities, may plug directly in the subtransmission system. [2]

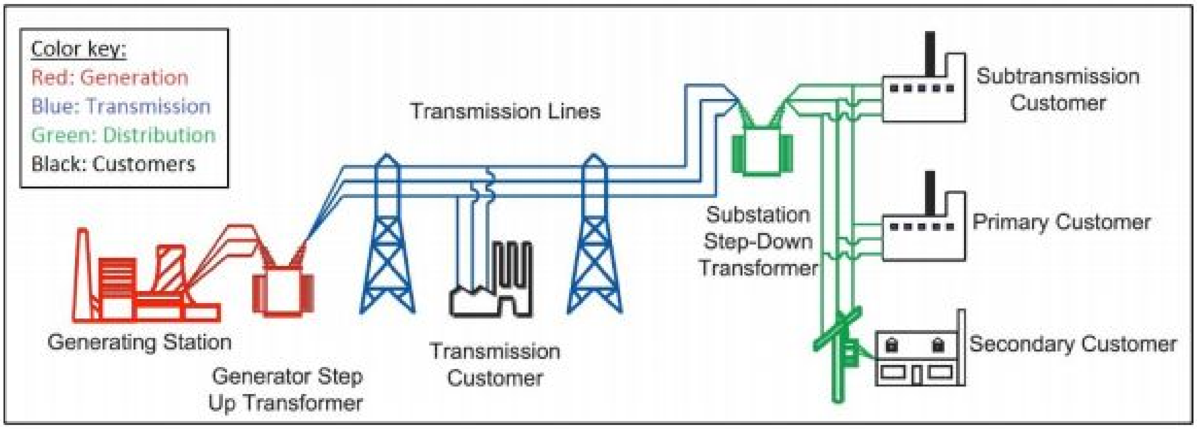
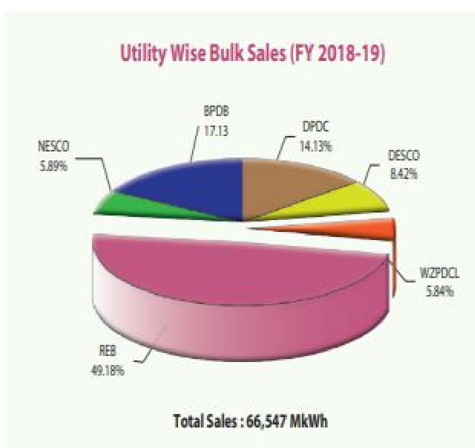


Figure 1: Overview of the traditional electric power system

A typical distribution system consists of:

- Substations.
- Distribution Feeder Circuits.
- Switches.
- Protective Equipment.
- Primary Circuits.
- Distribution Transformers.
- Secondaries, and.
- Services.



Power distribution entities in Bangladesh
BPDB
REB
DESCO
DPDC
NESCO
WZPDCL

Figure 2: Distribution entities of Bangladesh [1]

Distribution systems have been traditionally designed as passive networks, with a role of only carrying power in a unidirectional and radial scheme, i.e. from distribution substations to consumers. However, the increasing penetration of distributed generation and implementation of smart grid is envisioning substantial changes in the operation and complexity of these distribution systems.

1.2 Problem Statement

Energy security provides the backbone of industrialized societies and economies. Without uninterrupted power supplies, modern economies could not function.. The consequences of a disrupted power system to the economy and the environment can be severe. Blackouts lasting several days can lead to the breakdown of communication, transport, and district heating systems. They can threaten water supplies and sanitary systems. They can bring trade and production processes to a halt and oblige hospitals to work using emergency power supplies. In short, power blackouts can threaten the stability of entire regions. Recent data suggest that climate change leads to an increased number of extreme weather events, thus increasing the likelihood of severe impacts on electricity infrastructure that lead to blackouts.

Nowadays the power system is seriously challenged by natural disasters. In recent years natural disasters have caused a series of large-scale blackouts all over the world. For instance, a major blackout in Bangladesh affecting 150 million took place on November 1, 2014. A transmission line from India had failed, which "led to a cascade of failures throughout the national power grid. [3]

With global warming, the impact of climate and natural disasters on the operation of the power system will become more and more severe. Thus, the study on natural disaster emergency response theory is with important practical significance. [4]

Definition of disaster: Extreme and stress events cycle and phases: power distribution system in a given area may be subject to extreme events that could affect their operation by damaging or destroying infrastructure components or facilities or by affecting personnel health or the working environment. These extreme events include natural disasters, accidents or attacks. power distribution systems could also see their operation affected by less severe events that could also influence their operations by creating stress conditions, such as economic crisis or particular electricity market conditions that could lead to aging infrastructure components due to reduced capital investment plans. [5]

Moreover, extreme or stress events not only affect the power distribution system’s operations when these events are active, but also in their aftermath. Extreme or stress events may affect a given portion of a power grid directly or indirectly. [5]

Disasters create overwhelming demands to affected communities. Experience from recent disasters has demonstrated that damage to infrastructure adversely affects community resilience. Among critical infrastructure, the electric power distribution system is a cornerstone of modern economies. Electricity is ubiquitous in the daily lives of citizens and spans across all sectors of the national economy. In addition, all critical infrastructure systems depend, to a greater or lesser extent, on the reliable delivery of electricity. This research report focuses on hazards which affect the power grid either directly, by damaging critical components (e.g. storms) or indirectly, by altering the patterns of electricity consumption (e.g. heat waves and cold spells). [2]

Decrease of the risks produced by these hazards against distribution systems and the increase of the security grade, but also the return of distribution systems to the natural functioning state after such hazards take place represent one of the great challenges of specialists.

Deliberate terrorist or informatics human attacks or made by one of the states who possess satellites which revolve around the earth by means of electromagnetic waves are extremely dangerous and with potentially catastrophic effects.

The transmission and distribution of electricity is at high risk of being subjected to an attack which pose minimal risk from the attacker, a matter well-known by possible attackers or saboteurs. The fact that power transmission lines, power generating stations or communications facilities are located in remote locations or, for example, gas pipelines fuelling facilities are in less populated areas, allows a potential attacker to carry out his operations with minimal detection risk. [6]

Interdependency between power grids and communication networks is said to be established because communication facilities require electric power from power grids and because electric power grids need data and information connectivity to support management and control functions. That increased deployment of smart grid technologies at the power distribution level may lead to increased future dependence of power grids on public communication networks because deployment of dedicated communication networks with sufficient bandwidth may likely require a significant investment that may make the use of public communication networks by electric power distribution utilities an undesirable, but practically unavoidable necessity. Still, in the present, dedicated communication networks used by power grids require electric power and use locally-stored energy primarily in batteries located at substations to limit the effect that loss of power could have on the communication network nodes. Electric power utilities may rely on public communication networks to transmit information to coordinate and prioritize resource allocation and to manage and control service restoration and infrastructure repair processes.

Phases of a disaster:

Phase 1 (pre disaster planning): This phase may last from a few months to several years. The activities focus on preparing for the next event by planning and implementing mitigation actions, modifying relevant operating processes and modifying the existing infrastructure at the conclusion of Phase 3. Preparations and resource prepositioning for a following event that can be anticipated typically occurs at the end of Phase 3. Phase 1 concludes when the immediate next event happens.

Phase 2 (during the event): This phase typically lasts from a few minutes to a few days. The focus in this phase is to reduce the damage and loss of service. This phase starts when the first signs of the event are being noticed, lasts for a time given by Δt1 and concludes when the first repairs are made.

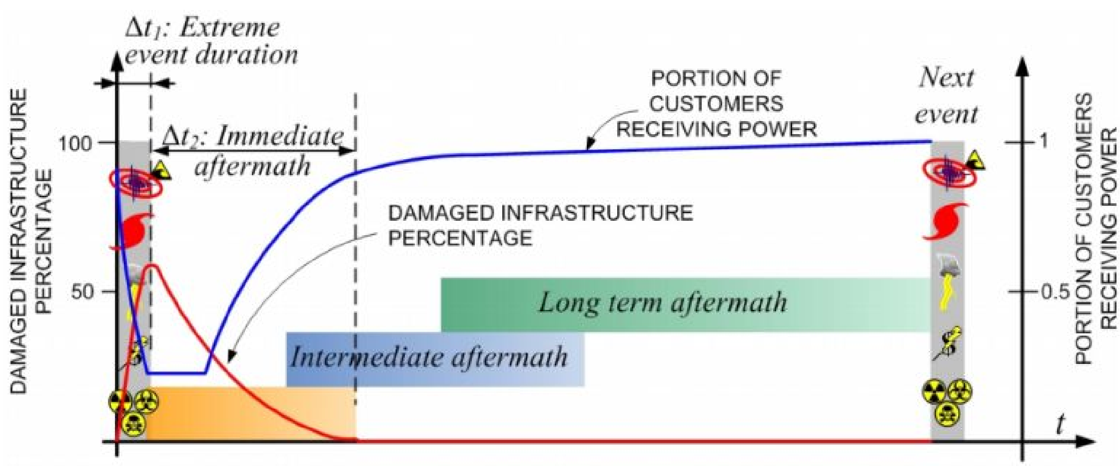


Figure 3: Representation of the phases of an extreme event. Both axes are not to scale

Phase 3 (aftermath): This phase usually lasts from a few days to a few weeks. The focus during this phase is to initiate restoration and repair activities, such as performing damage assessments to evaluate system status, followed by infrastructure restoration, repair and Energies reconstruction activities. This phase lasts for a period of time indicated by Δt2 and concludes when these activities are mostly completed. The main goal during this phase is to reduce service disruptions as quickly as possible. The focus during this phase transitions into studying the effect of the event on a given portion of the power grid by documenting damage and performance metrics evolution and by, possibly, conducting some form of forensic analysis. That is, in Phase 3, attention transitions from responding to the given event into Phase 1 in which the focus is to prepare for the next event. [5]

Besides climatic and geophysical disasters, other hazards are caused by human intervention deliberately, provoked by direct attacks against the distribution system and its components as well as through indirect, cybernetic attacks, carried out in the virtual space through informatics networks to which PS is connected. [6]

The transmission and distribution of electricity is at high risk of being subjected to an attack which pose minimal risk from the attacker, a matter well-known by possible attackers or saboteurs. The fact that power transmission lines, power generating stations or communications facilities are located in remote locations or, for example, gas pipelines fuelling facilities are in less populated areas, allows a potential attacker to carry out his operations with minimal detection risk. Selecting potential attack points and estimating the resulting consequences are the capabilities of antiterrorist specialists. The electricity system has various components such as: cybernetics, physical systems etc. and people who support these systems. Every day, threats are becoming more and more sophisticated and lasting, so the danger is increasing. Because of their complexity, threats have turned to one of the most effective weapons of our century. Increased use of IT-type products which grow more diverse and complex by the day lead to an increase in threatened areas if some entities decide to search and exploit their vulnerabilities. As utilities switched from electromechanical to digital equipment and, moreover, to interconnected digital equipment, the risks of external Cyber-vulnerabilities may have the following locations:

Indirect effects of disasters on distribution systems often lead to compromised pricing, billing and bidding systems. For instance, due to COVID-19 pandemic, bill collection by distribution entities (DESCO, DPDC, REB etc) has been severely deteriorated.

