FINAL REPORT

Study on Grid Stability in Bangladesh

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EXECUTIVE SUMMARY

1. Government of Bangladesh (GOB) has set targets of achieving the status of an upper middle-income country by 2030 and a high-income country by 2041. With the current installation of ~22GW, the targeted power generation would exceed 60 GW beyond 2041. Moreover, a large proportion of the power is anticipated to come from intermittent renewable sources. Electricity grid stability would therefore be of utmost importance to supplant the backbone of aggressive development.

2. Despite the exciting growth of generation capability, the Bangladesh Power System has its perks – there were blackouts and nationwide grid failures since 2000. These events indicate that the existing power grid is not stable enough, nor resilient enough, and may not even be smart enough.

3. Any power system is a non-linear system that operates in a constantly changing environment. The load, power generation, and transmission equipment availability are both variable and unpredictable. The grid-tied intermittent renewables will add to the variability and instability of the system even more. Variability is expected, but uncertainties are hard to track. Modern power systems are high-order multivariable processes whose dynamic response, hence, is influenced by many devices with different characteristics and response rates.

4. Electricity grid has a distinct topology. The interconnectedness of the grid enables long-distance transmission more efficient. However, it also makes it vulnerable as disturbances can also propagate long distances.

5. Power Grid Company Bangladesh (PGCB) owns the electricity transmission grid in Bangladesh. The National Load Dispatch Center (NLDC), under the PGCB, maintains the check and balances of nation-wide generation scheduling and load-shedding, frequency control under normal and emergency conditions, voltage profile assessment, reactive power monitoring etc. This whole business is managed by the Power Division, under the Ministry of Power, Energy and Mineral Resources, GOB.

6. The important technology gaps identified by this report are –

    a. Automation through a comprehensive SCADA is absolutely necessary.

    b. Remote terminal units must cover all power stations and grid sub-stations.

    c. For a complete dynamic study of the power system, the database for generating units and software tools must be comprehensive.

    d. The power system does not have automatic generation control.

    e. Governor “Dead bands” of generating units are not identified.

    f. Generating stations do not have sufficient reactive power reserve to respond to a system-wide voltage deviation. The amount of reactive power compensation also is not specified. Hence, developing a reactive power management plan is imperative.

7. Important policy gaps are –

    a. System operating states, such as normal, emergency, and restoration are identified but the boundary parameters are not clearly identified. Alert and extreme emergency states are absent.

    b. The grid code requires the presence of active spinning reserves but there is an insufficient active spinning reserve in the grid.

    c. There are provisions for under-frequency relays but there is no requirement for assessment of the event causing the system frequency to fall and how fast the frequency falls.

    d. Independent power producers have no obligation for ancillary services, e.g. frequency and voltage support.

8. Important operational gaps are as follows –

    a. Load dispatch methods and unit commitment must be automated rather than empirical, intuitive, and adhoc.

    b. The NLDC does not have real-time network stability applications necessary for blackout prevention.

    c. Traditional under-frequency load-shedding is done in an emergency state. The rate of change of frequency relays should be used. Also, there is no provision for a grid disintegration scheme in case of a country-wide blackout.

    d. Updated software platforms must be used for future integration of variable RE.

9. Stakeholders play an important role. The electric grid stability affects not only the operator but also the clients it serves, namely the individual and bulk customers, the industry, the investors, the business community, and the public sector as well. A mapping has been included to identify the role-plays of each stakeholder according to their depth of involvement and stakes.

Abbreviations

AGC	Automatic Generation Control
APSCL	Ashuganj Power Station Company Ltd.
AVR	Automatic Voltage Regulator
BEGC	Bangladesh Electricity Grid Code
BERC	Bangladesh Energy Regulatory Commission
BIPPA	Bangladesh Independent Power Producers Association
BPDB	Bangladesh Power Development Board
BPS	Bangladesh Power System
BPSN	Bangladesh Power System Network
BREB	Bangladesh Rural Electrification Board
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
ckt-km	Circuit kilometres
CPP	Captive Power Plant
DESCO	Dhaka Electric Supply Company Limited
DFDR	Digital Fault Data Recorder
DPDC	Dhaka Power Distribution Company
EDCF	Economic Development Cooperation Fund
EGCB	Electricity Generation Company of Bangladesh
EIB	European Investment Bank
EMD	Energy Management Division
EMT	Electromagnetic Transients
EUD	European Union Delegation
FD	Frequency Droop
FGMO	Free Governor Mode Operation
FOR	Forced Outage Rate
FY	Fiscal Year
GDP	Gross Domestic Product
GOB	Government of Bangladesh
GWh	Giga Watt Hour
HVDC	High Voltage Direct Current
IMD	Information Management Division
IPP	Independent Power Producer
LOEE	Loss of Energy Expectation
LOLF	Loss of Load Frequency
LOLP	Loss of Load Probability
MPEMR	Ministry of Power Energy and Mineral Resources
MW	Mega Watt
NESCO	Northern Electric Supply Company Limited
NLDC	National Load Dispatch Centre
NWPGCL	North-West Power Generation Company Ltd.
OPGW	Optical Ground Wire

PGCB	Power Grid Company of Bangladesh
PO	Presidential Order
PPA	Power Purchase Agreement
PSMP	Power Sector Master Plan
PSPGP	Private Sector Power Generation Policy
RAPSS	Remote Area Power Supply System
ROCOF	Rate of Change of Frequency
RPR	Reactive Power Reserve
RTU	Remote Terminal Unit
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SAS	Substation Automation System
SCADA	Supervisory Control and Data Acquisition
SOP	Standard Operating Procedure
SPP	Small Power Plant
SREDA	Sustainable and Renewable Energy Development Authority
SVC	Static VAR Compensator
WZPDCL	Western Zone Power Distribution Company Limited

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CHAPTER 1: INTRODUCTION

1.1. Rationale of the Study

Bangladesh is situated between India and Myanmar in South Asia and is a rapid riser, in terms of economic and development indices, among her neighbors. As of 2022, Bangladesh has a per capita GDP of about USD 2554.00, a total land area of 148460 square kilometers, and a population of 165.15 million (2022)[1]. Population density is quite large in Bangladesh, i.e., 1140 per sq km with an adult literacy rate of 75.6%.

Over the last decade, Bangladesh has gradually entered the club of developing countries. This is reflected in the current per capita GDP income, mentioned above, and through the fact that electricity demand is rising at a rate of 8-10% each year.

The Vision 2041 policy declared by the Government of Bangladesh Vision 2041 has set a target to achieve Upper Middle-Income Country (UMIC) status for Bangladesh by 2030, and High-Income Country (HIC) status around 2041. The Perspective Plan (2022-2041) being developed converts Vision 2041 into a development strategy. The first Perspective Plan covered the years 2010 to 2021. The Perspective Plan elaborates the required policies and programs and provide the road map for accelerated growth and lay down broad approaches for developing the country. These are the principal policy drivers for the power sector in Bangladesh.

Starting from 1971, right after her independence, Bangladesh started her power journey with a meager 547 MW (683 GWh)[2]. Now it can boast about 22 GW of installed capacity and net generation of more than 71,419 GWh (see Fig.1.1). This tremendous growth is corroborated by the fact that within a decade – between 2009 and 2018 – forced load-shedding reduced from 1107 GWhr to 32 GWh respectively. Another fact worth mentioning is that the private sector generation caught up with the public sector generation and even superseded it within that decade[2]. Within the same decade, the transmission and distribution system loss improved from 17% to 11%, and the distribution system loss is as low as 9.35% (as of Aug 2021)[3]. The Bangladesh Power Sector Master Plan 2016 (PSMP) has been developed under Vision 2041. PSMP covers energy balance, power balance, and tariff strategies and provides a roadmap for future power sector development until 2041. A revision of PSMP 2016 under the title 'Revisiting PSMP 2016' was adopted in November 2018.

The total installed generation capacity connected with the grid as on April 2022 stands at 22,348 MW which includes an import capacity of 1,160 MW. The total number of consumers is 37.3 million, and per capita electrical energy generation is 560 kWh (including captive and renewable energy), and the current electricity access rate is 100%.[4]

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[1] Bangladesh Census 2022

[2] Mujib Climate Prosperity Plan – Decade 2030: Power Sector Analysis, Aug 2021. p.20.

[3] http://www.powerdivision.gov.bd/site/page/6e9a5fcf-fb5c-4979-93a4-f1b4d2903949/%E0%A6%B8%E0%A6%BF%E0%A6%B8%E0%A7%8D%E0%A6%9F%E0%A7%87%E0%A6%AE-%E0%A6%B2%E0%A6%B8, accessed on 23 Aug 2022.

[4] Bangladesh Power Development Board (BPDB), "Annual report 2019-2020" and "Annual report 2020-2021."

The highest electricity generation has been recorded on 22nd July 2022 to be 14,792 MW[5]. During 2020-21, 2180 MW new generation capacity has been added, which increased the total generation capacity to 22,031 MW, and the annual increment of generation capacity was reported to be 8.09%. As on April 2022, the total installed capacity stands at 22,348 MW [3]. Table 1.2 presents the installed generation capacity by plant and fuel types and the percentage share of each type.

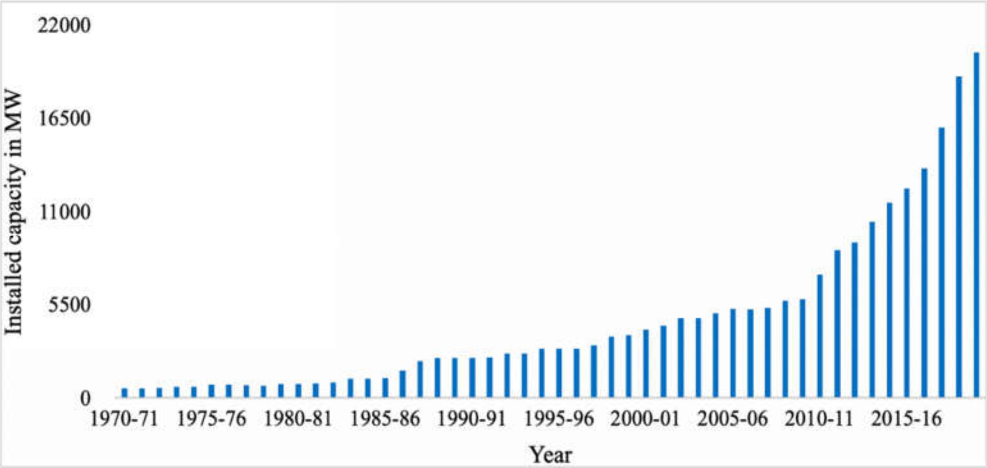

Figure 1.1: Installed capacity of Bangladesh – a historical snapshot (Source: Power Division, MPEMR)

Table 1.1: Power sector achievements by 2022[6].

	2009	**2022**
Power Plants	27	150
Generation Capacity (MW)	4942	25514
Highest generation (MW)	3268	14792
Length of Transmission lines (km)	8000	13213
Access to Electricity (per cent of population)	47	100
Per-capita generation (kWhr/capita)	220	560

The revised power system master plan (PSMP) in 2018 projects that by 2025, the demand for electricity will rise to ~28 GW, requiring a net generation capacity exceeding 40 GW. By 2030, the projected generation will be around 60 GW (58,399 MW).

It is expected that demand for electricity will continue to grow at a rate of almost 7% per annum over the next two decades, therefore requiring further *massive additions* to generation capacity, transmission, and distribution systems. This development is driven by population growth, extensive electrification, and GDP growth due to industrialization and advances in agricultural production.

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[5] BPDB website: http://www.bpdb.gov.bd/; last accessed on 28th July 2022

[6] https://www.thedailystar.net/business/economy/news/100pc-population-comes-under-electricity-coverage-2983111, accessed on 23 Aug 2022.

Table 1.2: Installed power generation capacity by plant and fuel types (as on April 2022) [4,7]

By type of plant		By type of fuel	
Hydro	230 MW (1.03%)	Hydro	230 MW (1.03%)
Steam Turbine	3,118 MW (13.95%)	Gas	11,342 MW (50.75%)
Gas Turbine	1,218 MW (5.45%)	Furnace oil	6,329 MW (28.32%)
Combined Cycle	7,963 MW (35.63%)	Diesel	1,290 MW (5.77%)
Reciprocating Engine	8,430 MW (37.72%)	Coal	1,768 MW (7.91%)
Solar PV	229 MW (1.02%)	Renewable	229 MW (1.02%)
Power Import	1,160 MW (5.19%)	Power Import	1,160 MW (5.19%)
Total	22,348 MW (100%)	Total	22,348 MW (100%)

The electric power transmission system of Bangladesh is governed by the Bangladesh Electricity Grid Code (BEGC 2019). The Grid Code is a set of principles and guidelines managed and serviced by the transmission system operator in accordance with the terms and conditions of the transmission license that have been approved by the Bangladesh Energy Regulatory Commission (BERC). The Grid Code lays down both the information requirements and the procedures governing the relationship between the transmission system and the users of the system. It covers all material-technical aspects relating to connection and operation and use of the transmission system, including the operation of electric lines and electrical plants connected to the transmission system as relevant to the operation and use of the transmission system.