1.3 Objectives

Only the past works most relevant to this report are cited. A complete literature survey is not in the scope of this report. Neither is it the goal of this paper to perform a technical study or detailed design analysis of particular components or sections of power distribution systems. Main objectives of this research are:

- To analyze the impact of natural and manmade disasters on the power distribution infrastructure and on the socio-economic situation of Bangladesh.
- To present a systematic assessment for the economic losses caused by equipment damage and load loss.
- To evaluate the losses of the whole society, including environmental damage and indirect economic losses, as well as social impact assessment.

1.4 Research Questions

1) What are the common natural and manmade disasters which take place in Bangladesh?
2) Which detrimental effects can disasters inflict upon the infrastructure of power distribution systems?
3) As a company, how much extra expenditure was required due to maintenance of disrupted lines/substation equipment?
4) As a company, how much extra expenditure was required due to buying safety equipment?
5) What is the overall financial loss of the company due to disasters?
6) What is the socio-economic loss caused by the disaster? Has the distribution company experienced indignation/dissatisfaction from the consumers/government?
7) Due to recent natural disasters (cyclone Amphan and COVID-19) pandemic, have the performance matrices of distribution companies worsened? If so, to what extent? As performance matrices, take SAIDI, SAIFI, and CB here.
8) How can distribution entities take steps to increase resilience against possible disasters?
9) How Bangladesh government formulated disaster risk management policy in case of power system?

Definitions of the performance matrices are given below:

SAIDI:

The System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI) are commonly used as reliability indicators by electric power utilities.

SAIDI is the average outage duration for each customer served, and is calculated as:

$SAIDI = \frac{\sum UiNi}{Nt}$ where Ni is the number of customers and Ui is the annual outage time for location i, and Nt is the total number of customers served. In other words,

$$SAIDI = \frac{\text{sum of all customer interrption durations}}{\text{total number of customers served}}$$

SAIDI is measured in units of time, often minutes or hours. It is usually measured over the course of a year.

SAIFI

$SAIFI = \frac{\sum \lambda i N i}{\sum N i}$ where λi is the failure rate and Ni is the number of customers for location i. In other words,

$$SAIFI = \frac{Total\ number\ of\ customer\ interruptions}{total\ number\ of\ customers\ served}$$

SAIFI is measured in units of interruptions per customer. It is usually measured over the course of a year.

Bill to collection ratio, CB:

The bill to collection ratio is the average period of time that an power distribution entity's trade accounts receivable are outstanding.

$$CB = \frac{total\ bill\ receivables}{average\ collection}$$

A lengthy period during which receivables are outstanding represents an increased credit risk for the power distribution entity, and also requires a larger working capital investment to fund the underlying inventory that was sold.

1.5 Methodologies

The research design for this study focuses on disruptions of the critical electricity distribution system caused by selected natural hazards (cyclone Amphan and COVID-19), and it explores the relationship between impacts and disaster type. The study was both primary and secondary data-driven.

For primary data collection, we relied on a survey with a total 13 questions regarding cyclone Amphan and COVID-19. The questionnaire helped us to acquire data from DPDC, DESCO, and REB. We sought COVID-19 related data from the two urban power distribution companies DESCO and DPDC, while we achieved data regarding cyclone Amphan from REB. Those primary data are empirically gathered and are based on a stratified random sampling surveying method. They reflect the socio-economic impacts of recent natural disasters on the power distribution system.

For the purpose of secondary data analysis, data was collected from the open technical literature, field survey reports and research papers, and national newspapers.

1.6 Significance of this Study

All these risks due to natural and manmade reasons could be incorporated in finding some technical and design solutions for the development of a safe and resilient power distribution system.

This report offers information related to the damages produced to the distribution system, the type of defects occurring in the system and the corresponding socio-economic effects.

This report can help to assess the ability of our country to manage the short term crisis of energy supply, caused by natural disasters, physical or cybernetic attacks, or the deliberate action of a state and needs the planning of strategic stocks, back-up systems and regional cooperation arrangements.

An overview on whether our distribution system is able to re-establish its essential services very quickly or not can be acquired from our report.

1.7 Limitations

For recent disasters, sufficient secondary resources are not available. As COVID-19 pandemic is a novel disaster, therefore the depth and length of its impact is yet to explore. On the other hand, extensive research work has not been done on the adverse effects of cyclone Amphan till now. Hence, we were limited by these constraints.

Another significant limitation of this report is that we prepared it within a short period of time. We could only work with limited areas due to time constraints.

1.8 Delimitations

Due to very short time, we could only seek primary data regarding two recent natural disasters (cyclone Amphan and COVID-19). For other natural disasters and manmade disasters, we worked with secondary data.

While analyzing primary data, we focused on the performance matrices and losses of power distribution companies (DESCO, DPDC, REB). We could not reach the consumers to know how they have been affected due to disaster caused interruption in the power distribution system.

CHAPTER 2: LITERATURE REVIEW

There is a limited number of studies and research on the effect of man-made and natural disaster in the distribution system. The literature can be studied in four distinct contexts: emergency planning, physical behavior analysis, outage prediction, and resource allocation.

Emergency planning:

In this context, reference [9] reviewed the models for substations and distribution feeders planning under normal and emergency conditions. So far there is still relatively little research on Natural Disaster Early Warning System for Power System. In [10], the natural disaster early warning system for the power system is proposed, and details of the four parts of the system are introduced respectively. A mathematical framework for analysis of the interaction between natural hazards and the power grid is presented in [11]. The outcome of this study can be used in any mitigation technique during the design or operation stages. [12] includes methods for quantitative vulnerability analysis of electric power delivery networks to enable effective strategies for prevention, mitigation, response, and recovery to be developed. Reference [13] studied three approaches for joint damage assessment and restoration of the power systems after natural disasters. The proposed approaches include i) an online stochastic combinatorial optimization algorithm which dynamically makes the restoration decisions once each potentially damaged site is visited, ii) a two-stage method that first evaluates the extent of the damage and then restores the system, and iii) a hybrid algorithm of both approaches which simultaneously performs the damage evaluation and system restoration tasks. A risk assessment method to infrastructure technology planning for improving the power supply resiliency to natural disasters was proposed in [14]. Reference [15] considered the last-mile restoration of power systems, i.e., how to schedule and allocate the routes to fleets of repair crews to recover the damaged power system as fast as possible. The power restoration and vehicle routing were decoupled to improve the computational efficiency of the model. The result indicates that the proposed model outperforms the models which are practiced in the field in terms of solution quality and scalability. A comprehensive survey of models and algorithms for emergency response logistics in electric distribution systems, including reliability planning with fault considerations and contingency planning models were presented in [16] and [17].

Physical behaviour:

It is necessary to study the impact of natural disasters on electrical power systems for understanding the causes of the blackouts, explore ways to prepare and harden the grid, and increase the resilience of the power grid under such events. Power system resilience characterizes the ability to resist, adapt to, and timely recover from disrupti**ons. [18] i**ncludes hardening measures and operational restoration measures. These two aspects of resilience measures are innovatively combined in this paper to improve the overall condition of the power system. The resilient power system is intended to cope with low probability, high risk extreme events including extreme natural disasters and man-made attacks. Various strategies for preparing, hardening and enhancing proactive resilience with a focus on microgrids for improving power system resilience are reviewed in [19]. [20] presents a framework to systematically measure and assess power grids' resilience with a focus on performance as perceived by customers at the power distribution level. This framework also provides a measurement for the degree of functional dependency of loads on power grids and demonstrates how the concepts of resilience and dependency are inherently related. [21] includes a theoretical analysis of the impact of the extreme weather events and deliberate attacks on the power systems, which is accompanied by several examples taken from existing reports. The power systems resiliency for these cases are presented and the used practices are being assessed. Optimized models to improve the power system reaction time to these new risks are also discussed.

In the context of physical behavior analysis of power system infrastructure in hurricanes, [22] analyzed the resilience of power distribution systems based on the power distribution infrastructure and its interaction with the biophysical environment, and the way that restoration processes are prioritized. It was concluded that even though the infrastructure does not have any significant effect on outage duration, the interaction between infrastructure and the biophysical environment significantly affects outage duration. Reference [23] proposed a comprehensive strategy for mitigation of hazards with the aim of creating resilient cities which are able to withstand disasters. The hazard mitigation practices, the definition of the resilient city, and discussion on the importance of resilience, and the ways that these principles can be applied to physical and social elements of cities were presented, as well. In [24], a data mining approach was proposed to evaluate the impact of soil and topographic variables on accuracy of the power outage prediction models in hurricane events. In [25], a method for characterization of the behavior of networked infrastructure, including power delivery systems in natural hazard events such as hurricanes was presented. The model also included resilience and interdependency measures. The proposed model could be utilized to develop design strategies for improved power infrastructure resiliency in natural disasters. Reference [26] proposed a probabilistic framework for vulnerability analysis of distribution poles subject to hurricane hazards considering the impact of a changing climate. The results indicate that changing climate and the age of the poles significantly increases the failure rate of distribution poles. The impact of tropical cyclones on United States power systems, under climate change scenarios was analyzed in [27]. [28] prepared as a sectoral note for the *Lifelines* report on infrastructure resilience, investigates the vulnerability of the power system to natural hazards and climate change, and provides recommendations to increase its resilience. [29] includes a detailed discussion of a case history: a 1993 flood that resulted in US$10–15 billion in losses. The article covers some of these impacts and how to harden substations against them. Among the various disasters, the frequency and severity of cyclones have increased at an alarming rate in the last two decades, which is attributed to climatic change. [30] explores the impact that cyclones have had on the sector in the last two decades in Odisha. [31] includes a detailed discussion of a case history: an earthquake registering 8.8 on the Richter scale struck the central part of Chile and a tsunami subsequently hit coastal areas, affecting all the principal supply systems electricity, water, gas, and telecommunications—collapsed, making matters even worse for the suffering population. Interruptions of electric service in the past few years caused by natural disasters have led to devastating economic losses in China and reduced the restoration and reconstruction speed of other related lifeline infrastructures, such as water supply systems and communication systems. [32] provides an overview of the damage to electric power grid infrastructure caused by three types of natural disasters that have taken place in China: severe windstorms, ice and freezing rain, and earthquakes. [33] introduces a recent and thorough electric power reliability analysis of Sweden and focuses on the country's struggle against climate change related natural disasters via updating the country's electric power policy to improve its service quality. The paper highlights the Gudrun storm of 2005 as a case study to demonstrate the severe impacts of extreme weather events on the power system. Wildfires are natural phenomena that play a crucial role in many forest and grassland ecosystems and affect the overall power system. A solution is put forth in [34] that enables the system operator to dispatch distributed generators, demand responsive loads, and microgrids in order to supply loads under such emergency conditions. [35] examines technologies and strategies that could make the power delivery system less vulnerable to attacks, restore power faster after an attack, and make critical services less vulnerable while the power is out. The approaches explored in the report can greatly reduce the grid's vulnerability to cascading failures, whether initiated by terrorists, nature, or malfunctions.