The Power Grid Company of Bangladesh (PGCB) is the sole transmission licensee in Bangladesh, and responsible for discharging its obligations under the transmission license as specified in the Grid Code. The power transmission network of Bangladesh consists of a total of 13,003.8 circuit km of transmission lines at voltage levels of 132 kV, 230 kV, and 400 kV. A total of 194 grid substations have an aggregate capacity of 51,470 MVA[2].

While the Bangladesh Power System (BPS) is rapidly enhancing, it is not without any perks. The system suffered blackouts and nationwide grid failures - twice in 2007, once in each of 2014 and 2017, respectively. These events indicate that the existing power grids, not only for Bangladesh but for many other countries (notably, the North American blackout in 2003), are not stable or resilient enough to tackle unanticipated transients. Any dynamical system is susceptible to failure for inherent reasons, and this is the reason why we deem it necessary to delve into the stability of this grid system.

1.2. Objectives

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[7] Bangladesh Power Development Board (BPDB), “Annual report 2020-2021.”

The objectives of this study are:

- To provide an overview of the national electricity grid.
- To evaluate the overall stability and general reliability of the grid.
- To identify what are the main causes of grid instability/blackouts.
- To propose a range of different solutions to the identified shortcomings to the grid stability and resilience.
- To identify information/data gaps, and recommend how to fill the gaps

1.3. Theoretical Basis of the Study

A power system is a highly nonlinear system that operates in a constantly changing environment. The load, generation, and transmission equipment availability are both variable and unpredictable. Variability is the expected changes in power system variables, while uncertainty is an unexpected change in power system variables. This variability and uncertainty can occur to some degree with all power system variables.

Since a load of electrical power changes continually, the generation output must also change to match closely the changing load demand. Key operating parameters also change continually. Apart from these, transient conditions may occur due to a short circuit on a transmission line or the loss of a large generator that may bring about a sudden change in the balance between generation and demand.

A modern power system is a high-order multivariable process whose dynamic response is influenced by a wide array of devices with different characteristics and response rates.

Power system stability is defined as the ability of a power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact.

The definition of stability is formulated by considering the given operating state and the system being subjected to a physical disturbance. The continually changing conditions are referred to as small disturbances, and the power system must adjust to changing conditions and operate satisfactorily. Large disturbances of a severe nature may lead to structural changes due to the isolation of faulted elements. When subjected to a disturbance, the stability of the system depends on the initial operating condition, i.e., system state, as well as the nature of the disturbance.

Stability is a property of system motion around the initial operating condition, called equilibrium set. At an equilibrium set, the system may be stable for a given physical disturbance, and unstable for another. However, it is not practical and economical to design systems to be stable for every possible disturbance. Hence, a power system is designed and operated considering contingencies that have a reasonably high probability of occurrence.

Furthermore, since stability is a condition of equilibrium between opposing forces, depending on network topology, system operating condition, and form of disturbance, different sets of opposing forces may experience sustained imbalance leading to different forms of instability, including rotor angle stability[8], frequency stability, and voltage stability.

Rotor angle stability refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a disturbance. Instability occurs in the form of increasing angular swings of some generators leading to their loss of synchronism with other generators. Although rotor angle stability occurs within the synchronous generators, it can be affected by dynamic interactions between synchronous and converter-based generation.

Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. Instability, in this case, occurs in the form of sustained frequency swings leading to tripping of generating units and/or loads.

Voltage stability of a power system is concerned with the ability of the system to maintain acceptable voltages at all buses in the system under normal conditions and after being subjected to a disturbance. Voltage instability occurs in the form of a progressive fall or rise of voltages of some buses. A system enters a state of voltage instability when a disturbance, increase in load demand or change in system condition causes a progressive and uncontrollable decline in voltage. The main factor causing instability is the inability of the power system to meet the demand for reactive power[9]. The possible outcome of voltage instability is loss of load in an area or tripping of transmission lines and other elements by their protective systems leading to cascading outages. Loss of synchronism of some generators may result from these outages or from violations of certain operating parameters. This sequence of events accompanying voltage instability may lead to abnormally low voltages in a significant part of the power system or to a blackout.

In order to test the stability of a power system, system dynamic responses to certain possible events or contingencies are analyzed. Loss of the largest generation unit or loss of load is generally used to assess the frequency stability. Short circuits at different locations are generally used to assess the voltage and rotor angle stability.

A steady-state analysis identifies if power flow in a grid exceeds static thermal and voltage limits of network elements, and the reinforcement requirements can be determined. Transient analysis of a power system examines the effects of large disturbances. The analysis is based on a dynamic simulation of the system which requires a time domain model of equipment. The time domain models can consider electromagnetic transients (EMT) for short-term investigations or electromechanical transients for mid-term and long-term investigations.

EMT simulations are generally used for detailed local investigations such as harmonics, detailed representation of inverters and high voltage direct current (HVDC)[10] systems, over voltages from switching, transformer inrush currents, etc. electromechanical transient simulations are predominantly used for transmission system studies dealing with critical fault

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[8] Rotor angle stability is the ability of interconnected synchronous generators to remain in synchronism during a disturbance.

[9] Total power in an alternating system consists of active power and reactive power. Reactive power is the imaginary part of the complex power that corresponds to the storage and retrieval of energy rather than actual consumption.

[10] A high-voltage, direct current (HVDC) electric power transmission system uses direct current (DC) for electric power transmission.

clearing times, load shedding investigations, spinning reserve[11] evaluation, and investigation of control devices.

Coal plants have lower ramp rates, gas/LNG-based plants are faster acting, while renewable power output can change abruptly and substantially. Generation dispatch and spinning reserve practices affect rotor angle stability and frequency stability. Reactive power reserve (RPR) management affects voltage stability.

An electric power grid network has a distinct topology. The inter-connectivity of the power grid enables long-distance transmission for more efficient system operation; however, it also allows the propagation of disturbances in the network. Topological studies can reveal the existence of intrinsic weakness in an electric power grid.