Outage prediction:

Outage prediction is an important tool for ensuring an efficient response to natural disasters. In this context, [36] introduced a method for estimating the restoration time of electric power systems after hurricanes, cyclones and ice storms. Using a large dataset of six hurricanes and eight ice storms, accelerated failure time models were developed to forecast the duration of each probable outage. In [37], negative binomial regression models for prediction of outages due to cyclones were developed. Reference [38] compared the regression methods and data mining techniques for predicting power outage durations during hurricanes and cyclones. The accuracy of Bayesian additive regression trees (BART) outperformed the other models in their study.

Resources Allocation:

In this context, [39] presented three mathematical goal programming models for locating the repair units and restoring the transmission and distribution lines in an efficient manner. The first model can find the optimal repair-unit dispatch tactical plan with a forecast of adverse weather conditions. The second model is able to derive the optimal repair-unit location for a short-term strategic plan under normal weather conditions. The third model finds the optimal number of repair units for a long-term strategic plan. A mixed-integer programming model and a general column-generation approach for inventory decision making of power system components throughout a populated area in order to maximize the amount of power served after disaster restoration was proposed in [40]. In [41], a stochastic integer program was proposed to find the optimal schedule for inspection, damage evaluation, and repair in post-earthquake restoration of an electric power system. Again, The resilience is assessed through different techniques like cascading failure analysis for assessing the hazard, risk quantification and ranking for measuring the hazard, and islanding operation and detection for managing the hazard at the post disaster stage is presented in [42]. In [43], the service restoration considering the restrictions on emergency response logistics was studied with the objective of minimizing the customers interruption cost. The reconfiguration and the resource dispatching issues were considered in a systematic way for deriving the optimal time sequence in every step of the restoration plan. In [44], a decision-making model to manage the required resources for economic power restoration operation was proposed. The optimal number of depots, the optimal location of depots, and the optimal number of repair crews were determined by their model in order to minimize the transportation cost associated with restoration operation. In [45], a decision support tool for improvement of information used by electric utilities for managing restoration of power distribution components damaged due to large-scale storms was described. The circuit layout, the placement of protective and switching devices, and the location of customers were taken into account to allocate the crew resources to manage the storm outage in a cost-effective manner.

CHAPTER 3: ANALYSIS

3.1 Impact of Natural Disasters on Power Distribution System

3.1.1 Floods

Flooding can cause severe damage to distribution lines, poles and substation equipment and lead to interruptions in service continuity and widespread outages.

Weather can have a significant impact on the asset management, planning, and operation of transmission and distribution systems, especially in the case of a utility with a large footprint that can be affected by different types of extreme weather. Of these extreme weather events, few inflict more punishing damage on substation equipment than floods. Restoring flooded substations takes much longer than restoring a downed power line damaged by ice or wind and requires different restoration procedures and personnel. [46]

Table 1: Impacts on power system by recent flood events [47]

Flood Events	Impact on Power System
1988	Eighteen electric power substations were flooded. About 2000 km 11-KV power lines had to de-energize.
1998	Prolonged floods severely affected the power supply system of Dhaka. Power lines had to de- energize in different parts of Bangladesh which affected over a million people.
2004	Power supply was shut down in some parts of Dhaka city for a few days. Some southeastern sub-districts were out of power for more than a week.
2007	Electricity poles were washed away by the flooded rivers in northwest and northeast Bangladesh which caused disruption of electric supply in many parts of the country and paralyzed the normal life of people.

Given the large amounts of water, rust, and mud left trapped in a piece of substation equipment following total submersion, repair of that equipment becomes a sizable task. Flooding becomes a problem for substations when the amount of water reaching the drainage network exceeds its capacity. [46]

Recent floods affected power distribution in Bangladesh in different ways. The impacts of most recent extreme floods on power distribution in Bangladesh are given in Table 1. All the extreme floods caused power supply to shut down especially in urban areas. Eighteen electric power substations were flooded in 1988. About 2000 km of 11-KV power lines had to be de-energized due to severe floods in 1988 and 1998. Severe flooding in 2007 washed away electricity poles in some parts of Bangladesh which caused disruption of electric supply Transformer load tap changers, voltage regulating relays are adversely affected by flood water.[47]

Figure 4: Substation flooded in Shingra, Natore

The soil is weakened by flooding and towers and poles may collapse. As a result electricity distribution is forced to be stopped for safety. In the 2019 flood in Bangladesh, Rural Electrification Board had to shut down 450 km of distribution line in Rangpur, Gaibandha, Dinajpur, Kurigram, Thakurgaon, Sherpur, Jamalpur, Bagura and Tangail. Around forty thousand consumers were affected and some areas were out of electricity for about a month. [50] In the 2017 flood, water got into the substation of Natore Palli Bidyut Samity in Shingra, Natore, this jeopardized distribution for around fifty thousand consumers. [51] In the 2020 flood, 19 kms of line, 37 transformers, 368 poles were damaged in different Palli Bidyut Shamitis. Supplies were shut down in 128 transformers and 34 kms of line. In primary estimations BREB incurred a loss of 15 million taka. [52]

Most of the electronic transducers and supervisory control and data acquisition (SCADA) equipment can be affected by flood water.

Some of the most vulnerable components in the substation are the control wiring in the lower cubicles of the control house, which may contain essential protection and control schemes. Loss of the DC battery system may occur. Water damage to those components during severe flooding could result in the outage of the substation or a large percentage of it.

Of all the equipment flooded, the damage inflicted on the power circuit breakers could be the most severe, since they operate at very high speeds and with great precision, making them sensitive to contamination and improper lubrication. This applies to metal-clad switchgear as well as outdoor circuit breakers for high-voltage systems.

3.1.2 Earthquakes

A major earthquake can devastate any populated area. Bangladesh is one of the most tectonically active regions in the world. It sits where three tectonic plates meet: the Indian Plate, the Eurasian Plate, and the Burmese Plate.

As the Indian Plate moves gradually northeast, it is slowly colliding with the Eurasian Plate, causing the Himalayas to rise. Bangladesh is located near the boundaries of the active seismic Indian plate & Eurasian plate and Indian plate & Burma plate. [55] Active faults are found along this boundary, particularly the 300km-long Dauki fault that borders northern Bangladesh. Active faults such as those in the north and east of Bangladesh can also be destructive. A fault line at Madhabpur near Dhaka can cause an earthquake of 7.5 on the Richter scale. So, the risk of a major earthquake is ever growing.

The potential effects of earthquakes and other natural disasters on the power system are system faults. The faults are not only limited to physical damage of power systems, but power quality disturbances may also take place. They may cause severe cascaded failures and black outs. [53] The key node for power system failure and blackout is the failure of substation equipment. Earthquakes can cause serious damage to electrical equipment, especially to equipment located in substations and switchyards. Transformers frequently slip from their position or the foundation is collapsed during earthquakes. [54]

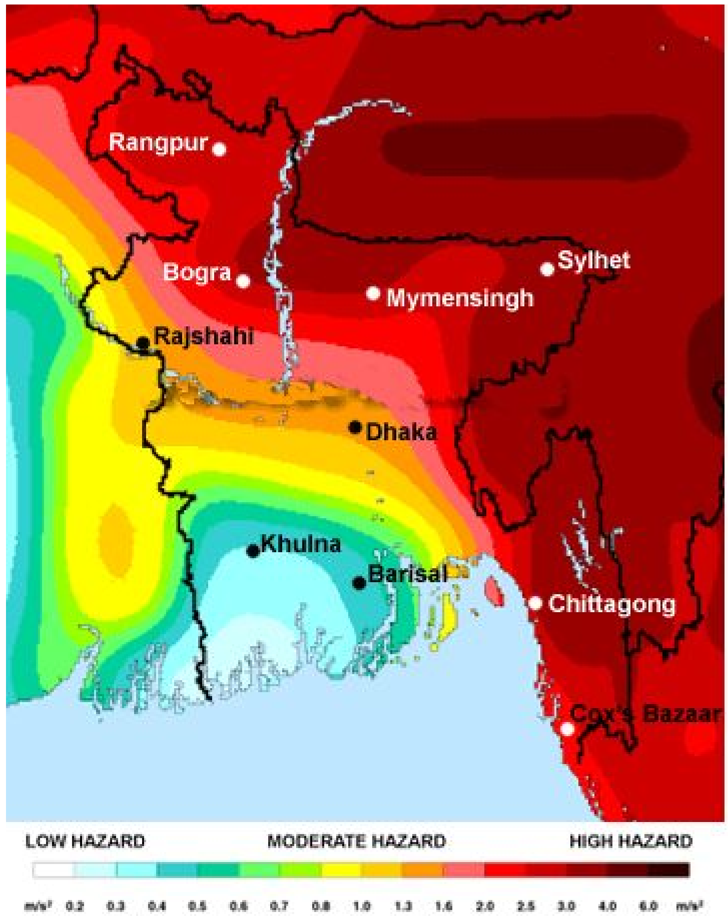


Figure 5: Earthquake hazard in Bangladesh

3.1.3 Cyclone and storm

Cyclones and Storm Surges: Nearly every year, cyclones hit the country's coastal region and a severe cyclone strikes the country every three years, on average. Intensity of cyclonic storm surges as well as depth and extent of storm surges induced coastal inundation are likely to increase in changing climate through rising sea surface temperature (SST) and sea level. The IPCC further reports that future cyclonic storm surges and related coastal floods in Bangladesh will likely become more severe as future tropical cyclones increase in intensity. In the extreme scenario, the areas vulnerable to inundation depths of more than 1 metre and 3 metres, respectively would be 14% and 69% higher than the current baseline scenario. A 10-year-return period cyclone in extreme scenarios will be more intense by 2050 and cover 43% of the vulnerable area, 17% more than the current coverage. [7]

Cyclones and tidal surges in 1991, 1998, 2000, 2005, 2008, and 2008 record the increase of extreme events both in frequency and severity. Super cyclone SIDR in 2007 exceeded previous records of its coverage and wind velocity. Bangladesh was flooded twice in a single year in 2007 (Mallick, 2008). Bangladesh is highly susceptible to tropical cyclones. A total of 117 tropical cyclones hit the coast of Bangladesh from 1877 to 2003 of which 39 were tropical depressions, 52 were tropical storms, and 26 reached hurricane intensity (Islam and Peterson, 2009). In the past century (1901–2000), the rate of tropical storms striking the coast was one storm per year. Since 1950, the rate of landfalling tropical storms has increased by 1.18 per year (Islam and Peterson, 2009). Using a hydrodynamic model Karima and Mimura (2008) predicted more intensified surge heights at the coast of Bangladesh due to climate change. They also predicted that flooded areas, flooding depth and surge intrusion length will be substantially larger under intensified surge conditions.