1.4. Methodology

Based on the above theoretical framework, the operating states of the Bangladesh Power System (BPS) were classified under different categories. The boundary parameters of the different operating states were identified through consultation with the system operator, the Grid Code, and relevant available data. It is believed that defining system states will enable possible scenario projections for stress tests.

The frequency response characteristics of BPS under different operating states were analyzed. Voltage data at different busses of different zones of the BPS were also studied. The correlation between frequency and voltage data with system operating conditions was investigated. Active power spinning reserve and frequency-dependent load-shedding schemes were studied. Qualitative indicators for grid stability and resilience were identified through these investigations. Published scholarly papers, official and technical reports, and previous studies were also used for this purpose.

Present practices of load forecasting, generation dispatch, frequency management, and reactive power management were thoroughly analyzed to identify any gap between the system response and system operations under normal operating conditions. Ancillary services such as frequency response, active power spinning reserve, reactive power, voltage management, inertia, black start, etc. were considered under different operating states. Topological analysis of the grid network was carried out and key network-topological weaknesses were identified.

Based on the above studies, an overview of the main causes of grid instability and blackouts, and technology gaps were identified. An outline of technical and operational solutions to grid stability and resiliency was also proposed.

1.5. Key Stakeholders

The stakeholders play an essential role in the successful completion of a project. Since they may be affected by the outcome of the project, the stakeholders may help the team implement the project in a variety of ways such as contributing their knowledge and experience,

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[11] Spinning reserve is the unloaded generating unit rotating in synchronism with a utility grid

providing necessary materials and resources, etc. The success or failure of a project depends largely on whether the stakeholders accept or reject the results of the project.

The public organizations that were identified as the key stakeholders of this study are:

- Power Division, Ministry of Power, Energy and Mineral Resources (MPEMR)
- Power Cell, Ministry of Power, Energy and Mineral Resources (MPEMR)
- Bangladesh Energy Regulatory Commission (BERC)
- Bangladesh Power Development Board (BPDB)
- Power Grid Company of Bangladesh (PGCB)
- Bangladesh Rural Electrification Board (BREB)
- Sustainable and Renewable Energy Development Authority (SREDA)
- Six state-owned power distribution utilities: DPDC, NESCO, WZPDCL, etc.

While the power sector of Bangladesh is mostly in the hands of public organizations, some private organizations are also contributing to the overall electric power generation. Also, the major consumers of electricity are relevant to this project as they are directly affected by the grid stability of Bangladesh. Therefore, the following organizations from the private sector were considered stakeholders of this project:

- Independent Power Producers (IPPs)
- Bangladesh Independent Power Producers Association (BIPPA)
- Major Industrial Consumers

1.6. Scope of the Study

The scope of the study is as follows:

- Present an overview of the national electricity grid. The overview consists of:
    - Structure of Bangladesh power system
    - List of actors involved in the Bangladesh power sector
    - List of laws, regulations, and rules pertaining to power generation, transmission, distribution, and consumption
    - Reliability indicators for power, generation, transmission, and distribution
    - Present practice of generation dispatch and operations planning
    - Operational management of the transmission system operator
- Analysis of the status of grid stability

  - List of reports and studies on BPS stability and resiliency
  - Classification of operating states of BPS
  - Topological analysis of the grid network
  - Generation capacity assessment
  - Analysis of grid failures
  - Frequency response characteristics
  - Present practice of frequency management
  - Voltage profile assessment and reactive power management
  - System restoration management
  - Assessment of ancillary service requirements
- Identification of the main causes of grid instability/blackouts
- Identification of technology gaps and needs
- Present an outline of technical and operational solutions to grid stability
- Mapping of all relevant stakeholders and their potential role.

CHAPTER 2: POWER SYSTEM OF BANGLADESH

2.1. Structure of Power Sector of Bangladesh

At present, the apex institution in the power sector of Bangladesh is the Power Division under the Ministry of Power, Energy and Mineral Resources (MPEMR), the Government of Bangladesh (GOB). It is followed by the Bangladesh Energy Regulatory Commission (BERC) which issues licenses for power generation. The Bangladesh Power Development Board (BPDB) is a public-sector organization that oversees the development of the power sector of Bangladesh. There are several government owned power generation companies, such as Ashuganj Power Station Company Ltd. (APSCL), Electricity Generation Company of Bangladesh (EGCB), North-West Power Generation Company Ltd. (NWPGCL), etc. as well as Independent Power Producers (IPPs). Power Grid Company of Bangladesh Ltd (PGCB) is the sole transmission company owned by the GOB while there are six distribution companies responsible for the distribution of electricity throughout the country. Power Cell is set up to promote private power generation in the country. Finally, Sustainable and Renewable Energy Development Agency (SREDA) is established to promote the development of renewable and sustainable energy sources in Bangladesh[12].

The structure of the power sector of Bangladesh are presented in Figure 2.1.