Bangladesh experienced the worst ever blackout in 2007 after the severe tropical storm SIDR. All major power plants tripped and failed for varying durations. It took two days to restore the full generation. Despite restoration of power generation in most of the power plants, electricity supply was hampered as the power lines and poles were severely damaged. It took 2 to 3 days to restore the full supply and many more days in severely affected southern districts.

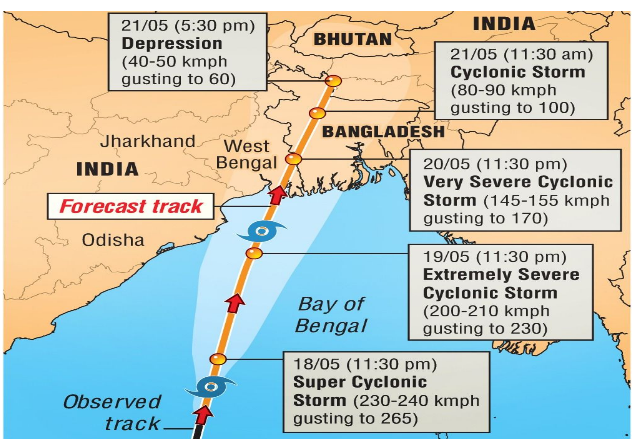


Figure 6(a): Route of a tropical cyclone

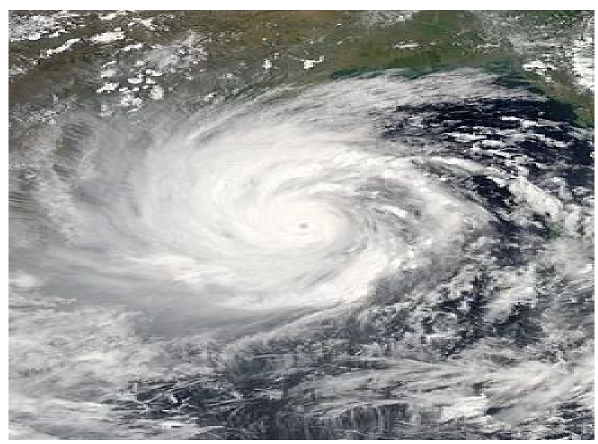


Figure 6(b): Aerial view of a cyclone

The power distribution system of Bangladesh was significantly affected by the recent cyclones. The impacts of the most recent five cyclones on the power distribution system of Bangladesh are given Table 2.

The strong winds of cyclone SIDR caused major destruction to the electricity transmission and distribution system of Bangladesh. Several transmission lines and substation components were damaged by high sustained winds and fallen trees. It caused disruption of electricity supply for the entire country for almost a full day. Full restoration of the distribution system took more than a month. Damage and loss to the power sector totaled US$ 13.4 million. Cyclone Bijli in April 2009 caused high waves and a tidal surge of up to three meters above the normal tide. The cyclone battered 14 southeastern coastal districts of Bangladesh with heavy rain and winds of up to 100 km/h. Hundreds of electricity poles were uprooted or damaged, leaving parts of the southeastern districts without power for a long time. Cyclone Aila in May 2009 uprooted numerous electric poles, downed power lines and caused widespread power outages in the southwest coastal area of Bangladesh (Sources: national newspapers). Increased frequency and severity of storms due to climate change may severely affect the power distribution system in Bangladesh in the near future. [5]

As a part of primary data analysis, we collected data on the disastrous impact of cyclone Amphan from REB (Rural Electrification Board). Amphan was responsible for significant financial loss and electricity interruption in the coastal region during may, 2020.

Table 2: Impacts on power system by recent storm events (source: national newspapers)

Storm Events	Impact on Power System
1991	The supply of electricity was cut-off for one to few days in several storm-hit cities including Chittagong, the main commercial city of Bangladesh.
2007	Bangladesh experienced the worst ever blackout after the severe tropical storm SIDR. All of the 26 power plants had tripped and failed for varying durations. The power lines and poles have been severely damaged. It took 2-7 days to restore the full supply.
2008 (April)	Cyclones uprooted electricity poles and damaged power lines, leaving parts of the southeast areas without power.
2008 (May)	Damaged the Wind Battery Hybrid Power Installation in the coastal region of Bangladesh. Three-months were taken to resume the supply.
2009	Caused numerous electric poles uprooted and power lines downed, causing widespread power outages in the southwest coastal area of Bangladesh.

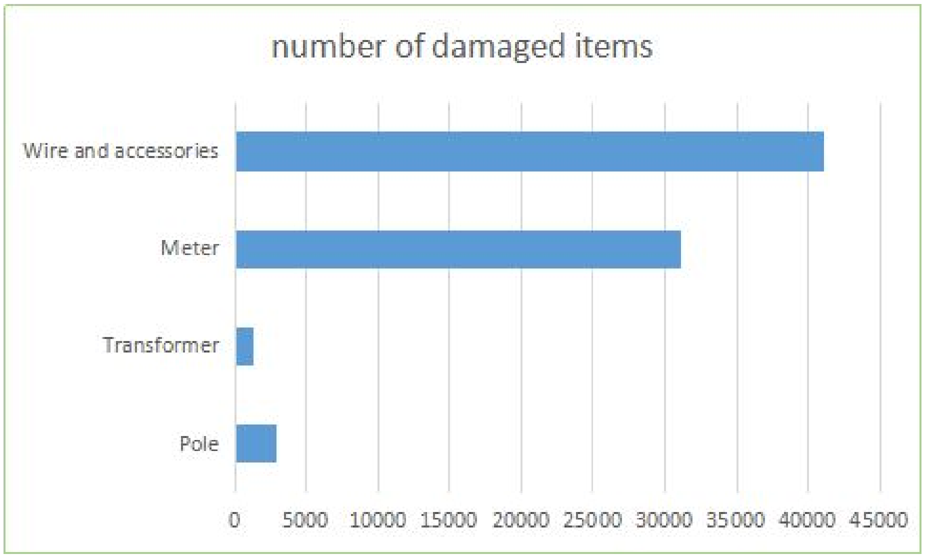


Figure 7: Loss of distribution system equipment of REB due to cyclone Amphan

Figure 8: Financial Loss of REB due to cyclone Amphan

3.1.4 Heat wave and Drought

Existing electricity generation, transmission and distribution systems were not designed to endure heat waves of today's magnitude [56]. Also, end users require more electricity during heat waves, further stretching electricity systems capacity [57]. During a heat wave the electricity sector can suffer problems with generation, transmission and distribution, potentially causing a blackout (the complete failure of electricity distribution) or a brownout (the reduced supply of electricity) [58]. Blackouts and brownouts that occur during a heat wave can have detrimental effects on human health and the economy as modern societies are highly dependent on electricity for all aspects of daily needs, including lighting, transportation, communication, cooling and industrial production. The impacts vary according to the duration of the failure power interruptions can be "momentary", lasting only a few seconds, or "sustained," meaning the event is longer than five minutes [59] but of course longer interruptions have greater impacts.

Effect:

During heat waves high temperatures affect the generation capacity of fossil fuel and nuclear powered plants as well to renewable technologies due to increased air and water temperature. When the air temperature becomes very high, fuel efficiency is affected due to a lower oxygen concentration in the air and thus shows a 0.1% reduction in gas and fuel powered plants for each increase of 1°C in the temperature. In the case of nuclear power plants, an increase of 1°C reduces the energy supply by about 0.5% via its effect on thermal efficiency. For its part every 5°C increase in water temperature represents a 1% loss of efficiency [60]. During droughts and heat waves, the loss of electricity production may therefore exceed 2% per °C given that refrigeration systems of power plants are limited by physical laws, regulations and access to cold water [61]. In addition, operating costs may increase during heat waves given the need of more staff (requiring an increase of between 50% and 100%) and a bigger stock (an increase of between 10% and 20%) and cascading failures leading to blackouts will become more likely [62].

Conversely, transmission and distribution systems lose efficiency at high temperatures because they limit the power of the transformers and lines and expand the resistance of electric transmission in networks, thereby increasing energy losses. The capacity of transformers decreases by 1% for each °C; in copper lines the temperature of the resistance increases by 0.4% for each °C. Hence, total network losses increase 1% for every 3°C [63]. Moreover, heat waves increase cooling demands, thereby boosting electricity consumption to its highest value and testing the ability of the system to meet this demand. In this sense, demand could increase by as much as 21% on particularly hot days by the end of the century [64].

Impact in Bangladesh:

(a) Rising Temperature and Power Demand:

With the rise of temperature, increasing trends in the number of hot days has also been observed in Bangladesh **[65]**. Increased temperature and hot days will cause more consumption of power for space cooling. It will cause an increase of total power consumption as well as the peak demand of power. As the main cause of frequent power failures in Bangladesh is the power demand surge during peak load hours, it is more likely that there will be more power failures in Bangladesh due to climate change if no initiatives are taken to increase the generation with the increase of demand due to the rise of temperature.

(b) Increased Irrigation Requirement and Peak Power Demand:

Groundwater is the main source of irrigation in most parts of Bangladesh especially during the dry season. Electric pumps are generally used to exploit groundwater and irrigate cultivated land. Ever increasing ground water extraction for irrigation during the dry season in recent years has caused the ground water level to fall to the extent of not getting fully replenished in the recharge season. This causes overdraft in some parts of Bangladesh. It has been reported that the irrigation rate during the pre-monsoon rice grown period will be increased from 8.5 mm/day in the base year to 8.9 mm/day in 2050 and 9.3 mm/day in 2100 **[66]**. As there is a direct relation between groundwater level and pumping rate, pumping out of more water in less time to meet the irrigation demand will cause more declination of groundwater level. Consequently, more energy will be required to sustain the yield of groundwater for sufficient irrigation. It will cause an increase of peak power demand and more load shedding during the pre-monsoon summer season in Bangladesh.

(c) Temperature Rise and Transmission Loss of Electricity:

Transmission loss is the major component of technical system loss in Bangladesh which is equal to 7.62% of total electricity fed into the transmission line **[67]**. Besides that about 5.17% of total electricity is lost in the distribution system which includes primary distribution lines, distribution transformers, secondary distribution lines and service drops to the individual consumers. Mainly copper wires are used for transmission of electricity in Bangladesh. The temperature coefficient for the resistivity of copper is 0.39% per °C. With an increase of 2°C, the losses in the lines and transformers will increase by about 0.8%.

(d) Temperature Rise and Transformer Lifetime:

Transformers are the most important and critical equipment in the transmission line grid. Increased temperature will have important effects on the lifetime of a transformer. Transformers are designed for a certain load rating at an ambient temperature according to its operation environment. Transformers are often fully loaded in the grid of Bangladesh. Temperature rise may cause the outdoor temperature to reach levels above the rated temperature of the transformer in summer. Operation of transformers above the rated temperature for long periods of time would accelerate the transformer aging rate. Therefore, probable increase of temperature by an amount of 2°C or more might cause a decrease of lifetime of transformers.

3.1.5 Global Pandemic of 2020

In 2020 the global pandemic COVID-19 has impacted almost every sector of public service and natural way of life. The most severely affected service in Bangladesh apart from the health sector was the power distribution sector. The regular operations of the distribution organizations were hampered. The estimated growth of the sales and development was delayed by the COVID-19.

Regular billing could not be done due to meter readers not being able to visit consumer premises in the lockdown. The organizations decided to prepare estimated average bills according to previous electricity usage of the consumers. But the estimation of electricity without real meter readings can not be close to the real usage for all the consumers. As a result, a large number of complaints were filed by the consumers about overbilling, consumers were aggrieved and the face of the organizations were tarnished. Dhaka Power Distribution Company (DPDC) received 4,330 complaints about overbilling. The public outcry was one of the major crises of the company's history.

Table 3- Bill collection information of distribution entities till May'20 (Source-Survey data)-

Organization	Due till May'20 (In million taka)	Collection target (2019-20)	Achieved till May'20	Comment
BPDB	18209.30	2.25	3.03	Target not achieved
BREB	40073.55	1.25	2014	Target not achieved
DPDC	13050.96	1.67	2.37	Target not achieved
DESCO	8957.45	1.61	2.58	Target not achieved
WZPDCL	4708.35	1.95	2.54	Target not achieved
NESCO	6883.63	3.00	3.45	Target not achieved
Total	**91883.24**	**1.58**	**2.45**	**Target not achieved**

Most of the consumers were confined in their homes, many losing income, furthermore banks operated at a reduced capacity, as a result the bill collections of the electricity supply organizations took a massive hit in the COVID-19 crisis. We can see from Table 3 that none of the organizations met their collection target. For the Dhaka Electric Supply Company the collection to billing ratio of April’20 was only 36.68% whereas the ratio of the previous fiscal year was 99.55%, a massive 53% reduction. For DPDC the collection to billing ratio of April’20 was only 61% whereas the ratio of the previous fiscal year was 100.03%.Below table shows the outstanding bill of all distribution companies of Bangladesh during COVOD-19.

Another major issue was that all the large consumers were completely shut off for three months, the distribution organizations lost a large portion of their sales as a result, we see that DESCO lost 36% of its sales in April’20 compared to April’19. Government announced that the late fee charges from February’20 to June’20 will not be taken, which also affected the supply organizations revenue. This low influx of return put the companies at a financial hazard.

Many employees of the distribution organizations were positive of COVID-19, some even died. In DPDC 162 employees were isolated, 129 were COVID-19 positive and 3 employees unfortunately died. The lost man hours due to isolation and medical care put the organizations at an unfavourable position. Furthermore, the cost of medical care for the employees are borne by the organizations which ultimately is a loss of revenue. The organizations had to provide safety equipment for their employees and install disinfectant tunnels at the entrance of the vicinity. DPDC spent 3.68 million taka to acquire safety equipment for it’s operation during the pandemic. As a responsible stakeholder of social development, DESCO incurred a cost of 16.5 million taka to support welfare activities during COVID-19 pandemic.

Large number of employees were isolated and maintenance teams were operated with a reduced number of staff working in shifts due to COVID-19 risk and so the regular system maintenance works were affected. This is further proved when we see that in April’20 the SAIFI of DPDC was 1.397 which in the same time last year was 1.071, meaning that the frequency of electric disruption increased by almost 30%.

3.2 Impact of Man made Disasters on Power Distribution System

3.2.1 Reasons of vulnerability in distribution system

The power system is inherently vulnerable because transmission and distribution lines may span hundreds of miles, and many key facilities are unguarded. This vulnerability is exacerbated by the fact that the power grid, most of which was originally designed to meet the needs of individual vertically integrated utilities, is being used to move power between regions to support the needs of competitive markets for power generation. Today most power is generated by large central generating stations that are located far from the customers they serve. Transformers located near the power plant increase the voltage so that it can be carried efficiently over long distances. Substation transformers near the end user then reduce the voltage and carry the power into the distribution network for delivery to customers. Unlike trains or natural gas in pipelines, electric power cannot simply be sent via specific lines wherever dispatchers choose. The electrical current flows through the system according to a set of physical laws and it must be continually adjusted to keep all parts synchronized and in electrical balance. If corrections are not made immediately when imbalances occur, the result can be oscillations and other disturbances in the system that can result in a cascading failure over a wide area. In some states, traditional vertically integrated companies that owned and operated the entire system from the generators to the customers' meters have been restructured in an effort to introduce competition. The introduction of competition in bulk power across the country has resulted in the transmission network being used in ways for which it was not designed. As a result, the physical capabilities of much of the transmission network have not kept pace with the increasing burden that is being placed on it— subsequently many parts of the bulk high-voltage system are heavily stressed. In addition, many important pieces of equipment are decades old and lack improved technology that could help limit outages. There are many men- made disasters which may hamper the power distribution system as a whole, risking the country wide blackout for a long time.

3.2.2 Terrorism

One of the frightening threats in power distribution system is terrorism. Since terrorism uses excessive power to threat the stability and normal situation of the country so, they will target the electric establishments for the attack for its cascading negative and pernicious effects on the people. Distribution lines and substations generally remain unguarded for the nature of their kinds which make them vulnerable to the terrorist organizations. If carried out in a carefully planned way, by people who knew what they were doing, such an attack could deny large regions of the country access to bulk system power for weeks or even months. An event of this magnitude and duration could lead to turmoil, widespread public fear, and an image of helplessness that would play directly into the hands of the terrorists. If such large extended outages were to occur during times of extreme weather, they could also result in hundreds or even thousands of deaths due to heat stress or extended exposure to extreme cold. Although there are many examples of terrorist and military attacks on power systems elsewhere in the world, at the time of this study international national terrorists had shown limited interest in physically attacking Bangladesh grid and its distribution lines. However, that should not be a basis for complacency.

3.2.3 Civil Unrest

Bangladesh had a huge gap in the demand and supply of electricity. Blackout was the common phenomenon as minimal generation capacities were there against the whopping demand of electricity. For the demand of electricity people besieged the different substations of the distribution companies, assaulted the officers and damaged different power establishments which ultimately led towards regional load shedding with hectic task for restoration and wasting a whopping amount of money to replace the instruments.

Kansat civil movement for electricity: Kansat was one of the incidents in the history of Bangladesh where people died for the demand of electricity. It was a non-violent people's mobilization for fair access to electricity that lasted for nine months, starting in September 2005 and ended in April 2006; this mobilization was spontaneous and sporadic by the people, for the people and with the people. Kansat is a village, under Shibganj Upazila in Chapainawabganj district of Bangladesh, 27 km from the district township and about 250 kilometers from Dhaka city. The peasants of Kansat under the banner of Palli Biddyut Samity (PBS) have a legitimate complaint against Rural Electrification Board (REB). They say that they receive very little electricity per day; hardly 1-2 hours with which they cannot do any agricultural operations. Each month they pay a fixed amount of money no matter how much electricity comes to their doorsteps. And to make matters worse, some men from the electricity department are charging Taka 10 every month as meter rental fees, which the peasants say are not in the contract. At the beginning the people of Kansat tried to fulfill their demands through negotiations and appeals. They started agitation after being failed to get their demands fulfilled through negotiations. They submitted a memorandum and arranged a press briefing. After that they organized peaceful mobilization like gherao . At that stage, the leader of the movement was arrested with a threat to be killed. The people, instead of getting nervous, became resilient. The number of agitated people in the street increased at a geometric rate. A total of 20 innocent people were killed by the police. The police showed their highest cruelty, attacked unarmed people in their sleep –aged people and children were not spared, and villages at night found government forces behaving like foreign invaders, killers and looters. Poor peasants and workers, on the other hand, showed their highest courage and unity. It resulted in a mass upsurge in Kansat.

Finally, the state bowed down to the poor people who were unarmed. PBUSP leaders and a high powered government committee signed a memorandum of understanding (MoU) that brought an end to the nine month movement. The authority was forced to accept all of their demands.

3.2.4 Cyber Vulnerability

Modern power systems rely heavily on automation, centralized control of equipment, and high-speed communications. The most critical systems are the supervisory control and data acquisition (SCADA) systems that gather real-time measurements from substations and send out control signals to equipment, such as circuit breakers. The many other control systems, such as substation automation or protection systems, can each only control local equipment. All SCADA systems are potentially vulnerable to cyber-attacks, whether through Internet connections or by direct penetration at remote sites. For example we can look at the power system hacking incident of Ukraine: "On 23 December 2015, hackers were able to successfully compromise information systems of three energy distribution companies in Ukraine and temporarily disrupt the electricity supply to consumers. It is considered to be the first known successful cyberattack on a power grid. 30 substations were switched off, and about 230 thousand people were left without electricity for a period from 1 to 6 hours [75]. At the same time consumers of two other energy distribution companies were also affected by a cyberattack, but at a smaller scale. According to representatives of one of the companies, attacks were conducted from computers with IP addresses allocated to the Russion Federation [76]. Any telecommunication link that is even partially outside the control of the system operators is a potentially insecure pathway into operations and a threat to the grid. Wireless communications within substations is a particular concern. If they could gain access, hackers could manipulate SCADA systems to disrupt the flow of electricity, transmit erroneous signals to operators, block the flow of vital information, or disable protective systems. Cyber attacks are unlikely to cause extended outages, but if well-coordinated they could magnify the damage of a physical attack. For example, a cascading outage would be aggravated if operators did not get the information to learn that it had started, or if protective devices were disabled. Cyber security is best when interconnections with the outside world are eliminated. When interconnections are unavoidable, best practices for security must apply

3.2.5 Political instability

Political culture of our country makes the electric supply system vulnerable to attacks. Political parties resort to the vandalism for pressing their demands before the government. Bangladesh has witnessed lots of incidents where political parties' activists have attacked electric poles and other establishments. Damage of Kansat Palli Bidyut Office in 2013 is one of the glaring examples in this regard. "Property, documents and machinery worth Tk 250 crore have been destroyed while 40,000 electricity connections to Shibganj upazila have been disrupted, said Nurul Islam, the office's assistant general manager (finance). He said a substation and all official documents were completely burned down and there was no knowing when restoration works would begin. Farmers of Shibganj are suffering the most as large areas of land could not be irrigated due to the absence of electricity for the last three days. Many electricity-dependent appliances are now inactive. People were partially detached from the rest of the country as they are unable to watch televisions and use mobile phones while food is spoiling in refrigerators" [77].