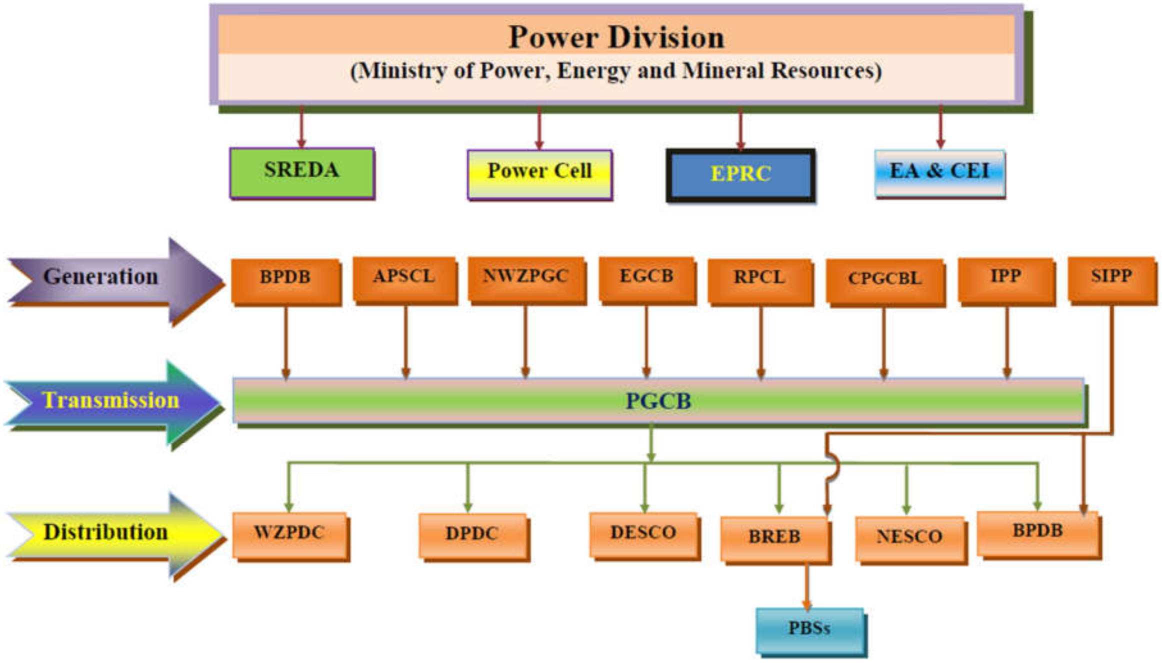

Figure 2.1: Structure of the power sector of Bangladesh (Source: Power Cell)

2.2. Actors and Their Roles

There are numerous organizations that are constantly playing their roles in managing and developing the power sector of Bangladesh. These organizations may be either government owned or private, national or international. The roles and responsibilities of some of the key organizations are discussed in brief.

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[12] Power Cell, "Glimpse of Bangladesh Power Sector (2019)".

A. Power Division

Power Division of the Government of Bangladesh (GOB) was established in 1998 under the Ministry of Power, Energy and Mineral Resources. This division is responsible for the governance and development of the power industry of Bangladesh[13]. The key responsibility is to ensure quality and uninterruptable electricity for all by 2030 through integrated development of power generation, transmission and distribution system.

B. Bangladesh Energy Regulatory Commission (BERC)

The Bangladesh Energy Regulatory Commission (BERC) was established in 2003, although it became fully functional in 2004. The commission is responsible for regulating electricity, gas and petroleum products[14].

The responsibilities of BERC are[14]:

i. Establishing a sustainable energy sector in Bangladesh
ii. Protecting consumer interest through fair practice.
iii. Promoting equal opportunities for public and private investments
iv. Developing competitive market.
v. Ensuring transparency in power sector of Bangladesh
vi. Introducing uniform operational standards and ensuring supply quality.

C. Power Cell

The GOB established Power Cell under the MPEMR in 1995 to facilitate development of private power sector. It is also responsible for the formulation of regulatory framework for the power sector of Bangladesh. The main objective is, however, to promote and implement private power generation projects and identify the areas of improvement. It also helps project sponsors to get necessary consents and permits from GOB where needed.

D. Bangladesh Power Development Board (BPDB)

The Bangladesh Power Development Board (BPDB) operates under the MPEMR. It was created as a public-sector organization to boost the country's power sector after the emergence of Bangladesh as an independent state in 1972[5]. BPDB is responsible for generation and transmission of power in the country and distribution in urban areas except the area under Greater Dhaka.

The responsibilities of BPDB are to:

i. engage in implementing the development program of the government in the power sector;
ii. adopt modern technology and ensure optimum utilization of the primary and alternative sources of fuel for sustainable development of power generation projects;
iii. purchase power as a single buyer from power producers
iv. provide reliable power supply to customers enabling socio economic development

E. Sustainable and Renewable Energy Development Agency (SREDA)

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[13] Power Division website: http://www.powerdivision.gov.bd/; accessed on 28th July 2022.
[14] BERC website: http://www.berc.org.bd/; accessed on 28th July 2022.

Sustainable and Renewable Energy Development Agency (SREDA) was established under the Companies Act 1994. It was formed to ensure development and promotion of 'sustainable energy sources' such as renewable energy and high efficiency energy sources. SREDA Board comprises of representatives of stakeholders including business community, academics and/or representative from Bangladesh Solar Energy Society, NGOs, and financial institutions and implementing agencies.

The responsibilities of SREDA are to:

i. provide coordination of sustainable energy planning;
ii. integrate the development of renewable energy and other clean energy technologies within the national energy policy;
iii. support new technologies and business models for sustainable energy technologies;
iv. create market opportunities for renewable and clean energy technologies.
v. conduct studies to identify the renewable energy resource base;
vi. provide financial support to the research and development projects of renewable energy technology;
vii. analyze the feasibility of grid connected renewable energy projects.

F. Bangladesh Rural Electrification Board (BREB)

The Bangladesh Rural Electrification Board or BREB is responsible for the electrification of the rural areas of Bangladesh. It was established in 1977 as a government organization. Palli Bidyut Samities (PBS) in a subsidiary of the board and acts as a consumer cooperative. It is the largest power distribution organization in Bangladesh and has brought all the 461 upazillas on grid under 100% electrification[15].

G. Power Grid Company of Bangladesh (PGCB):

Power Grid Company of Bangladesh (PGCB) is the only organization responsible for the transmission of electric power throughout the country. It is an autonomous Government organization which owns and operates the national electricity grid of Bangladesh. It was established in 1996 under the Companies Act, 1994. Since its establishment, it is responsible for the effective management of national electricity grid. In addition, the operation and maintenance of transmission line, grid sub-station, National Load Dispatch Center (NLDC), and communication facilities are also within the scope of PGCB. Presently, there are 400 kV, 230 kV and 132 kV transmission lines of PGCB across the country.[16]

The vision and mission of PGCB are to:

i. ensure economic uplift of the country by ensuring electricity access to all through reliable transmission.
ii. ensure efficient and effective management of the national power grid for reliable and quality transmission of electricity throughout the country.

H. Independent Power Producers (IPPs):

Independent power producers (IPPs) generate electricity and sell power mainly to BPDB. They can also sell power to a third-party customer through a power purchase agreement

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[15] BREB website: http://www.reb.gov.bd/; accessed on 28th July 2022
[16] Power Grid Company of Bangladesh (PGCB), "Annual Report 2020-21"

(PPA)[17]. IPPs may either use the national grid for distribution purpose or they can supply it directly to the customer.

As of April 2022, the installed capacity of the existing IPPs in Bangladesh is 8141 MW, with a net energy generation of 34822GWh in the FY 2020-21. Twenty power plant projects are under signing process and 4 more are under tendering process[17].

I. Distribution Companies:

Six distribution utilities handle power distribution in Bangladesh. These distribution companies are all owned by the GOB and are responsible for specific zones. The distribution companies are:

i. Bangladesh Power Development Board (BPDB),
ii. Dhaka Power Distribution Company (DPDC),
iii. Dhaka Electric Supply Company Limited (DESCO),
iv. Western Zone Power Distribution Company Limited (WZPDCL),
v. Bangladesh Rural Energy Board (BREB),
vi. Northern Electric Supply Company Limited (NESCO).

J. International Funding Agencies:

There are numerous international funding agencies, multilateral and bilateral development partners which are generously supporting the infrastructural development of the power sector of Bangladesh. Some of the major funding agencies (hard and soft) in the power sector are:

i. The World Bank (WB),
ii. Asian Development Bank (ADB),
iii. Japan International Cooperation Agency (JICA),
iv. Islamic Development Bank (IDB),
v. Exim Bank,
vi. European Investment Bank (EIB),
vii. Kreditanstalt fur Wiederaufbau (KfW),
viii. Economic Development Cooperation Fund (EDCF).

Other international agencies, interested in and keep a close look at the power sector, are United States Agency for International Development (USAID), European Union Delegation (EUD), and United Nations Development Programme (UNDP) among others.

2.3. Overview of the National Grid of Bangladesh

The national electricity grid of Bangladesh covers the entire country and operates at 400KV, 230KV and 132 kV. Besides, the transmission system of the country is connected to the national grid of India through 400 kV lines at Bheramara. During fiscal year 2020-21, an extra length of 552.398 circuit kilometers (ckt-km) of transmission line were added to the system through different projects. In the same period, transmission line length increased by 4.5% than that of previous year[4]. Total length of 400 KV transmission line increased to 950.14 ckt-km from the previous year of 861 ckt-km. The total length of 230 kV transmission

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[17] PPA is the contract between the public and private sector parties for purchase of power.

line is 3,658 ckt-km that remained the same as previous year. The total length of 132 kV transmission line increased to 8,227.8 ckt-km from the previous year (7764 ckt-km)[4]. Figure 2.2 shows the transmission network of Bangladesh power system. During fiscal year 2020-21, transmission grid substation capacity also increased due to completion of new sub-stations and augmentation of existing grid substation. At the end of fiscal year 2020-21, grid capacity increased by 13% at different voltage levels[4]. The transmission losses were recorded to be 3.07% in the FY 2020-21. On the other hand, total duration of power interruption in the grid network was 167 hours 04 minutes. Table 2.1 presents the type of faults and their contribution to the overall power interruptions during the FY 2020 and FY 2021.

Table 2.1: Interruption of National Grid[4]

Type of fault	**Total Duration**	
	FY 2020 (Hours/Minutes)	**FY 2021 (Hours/Minutes)**
Partial power failure due to trouble in grid equipment	33/15	146/29
Partial power failure due to fault in transmission line	14/45	13/39
Partial grid failure	00/44	06/56
Total	**48/44**	**167/04**

As the single buyer, the Bangladesh Power Development Board (BPDB) purchases electricity from generation licensees and sells to distribution licensees using the transmission network owned and operated by Power Grid Company of Bangladesh (PGCB) while six distribution utilities handle power distribution.

Table 2.2: Transmission infrastructure information of BPS

Transmission line	
400kV	950 Circuit km
230kV	3,770 Circuit km
132kV	8,282.8 Circuit km
Substation	
400kV	1 Nos. 2x500 MW HVDC back-to-back station
400/230kV	5 Nos. 5,330 MVA
400/132 kV	2 Nos. 1,300 MVA
230/132kV	32 Nos. 16,965 MVA
132/33kV	162 Nos. 30,450 MVA
Dispatch Capacity at 33 kV level	27,516 MW (including all organizations)

The PGCB has taken over about 1144 ckt-km of 230 kV lines, 5255 ckt-km of 132 kV lines, six 230/132 kV substations and sixty-three 132/33 kV substations from BPDB and previous DESA (the then Dhaka Electric Supply Authority, now DPDC and DESCO) at different stages. Transmission lines of the company stood at 950 ckt-km of 400 kV lines, 3770 ckt-km of 230 kV lines, 8,110.5 ckt-km of 132 kV lines and one 400 kV Station, including five 400/230kV substation, two 400/132kV substations, thirty-two 230/132 kV substations and one hundred and sixty-two 132/33 kV substations by the end of December 2021[5]. Table 2.2 presents the details of the transmission system data as of December 2021.