3.2.6 Irresponsible Activity

Kites Flying: kites flying around power lines, residing under electricity transmission structures and using the tower legs for drying clothes had caused feeder tripping many times. This will lead to interruption of power supply and cause accidents sometimes resulting in loss of life. Such accidents also lead to outages and irreversible damage to electrical equipment at generating stations and substations. The U.S. consumer product safety commission made some guidelines about kite flying to avoid accidents.

"Contacting a power line with an antenna, metal ladder, kite line or metal pole is a major cause of electrocutions associated with consumer products. Because children can come in contact with power lines when flying a kite, they should be encour-aged to follow these safety guidelines:

1. Avoid flying kites in wet, stormy weather. A wet kite string is a good conductor of electricity and may cause electrocution if it touches a power line.
2. Don't use metalized strings or strings with metal fibers.
3. Kites should be flown only in open areas never near power lines.
4. If a kite falls into a power line, abandon it. Attempting to remove it is dangerous.
5 Don't use metalized kites. This type of kite has been banned by CPSC." [78]

Stealing Grounding Wire: It's a very common case especially in the countryside where thieves have cut the safety wires that ground electrical current. This leaves state workers exposed to a risk of electrocution when making repairs or doing maintenance.

Accident due to hooking: Countryside maximum L.T. lines are nacked wire which is very easy to steal power by tapping or hooking, during such activity the thief him-self can be electrified and short circuit fault can occur which will lead to power interruption and power equipment damage. Electricity act 2018 state that "If it is proved that illegal tapping into, or consumption or use of, the electricity connection of a licensee has taken place by installing a machine,device oi artificial means in a dwelling-house, then the occupant of that premises shall, unless otherwise proved, be deemed to have committed an offence under sub-section." [79]

CHAPTER4: FINDINGS

4.1 Weak links/ Vulnerability Assessment-

Distribution and transmission network failures are responsible for most outages. Transmission infrastructure is usually more robust than distribution infrastructure and hence more resilient to natural disasters. Distribution systems are based on poles, often wooden ones. Distribution lines are vulnerable to many natural disasters, including wildfires, high winds, freezing rain, heavy snow, earth movement (liquefaction, earthquake, landslides) or even extreme heat [81]. Damages occurred most commonly from storm eventsThese damages may be a result of flying debris, falling trees, or lines breaking during winter storms because of the combined impact of ice and wind – factors that topple lines and poles. Grid infrastructure is also vulnerable to liquefaction in earthquake-prone areas [82]. During very high temperatures, sagging of the lines has also been observed, sometimes leading to failures. Wildfires present an interesting and unique case, in which distribution assets are the source of risks (sparks causing ignition).

Substations are highly vulnerable to floods, earthquakes, and cyclones. If their components are not properly anchored, earthquakes can cause substantial damages to substations. Tall components (such as disconnect switches) of electrical substations are susceptible to damage from wind, while floods can damage expensive components and lead to extensive service interruption. Extreme heat events can affect transformer performance, but they do not cause long-lasting damages.

Several climate change–induced phenomena are likely to increase power sector vulnerability. With increased drought frequency and higher temperatures, the efficiency of the power system is likely to decrease. Research suggests that a 1°C temperature increase could reduce power output by 0.45 to 0.8 percent [83].

At the same time, these events will impact substation equipment and the current rating of cable and lines, and are also likely to increase system stress because of additional demand for air conditioning. Extreme weather events could disrupt infrastructure, affecting the delivery of electricity; higher temperatures may also result in greater transmission losses because of the increased resistance of power lines.

Climate change will also affect flood frequency and hydrological outputs by changing not only river flow and evaporation, but also the frequency of erratic river flow, which results in the distribution pole, cable and sometimes substation going under water [84].

4.2 Recovery/Restoration Time

Although different natural hazards affect electric utilities in a different way, as the intensity of the hazard increases, the level of damage increases as well. As damage accumulates, more complex, time-consuming and costly repairs need to be conducted to restore power supply to customers and repair critical equipment and facilities. Therefore, recovery time is prolonged. However, for a given damage level, recovery time depends on the capability of the affected electric utility companies and TSOs to respond promptly and effectively. Emergency response capabilities encompass trained staff, adequate resources, and an appropriate organization [85].

Both earthquakes and floods cause widespread damage to electrical equipment and power grid components. The damaged items need to be either repaired or replaced, and the time to conduct repairs or install new equipment drives the recovery of the power grid. In the case of earthquakes and floods, it was the number of items which drove recovery time in this study.

In addition, access to the damaged sites was a major determinant of recovery time in the aftermath of both earthquakes and floods. In some cases, access to substations or transmission towers was blocked by landslides (triggered by strong ground motion or rainfall) [85].

Other factors which were found to affect recovery time in this study were the extent of the damage, the complexity of required repairs, the availability of spares (either with the affected utility, through mutual aid agreements, or from the manufacturer), and transportation arrangements.

Damage to ports and airports can hinder the transportation of critical equipment or parts, and can cause significant delays to the recovery process. In addition, the disruption of sea and/or air transportation can delay the delivery of key resources, such as Distribution transformer, CB, Meter etc for emergency connection, thus further exacerbating power outages. Islands are particularly vulnerable to port and airport transportation disruptions. For instance, due to hurricane Katrina in America when the distribution tower, Meters, Substation was destroyed in 2011, the country's ports and airports were not affected. All emergency distribution equipment used to temporarily restore power supply to the affected area were brought in by boat. Therefore, the restoration and recovery process would have certainly taken significantly longer if sea and/or air transportation had been compromised.

In addition to ports and airports, road and railroad transportation networks are also susceptible to earthquake damage. Road and railroad bridges are the most vulnerable part of these networks. The most common failure mechanism is damage to the substructure and foundations. The unavailability of bridges may delay restoration and repairs, as personnel and equipment need to find alternative routes to reach the affected areas [86].

Furthermore, traffic congestion is not uncommon in the immediate aftermath of major earthquakes. Traffic jams are caused in urban areas, as people attempt to self-evacuate for fear of aftershocks. Unfavourable traffic conditions are likely to delay the movement of repair and maintenance crews, and hinder the recovery process in the early hours of the response. Nevertheless, traffic congestion usually subsides within a few hours of the earthquake [86].

Other than because of the disruption of the transportation infrastructure, the recovery of the power grid after an earthquake may be hindered by the failure of telecommunications systems. Electric utility companies rely on two-way radios and/or cellular telephones to coordinate repair and maintenance crews in daily and emergency operations. Both telecommunications systems were damaged by earthquakes reviewed in this study. In several cases, seismic forces caused structural damage to two-way radio repeaters and mobile network cell towers. Without a working repeater, two-way radios can only support line-of-sight communications, which are practically useless in urban areas. When a cell site is damaged, mobile phone service in the cell is lost until another antenna takes over or the damaged antenna is fixed. In addition, cell phone networks were often congested in the immediate aftermath of earthquakes, as people sought to communicate with family members and loved ones in the affected area. Cell phone congestion usually subsided within a few hours or days after the earthquake. However, without working communications, electric utility companies had a hard time coordinating repair and maintenance crews, which arguably slowed down the recovery process [85].

4.3 Economic Damages of Natural and Man-made Disasters

Our modern society largely depends on electricity. We can't imagine to pass single day without electricity. From our household work to the industrial sector, all economic activities lead by power. We can't make our country developed without the availability of electricity. Due to natural disasters or man made disasters hundred/thousand dollar's power equipment have been damaged each year. Billions of dollars are spent by utility companies to improve their power system against natural disaster and man made disaster across the globe. This chapter illustrated economical damage due to different disasters faced by different countries.

The energy sector comprises subsystems ranging from power generation to transmission and distribution. It is estimated that, globally, USD 26 trillion will have to be invested in this sector from 2016 to 2030 to sustain the current growth rate. An additional investment of USD 2.9 trillion will be required to meet the SDG targets for the energy sector [87].

Odisha is a state in the eastern part of India frequented by floods, cyclones, droughts and tsunamis, among other hazards [88]. The state faced the 1999 super cyclone which killed 10,000 people, affecting 15 million people and causing damaged worth USD 2.5 billion [89]

The super cyclone of 29th October 1999 was one of the most severe of all cyclones with a 50-year return to impact India [90]. The cyclone led to the damage of telecommunication lines, water supplies, roads, irrigation and power supplies. As many as 36 towers along 220 kV and 130 kV lines suffered irreparable damage or total collapse in the coastal districts, Bhubaneswar and Cuttack [91]. The power disruptions in Bhubaneswar and Cuttack city lasted for four days while the power in the other districts

was restored by 15th December 1999. Human resource support was provided by GRIDCO and was also pulled in from the adjoining state of Andhra Pradesh. Of INR 6227.59 crores (1 crore is 10 million) requested from the government of India, only 400 crores were earmarked for the energy department.

Cyclone Fani, 2019: The very recent Cyclone Fani of 2019 resulted in serious damage and the disruption of critical services and infrastructures in 14 districts of Odisha [92]. The wind speed was reported to be more than 230 km per hour along with heavy rainfall for four hours. Cyclone Fani caused a major setback to the state, with total losses to the tune of INR 24,176 crore. Damage to the power sector remains very high. The power infrastructure in the 14 affected districts consists of about 500 substations and 110,000 distribution transformers. These are connected with a total of approximately 14,000 transmission lines and 190,000 km of distribution lines. While damage to the transmission system was minor, damage to the distribution system included approximately 80,600 km of distribution lines, 202 distribution substations, and 13,400 transformers. The total damage was assessed at INR 8139 crore and corresponds to the requirement of “bringing back the system to the pre-cyclone level”. Another INR 253.5 crore was lost in revenue, bringing the total loss of the power sector to INR 8392.50 crore.

For a risk free power system, utility companies should adopt new technology like GIS or SCADA which need huge investment to install. Geographic Information Systems (GIS) can enable visualization of damaged areas during a power outage. This was the case during New Zealand’s successful public communication response after the Christchurch earthquake. Through accurate maps, immediate data on network status and recovery times was available to the media. With the single-city overviews, residents could determine areas of the network that were damaged and where they could find power. The power sector’s rapid, transparent information-sharing enabled customers to take appropriate action. To install the GIS system, New Zealand power company invested a total of 10 million dollars[93].

Additionally, it is important for utilities to have back-up centers to resume system operations after failures at the main control center, as well as mobile substations and emergency restoration systems to reduce restoration time. These facilities should be supported by the creation of and good use of communication links with priority users to share information.

With the increasing threat of manmade around the world, more attention is

being paid to the security of the electric infrastructure. The experience of countries like Colombia, which has faced as many as 200 terrorist attacks on its electric infrastructure per year during the last 11 years, demonstrates the vulnerability of the power system to such events. Although it is very difficult to avoid these events or predict when and where terrorist acts will occur, quick assessment of the situation can help operators take optimal actions to avoid cascading events and the resulting partial or total blackouts.

The attacks on different lines of Colombia's national electric system have affected the availability of the network, reducing transport capacity and causing the operational costs of the system to increase considerably, due to the need to use generation resources bid at higher prices. In addition, the attacks caused the isolation of some operational areas, forcing them to supply their demand using their own generation resources. One effect of the attacks on the electric system has been an increase in the total cost of constraints [94].

table 1. Costs of repair or replacement of Colombian towers, 2001–2010 (data courtesy of ISA).

Year	Costs (US$ Thousands)
2001	11,741
2002	15,909
2003	5,769
2004	6,598
2005	8,141
2006	10,591
2007	5,640
2008	5,651
2009	2,783
2010	914

Damage to power infrastructure can cause power disruptions. Although power interruptions are inconvenient and lead to economic losses for all users, certain priority users are essential for the efficient and effective recovery of lifeline services and the mitigation of disaster impacts. The main priority users are listed below:

• ***Hospitals and health facilities***. Power disruptions from natural disasters disproportionally affect health facilities, often rendering them unable to provide lifesaving or other medical care. To ensure care continuity, hospitals must have an updated inventory of assets to ensure that the number of backup generators and the amount of fuel stored will be sufficient should prolonged power outages occur.

• ***Water sector***. Water service providers are dependent on electricity to provide reliable water services for pump-driven networks. Water utilities should focus their emergency preparedness efforts on pumping stations, reservoirs, and storage tanks – for example, by installing an uninterrupted power supply at pumping stations to prevent service disruption during a blackout, or installing emergency shutoff valves at primary reservoirs.

• ***Food sector.*** For the food sector, refrigeration is critical. Warehouses need to review and upgrade their backup power generators and fuel supplies, and have emergency plans for replenishing their fuel quickly after a disaster [95].

• ***Transportation.*** Power outages after a natural disaster can cause critical disruptions in transport systems, including the shutdown of airports, ports, and public transit systems. With the increasing use of 'Intelligent' Transport Systems (ITS), power supply has become even more important to maintaining the continuity of transport services. Transport agencies should have emergency plans and an emergency operation center.

• ***Telecommunications.*** After a natural disaster, system operations may not be able to maintain telephone, cellular, email, or dedicated broadband networks for communications. It is a common practice for telecommunication facilities to have reserve power (battery banks) for short-duration outages; in North America, these battery banks can store from three hours' to eight hours' worth of power. It is essential for key telecommunication facilities to also have backup power generators for prolonged power outages.

4.4 National Security Issues of Power System Vulnerability

A successful terrorist attempt to disrupt the power-delivery system could have adverse effects on national security, the economy, and the lives of every citizen. Secure and reliable operation of the system is fundamental to national and international economy, security and quality of life. Their very interconnectedness makes them more vulnerable to global disruption, initiated locally by material failure, natural calamities, intentional attack, or human error [96].

Electric power utilities typically own and operate at least parts of their own telecommunications systems which often consist of backbone fiber optic or microwave connecting major substations, with spurs to smaller sites. Increased use of electronic automation raises significant issues regarding the adequacy of operational security, if security provisions are not built in.

Security of cyber and communication networks is fundamental to the reliable operation of the grid. As power systems rely more heavily on computerized communications and control, system security has become increasingly dependent on protecting the integrity of the associated information systems. Part of the problem is that existing control systems, which were originally designed for use with proprietary, standalone communication networks, were later connected to the Internet (because of its productivity advantages and lower costs), but without adding the technology needed to make them secure.

Like any complex dynamic infrastructure system, the electricity grid has many layers and is vulnerable to many different types of disturbances. While strong centralized control is essential to reliable operations, this requires multiple, high-data-rate, two-way communication links, a powerful central computing facility, and an elaborate operation-control center, all of which are especially vulnerable when they are needed most—during serious system stresses or power disruptions. For deeper protection, intelligent distributed secure control is also required, which would enable parts of the network to remain operational and even automatically reconfigure in the event of local failures or threats of failure [96].

Modern power systems rely heavily on automation, centralized control of equipment, and high-speed communications. The most critical systems are the supervisory control and data acquisition (SCADA) systems that gather real-time measurements from substations and send out control signals to equipment, such as circuit breakers. The many other control systems, such as substation automation or protection systems, can each only control local equipment. All SCADA systems are potentially vulnerable to cyber-attacks, whether through Internet connections or by direct penetration at remote sites. Any telecommunication link that is even partially outside the control of the system operators is a potentially insecure pathway into operations and a threat to the grid. Wireless communications within substations is a particular concern.

If they could gain access, hackers could manipulate SCADA systems to disrupt the flow of electricity, transmit erroneous signals to operators, block the flow of vital information, or disable protective systems. Cyber-attacks are unlikely to cause extended outages, but if well-coordinated they could magnify the damage of a physical attack [97]. For example, a cascading outage would be aggravated if operators did not get the information to learn that it had started, or if protective devices were disabled. Cyber security is best when interconnections with the outside world are eliminated. When interconnections are unavoidable, best practices for security must apply.

4.5 Improving Resilience of Power Sector against Natural and Man-made Disasters

Because of its networked nature, the vulnerability of the power sector cannot be calculated by simply summing up the vulnerability of its individual components [98]. In interconnected power grids, power utilities have to maintain a dynamic balance between load and production. When disruptions occur, the balance needs to be quickly re-established to prevent generators and load breakers from tripping. Otherwise, the result can be cascading outages that can lead to total blackouts, as it was the case in the 2009 blackout in Brazil, which followed the shutdown of the Itaipu hydroelectric facility [99]. Researchers also suspect that transmission and distribution systems experience what is called self-organized criticality: they evolve by their own means to a critical state in which even a minor event can lead to major failures [98]. As such, it does not necessarily make sense to consider the resilience of individual parts of the system. A network-based approach is necessary.

Hardening of infrastructure is one of the ways to improve the resilience of distribution systems. Measures to harden infrastructure depend on the type of hazard that most threatens a country's grid. For instance, Tonga, which is highly exposed to cyclones, began to upgrade its grid by replacing its low-voltage overhead network with aerial-bundled conductors (ABCs), installing underground service cables to customer premises, and installing new smart meters. The project was undertaken for its technical benefits (to reduce losses and outages) as well as to improve resilience to hazards [100]. An estimated 54 percent of the network had been upgraded [101] when Tropical Cyclone Gita made landfall in Tongatapu, Tonga. The cyclone damaged 45.9 percent of the portions of the power grid that had not been upgraded, compared to only 4.7 percent of the upgraded segments of the grid [102].

To build the resilience of the power system against heavy wind, structural interventions are a necessary step toward it. Structural interventions include using concrete or steel poles instead of wooden poles; using more stay wires with modified pole or tower foundations; and modifying tower designs. For transmission lines, the aluminium structures can also be upgraded to galvanized steel lattice or concrete structures [103]. Aerial bundled cables/conductors and underground cables can also help reduce outages during storms. ABCs offer better resistance to winds and to growing trees and shrubs compared to exposed conductors, but are multiple times (2–15 times) more expensive than overhead conductors. Using underground lines also improves resilience of the grid, as they are shielded from the elements of nature. However, burying overhead wires costs between $300,000 and $1.25 million per kilometer (compared to $80,000-$240,000 for suspended wires), plus expenses for coolants and pumping stations [104]. Additionally, underground cables take longer to restore in the event of a fault, and repair costs are also higher. The advantages therefore need to be balanced carefully against the disadvantages.

In the case of earthquakes, higher design standards for improved performance are quite similar across different types of power infrastructure: they often involve deeper foundations in liquefaction-prone areas, better anchorage of both electrical and mechanical components, or using seismic protection devices to reduce demand on the components or buildings.

One straightforward way to improve power system performance during floods is to elevate substations in an elevated area that will not be flooded – and, when possible, far enough from the coastline to avoid coastal flood. For existing substations that cannot be moved, elevating critical components is an option as is building dikes or flood protection walls. In the Tonga Ha'apai Islands, for example, following Tropical Cyclone Ian in 2014, the government decided to move transformers above the maximum possible sea flood level. Similarly, following Hurricane Sandy in 2012, Con Edison installed flood walls and flood doors, and raised one substation control room above storm-surge levels [105]. Installing flood monitoring devices to notify operators during a flood event can also help mitigate the inundation [103].

In addition to restoration capabilities, network interconnections also increase resilience, not by speeding repairs, but by providing alternative power supply routes. These often make it possible to reroute power from other sources quite quickly and minimize the duration of power outages while repairs are being conducted. For instance, after the Kocaeli, Turkey earthquake of August 17, 1999, power received from Bulgaria, Georgia and Iran was used to restart power plants outside the affected area [106]. In the aftermath of the 1989 Quebec blackout, caused by GICs from a geomagnetic storm, power rerouted from New Brunswick, Ontario, New York and New England was used to temporarily restore power supply to customers while repairs were underway [107]. By the same token, independent power producers also increase the resilience of electric utilities by providing alternatives for temporary restoration of power supply to either domestic users or critical customers, such as hospitals and industry). For example, 5 days after the Chi-Chi, Taiwan earthquake of September 21,1999, power from an independent producer was used to restore electricity supply to the

high-tech facilities at the Hsinchu Science Park, the disruption of which was already affecting the global computer industry [108]. Nonetheless, interconnections may also contribute to damage from GICs.

Last, network configuration may also increase the resilience of electric utilities. Grid configurations allow the network to be modified in case of failure of one or more nodes and arcs, by opening and closing switches. Switches may be controlled automatically, manually, or remotely from a control room using SCADA systems. Sub-transmission and distribution circuits are usually arranged in non-radial grid configurations. Therefore, even catastrophic damage to individual facilities or components may result in shorter outages because utility operators are able to divert power through other parts of the network. For example, when the small distribution substation at Sumner Redcliffs was destroyed by a rockfall triggered by the February 22, 2011, earthquake in Christchurch, New Zealand, the disruption was minimal, because the distribution system operator was able to bypass the substation using the existing network [109]. On the other hand, radial networks have less redundancy. For instance, four transmission lines were used by Taipower (Taiwan Power Company) to carry power from the south and central parts of the island to the north, where demand exceeds generation supply. The loss of a single transmission tower, which carried two of these circuits during the Chi-Chi, Taiwan earthquake of September 21, 1999, severely compromised Taipower's capability to carry power to the north of the island, and contributed to a long-term blackout [110].