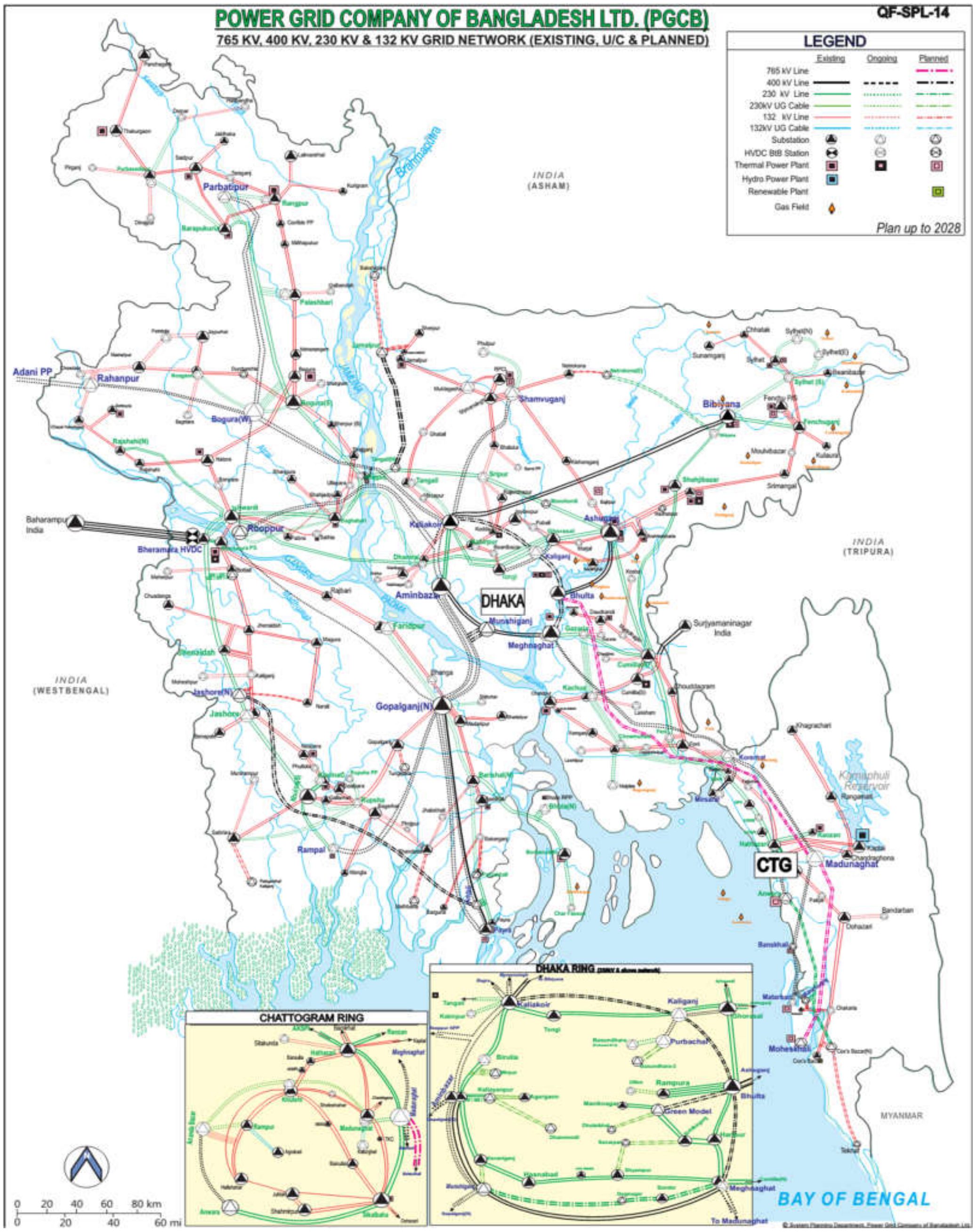

Figure 2.2: Transmission network of Bangladesh power system (Source: PGCB)

2.4. Acts and Policies

There are several acts and policies established to promote the flourishment of power sector in Bangladesh. Most of these acts and policies have been amended to ensure transparency, equal opportunity and proper management of the sector. Some of the well-known acts and policies are mentioned in this section.

2.4.1. Acts and Ordinances

Acts and ordinances are various types of laws that are formed at different levels. Acts are passed in the parliament whereas ordinances are passed by specific authorities and applicable to a certain area or sector only. Some important acts and ordinances related to the power sector of Bangladesh are listed below.

A. Electricity Act 1910

The Electricity Act, 1910 governed the law relating to supply and use of electrical energy and extends to whole of Indian subcontinent. It is a pre-partition act and was succeeded by Electricity Act 2018.

B. PO 59 for Creation of Bangladesh Power Development Board (BPDB) 1972

The Presidential Order (PO) was issued in 1972 to provide for the constitution of Bangladesh Power Development Board (BPDB) to replace the East Pakistan Water and Power Development Authority.

C. Rural Electrification Board Ordinance 1977

This ordinance was issued in 1977 to transfer the responsibility of rural electrification from PDB to BREB since it didn't violate Presidential Order 59.

D. Bangladesh Energy Regulatory Commission Act 2003

The Bangladesh Energy Regulatory Commission Act, 2003 was passed to ensure the establishment of an independent regulatory commission for the energy sector of Bangladesh.

E. Emergency Energy & Power Supply Special Act 2010

It is an Act to make special provisions for facilitating effective and urgent measures to enhance the generation, transmission, transportation and marketing of electricity and energy to ensure uninterrupted power supply for crucial sectors like agriculture, industry, etc.

F. Sustainable Renewable Energy Development Authority Act 2012

This Act establishes the Sustainable and Renewable Energy Development Authority (SREDA) in order to ensure energy security and to mitigate risks associated with natural calamities stemming from global warming.

G. Electricity Act 2018

The Electricity Act, 2018 aims to repeal and re-enact the Electricity Act, 1910 with modification for developing and reforming the sectors of power generation, transmission, supply and distribution.

2.4.2. Policies

Policy is a set of action plan formulated to address particular situations. The policies nationally adopted for the development and proper implementation of projects related to power sector are listed below.

A. National Energy Policy 1996 (Revised on 2004)

The National Energy Policy 1996 targeted to achieve the sustainable development of the energy sector. In particular it sets out its goals to provide energy for sustainable economic growth so that the economic development activities of different sectors are not constrained due to shortage of energy, ensure optimum development of all the indigenous energy sources, meet the energy needs of different zones of the country and socioeconomic groups, ensure sustainable operation of the energy utilities, ensure rational use of total energy sources, ensure environmentally sound sustainable energy development programs, with due importance to renewable energy, causing minimum damage to environment, encourage public and private sector participation in the development and management of the energy sector, integrate energy with rural development to boost rural economy and to ensure reliable supply of energy to the people at reasonable and affordable price.

B. Private Sector Power Generation Policy 1996 (Revised on 2004)

The goal of the Private Sector Power Generation Policy of Bangladesh Act of 1996 is to attract private investment in power sector.

C. Policy Guideline for Small Power Plant (SPP) in Private Sector 1998 (Revised on 2008)

This policy is prepared by the Ministry of Energy and Mineral Resources Government of the People's Republic of Bangladesh to allow private sector investors to establish Small Power Plants (SPP) on a fast track basis for generation of electricity. The target is to develop SPPs on a Build-Own-Operate basis.

D. Bangladesh Private Sector Infrastructural Guidelines 2004

These guidelines aim to establish within the Government, procedures to identify Private Infrastructure Projects, document a set of guidelines, for both the private sector Investors and Government, enabling the procurement and implementation of Private Infrastructure Projects, and establish institutional arrangements to monitor and expedite the implementation of such projects at a national level.

E. Power Pricing Framework 2004

The framework was proposed to begin codifying the process and principles of tariff adjustment and to phase out prevailing distortions in tariff structure.

F. Guidelines for Remote Area Power Supply System (RAPSS) 2007 (revised on 2009)

Recognizing the importance of adequate supply of electricity to achieve socio-economic development and for alleviating poverty, the Government of Bangladesh has created the Guidelines for Remote Area Power Supply Systems (RAPSS). The guidelines sets selection criteria of the RAPSS, the investors and issues related to operation and maintenance.