CHAPTER 5: RECOMMENDATION

5.1 Measures to minimize impacts of floods on the power system-

For existing substations, it is possible to install a permanent barrier, typically a continuous wall 3 to 4 feet high made of concrete blocks, at the side or sides of the substation most vulnerable to flooding. Relocatable (nonpermanent) barriers can also be used.

For new substations whose location has been finalized, one solution is raising the critical equipment (or for smaller substations, raising the whole substation) by several feet.

A relatively low-cost solution to detect substation flood inundation is a flood monitoring system. This early warning system can allow operators to de-energize equipment or substations prior to loss of control and eventual damage. Float switches are strategically installed at critical locations throughout a substation (e.g. HV equipment areas, MV switchgear lineups, control houses, etc.). The output contacts from the float switches are then hardwired into the substation's SCADA system and monitored via status points to alert operations of a flood event.[49]

The costs for elevating substations to 25ft or more water surges are prohibitive, and utilities in such cases must invest in spare equipment to address such flooding risks.

Good practices to harden substation assets and reduce the impact of the floods on substations[46][48]-

- 24-hour control room surveillance and continuously pumping water out of substations that are threatened with flooding.
- Raising control equipment above the expected water level.
- Removing critical components from flooded substation.
- Consolidating load on the minimum number of energized transformers.
- De-energizing the flooded areas to safeguard the emergency and rescue services staff from electrocution.
- Using mobile substations in areas where major substations are flooded.
- Building new temporary lines to reroute power around flooded substations.
- Cooperating closely with officials to shut off electricity to those slated for evacuation.

- Sealing and waterproofing (as much as possible) items such as tap changes and motors for motor-operated switches

5.2 Recommendations for minimizing earthquake damages on power system

Transformers have to be welded to their foundations in order to prevent slippage. Rigid buses have to be replaced by flexible buses in earthquake-prone areas. Seismic fortification intensity has to be increased in substations and towers in earthquake prone areas. [54]

5.3 Measures to minimize impacts of cyclones on the power system

- The impacts may be much more severe and diverse as we still do not have any quantitative assessment of climate sensitivity of power distribution and consumption in Bangladesh. More research is needed to identify the climate sensitive sectors of the power system in Bangladesh. Research should also be undertaken to identify the adaptive measure to reduce the negative impacts. Climate change issues should be taken into consideration in planning new power infrastructure development as well as in restructuring of old infrastructure.
- Geographic Information System (GIS) maintains the spatial location of sampling points, and provides tools to relate the sampling data contained through a relational database. Therefore, GIS can be used to develop a spatial decision support system to deliver climate change impact and vulnerability information in understandable format such as maps, reports etc to help the development/planning authorities in policy formulation in terms of climate change vulnerability risk reduction in Bangladesh.
- Power system structures in the coastal region should be designed and developed by considering impacts of increasing trends of storms, floods and water levels. Strengthening of power supply structure is necessary considering more severe and frequent storms and floods in the future (CCSP 2007). Cyclones have often uprooted electricity poles and damaged power lines in the coastal region of Bangladesh which resulted in power outages in the region for long periods of time.
- Instead of centralized power systems, decentralized power systems should be considered especially for the coastal region. Currently, Bangladesh like most of the other countries generates most of the electricity in large centralized facilities and transmit electricity long distances through the national grid. Disruptions in the national grid due to natural disasters often cause widespread power outages. Decentralized power systems generate electricity from many small energy sources and supply power to localized microgrids. Distributed power systems are very easy to maintain and much easier to modify, redesign, or replace and therefore, may be an adaptation option in the context of increasing extreme events.

Generation and distribution of power at local level in coastal zones can be helpful to resume supply soon after the disaster.

- Burge mounted plants can be planned for the coastal region which can be moved to fresh water zones when salinity increases in river water. It can also be taken to a safe location during severe storms or floods.
- Underground distribution lines can be implemented to protect power distribution systems from cyclones and storms and decreased susceptibility to outages. Though the costs associated with it's installation as well as future expansion and repairs are very high, it has been reported that underground construction might be the least-cost approach in areas where overhead lines are susceptible to storms, because of the life-cycle cost of poles and their replacement might exceed the cost of underground construction (ESMAP 2000).
- Standing Orders on Disaster (SOD) 2019 is a concise but definitive document that pinpoints the duties and responsibilities of all government organs along with NGOs, Red Crescent, Bangladesh Scout, Bangladesh National Cadet Core (BNCC) etc voluntary organisations. SOD 2019 precisely describes the roles of 54 ministries or divisions and their attached departments and subordinate offices. There is also a general guideline for ministries, divisions, departments, and subordinate offices which are not mentioned specifically. As part of Risk Reduction Activities of Power Division, risk assessment of power stations, substations, switching stations have to be done. BPDB/BREB shall determine the amount of stored spare parts and other equipment in all central stores. Response Preparedness Stage calls for installation of alternative power sources (generators, IPS, solar system etc) for emergency service providers, e.g. hospitals, radio/television transmitters/centres, mobile towers etc. In Cautionary/Warning Stage 132 kV tower, 33 kV tower/pole, 11 kV pole, LT pole, line conductors of different sizes, transformers of various capacities, generator parts, emergency electrical equipment have to be stored in safe places. A liaison officer at disastrous area will communicate with headquarters in Dhaka, local disaster management committee and other electrical stations. During disaster on the occasion of cable or conductor fault or failure, the nearby power house or substation feeding power to the damaged portion has to be shut down instantaneously to prevent further accidents. If possible, damaged lines will be repaired with necessary instruments and transformers as fast as possible. In the rebuilding and rehabilitation process, electrical distribution systems of emergency service providers, e.g. hospitals, radio/television centres, civil and military establishments, mobile towers shall be renovated as early as possible. [8]

5.4 Future development needed for minimizing heat wave damages on power system:

Herein we have briefly reviewed how heat waves, drought and generally extreme temperatures represent a risk for the energy sector. We also discussed some clues on how climatic variability relates to seasonal predictability. From the preceding it is possible to extract some conclusions that support a number of recommendations:

- The efficiency and reliability of thermal power plants may be improved through heat related efficiency standards, cooling technology standards, and siting requirements. New and retrofitting technologies may include changing the types of turbines and using heat-resistant technology. For example in PV systems heat-resistant cells and modules improve the airflow in systems and keep them cooler **[68].** However, retrofitting investments for cooling should be justifiable due to electricity efficiency gains; alternatively, decommissioning of old plants and their replacement by new, more heat proof plants should be considered [69]**.**
- Diversification of supply sources can be an effective idea to decrease exposition to power outages. This includes the possibility of using off-grid small generation facilities for backup (e.g., solar photovoltaic).
- Renewables are the only sustainable solution for both diversification and decentralization but there are some concerns regarding their integration to existing systems. A recent report by the International Energy Agency (IEA) indicates that there are two primary obstacles of integrating wind and solar energy at large scale, into the grid **[70].** First, these sources are variable, depending on weather conditions, such as wind patterns and daylight and constant supply is uncertain **[71]** Currently, to balance this variability and back up electricity in times of need in most cases the solution is supply from conventional generation sources **[72]**. Second, the location of a source might be distant from the demand and the transmission and distribution costs are high **[73]** Existing electricity transmission and distribution systems require technology adjustments for accepting bigger loads from renewable sources.

- The existence of potentially huge benefits from improvements in seasonal forecasts and their application in the energy sector. Short-term demand forecasting is already a common tool to control electricity supply but long-term demand forecasting is important for utilities and their future investment plans. There are two important elements to long-term demand forecasting: heat wave predictions and electricity demand predictions. Utilities have to collaborate with climate scientists and develop long-term temperature forecasting tools **[74]**

Conclusion

The Power Sector is one of the most important infrastructure of a country, as growth of this sector is directly correlated with economic growth. Any disruption in the Power Sector due to crisis or disaster creates hardship to the human beings, as every aspect of human life is directly or indirectly associated with electricity. Bangladesh has experienced many natural disasters such as drought, flood, earthquakes and cyclones during the past. It has also experienced many man made crises such as terrorist attacks, bomb explosions, strikes, fires etc. Due to its sub-tropical hot climate, climate change will cause a number of negative impacts on power generation, transmission and distribution. Increase consumption of power especially during the pre-monsoon hot summer season, reduction of efficiency of power plants, more losses in transmission and distribution, more damage of power infrastructure by natural disasters. The impacts may be much more severe and diverse as we still do not have any quantitative assessment of climate sensitivity of power generation, distribution and consumption. More research is needed to identify the climate sensitive sectors of the power system in Bangladesh. Research should also be undertaken to identify the adaptive measure to reduce the negative impacts due to natural and man made disasters. The challenges that remain to achieving grid resilience are so great that they cannot be achieved by research or operations related activities alone. While new technologies and strategies can improve the resilience of the power system, many existing technologies that show promise have yet to be fully adopted or implemented. In addition, more coordination between research and implementation activities is needed. Immediate action is required both to implement available technological and operational changes and to continue to support the development of new technologies and strategies. Though there exist a number of big problems in the power sector of Bangladesh which need immediate attention, the effects of disasters should also be taken into consideration, especially in planning new power infrastructure development as well as in restructuring of old infrastructure. On time attention can substantially reduce negative impacts of natural and man made disasters on the power sector of Bangladesh.

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Appendices

Questionnaire regarding COVID-19 pandemic effects on power sector-

1. What are the monthly billed and collection amounts from March'20 to June'20?
2. What was the collection to billing ratio of the 2018-19 fiscal year?
3. How much did it cost for buying safety equipment and other things for COVID-19?
4. Approximately how many employees were in isolation for COVID-19? How many employees were COVID-19 positive? How many employees have died from COVID-19? What was the cost incurred by the organization to provide support for affected employees?
5. How many complaints were received from consumers regarding overbilling?
6. Did the organization face revenue loss for COVID-19? If yes, how much approximately?
7. What were the monthly SAIDI and SAIFI of April'19 and April'20?

Questionnaire regarding cyclone Amphan effects on power distribution in coastal area-

1. How many poles and transformers were affected?
2. How many kilometers of distribution lines were damaged?
3. Were any substations damaged? If so, how?
4. What were the monthly SAIDI and SAIFI from April'20 to June'20?
5. How did the organization improve the resilience of the system after cyclone Amphan?
6. What types of problems did the organization face while repairing their electric system during and after the cyclone?