G. Policy Guidelines for Power Purchase from Captive Power Plant 2007 (Revised on 2019)

To decrease the gap between demand and supply for electricity, the GoB adopted these guidelines to harness the surplus capacity of captive power plants, and permit electric utilities to buy from such power plants.

H. Policy Guidelines for Enhancement of Private Participation in the Power Sector 2008

Government of Bangladesh (GOB) adopted the Private Sector Power Generation Policy (PSPGP) to promote private sector participation in the generation of electricity with a view to promote economic growth. GOB desires to promote further private participation in the power sector, harness competition, ensure optimal use and conservation of country's limited natural gas resources, and develop new power plants and reopen some of the old power plants through public-private collaboration.

I. Renewable Energy Policy 2008 (Revision ongoing 2022)

The objectives of renewable energy policy are to harness the potential of renewable energy resources and dissemination of renewable energy technologies in rural, semi-urban, peri-urban and urban areas, enable, encourage and facilitate both public and private sector investment in renewable energy projects, scale up contributions of renewable energy both to electricity and to heat, create enabling environment and legal support to encourage the use of renewable energy, and promote development of local technology in the field of renewable energy.

J. Operational & Management Procedures for Remote Area Power Supply Systems Fund (RAPSS Fund) 2012

This policy addresses the creation and functioning of Remote Area Power Supply Systems Fund (RAPSS Fund) fund. The GOB established this fund so that the poor people in the remote areas can enjoys electricity facilities at a reasonable and affordable price.

K. Electricity Grid Code 2019

The grid code, published by the BERC, establishes the generalized rules, guidelines, standards, and procedures for the smooth and reliable operation of the national grid of Bangladesh. The objective of this document is to ensure a safe, efficient and reliable operation of the electricity transmission system and specify the legal obligations of the stakeholders.

2.5. Reliability Indicators

In order to analyze the reliability of a power system, it is necessary to interpret the available qualitative and quantitative data. This is done with the help of numerous reliability indicators. For obvious reasons, the reliability indicators for power generation, transmission and distribution, and consumption systems are different.

The reliability and performance indicators applicable for power generation system are:

i. Operating Availability (OF),
ii. Forced outage rate (FOR), etc.

There are several basic indices which evaluate generation and transmission system reliability. These indices include:

i. Loss of Load Probability (LOLP),
ii. Loss of Load Expectation (LOLE),
iii. Loss of Energy Probability (LOEP),
iv. Loss of Energy Expectation (LOEE),
v. Expected Energy Not Served (EENS),
vi. Loss of Load Frequency (LOLF),
vii. Loss of Load Duration (LOLD), etc.

For evaluating the performance and reliability on the consumer side, the following indices are utilized:

i. System Average Interruption Frequency Index (SAIFI),
ii. System Average Interruption Duration Index (SAIDI),
iii. Customer Average Interruption Frequency Index (CAIFI),
iv. Customer Average Interruption Duration Index (CAIDI),
v. Average Service Unavailability Index (ASUI),
vi. Average Service Availability Index (ASAI),
vii. Momentary Average Interruption Frequency Index (MAIFI), etc.

In case of BPS, only the reliability indicators of the distribution system such as SAIFI, SAIDI, CAIFI, CAIDI, etc. are being used to access the system performance. However, the reliability indicators corresponding to the generation and transmission systems are not yet being utilized.

CHAPTER 3: PRESENT PRACTICE OF GENERATION SCHEDULING AND OPERATIONS PLANNING

3.1. System Operations Setup of PGCB

Power Grid Company of Bangladesh (PGCB) is the sole transmission licensee in Bangladesh, and is responsible for the planning, development, maintenance and operation of the electricity transmission grid. The various divisions of PGCB are involved in their current practices in generation and load forecasting, generation dispatch, load allocation and load control, frequency and voltage control, emergency operations and control, and various other aspects of the operation and control.

The system operations activities of PGCB include demand forecasting, generation dispatching, frequency and voltage control, emergency operations, security analysis (i.e., effects of generation maintenance schedule upon the system), outage management, operational database management, operational report preparation, operation and maintenance of SCADA system, operation and maintenance of communication system, and system protection and metering.

The operational activities of PGCB are organized under four circles. These circles are:

1. Load dispatching circle
2. SCADA circle
3. Communication circle
4. System Protection and Metering circle.

The load dispatching circle comprises of three divisions. These are:

i) Energy management division (EMD)

ii) Network operations division

iii) Information management division (IMD).

The energy management division (EMD) carries out the pre-dispatch tasks. These include load forecasting and generation scheduling, fuel resource monitoring, and communicating with the Indian side for management of power import. EMD also prepares the transmission outage schedule. Bangladesh Power Development Board (BPDB) prepares the generation maintenance and outage schedule and the EMD collects it from them.

The National Load Dispatch Centre (NLDC) of PGCB is responsible for the operation and control of the Bangladesh power system. This is a quintessential organizational component for this study and for the hourly power management of BPS. It provides a centralized coordination among generation, transmission, and distribution system. The NLDC facility includes a modern SCADA and EMS to control and manage the electrical power network.

The network operations division operates NLDC control room round the clock, i.e., 24/7. They also run the *area load Dispatch Centres (ALDCs)* in shifts.

Functions of the network operations division include,

- Generation economic dispatch
- System frequency monitoring and control
- Voltage monitoring and control
- Line load monitoring and control
- Cross border import schedule implementation
- Load management
- Ensuring system stability
- Managing emergency and planned outages
- Restoration from blackout
- Reporting.

The information management division (IMD) carries out the post-dispatch tasks. These include operational data management, preparation of daily operations report; supply of data/information for determining availability of private power producer by BPDB, preparing monthly operational report etc. The IMD also prepare various reports for operational planning, project planning and policy making.

Responsibilities of the SCADA circle includes operation and maintenance of telemetering and SCADA system, maintenance of NLDC mimic board, SCADA consoles, station servers, substation automation system (SAS) etc.

The communication circle operates and maintains the communication system. The communication system of PGCB includes a fiber optic backbone network comprising optical ground wire (OPGW) on top of transmission line tower. A power line carrier system works as a backup.

Responsibilities of the system protection and metering circle include relay testing and co-ordination, annual maintenance of relays, troubleshooting of protection and control system, pre-commissioning test and commissioning of protection scheme of the grid substations and transmission lines, setting the auto load shedding scheme using under-frequency relays[18], inter utility energy meter testing and calibration etc.

3.2. Generation Scheduling and Operations Planning

The basic steps followed by the EMD in daily operations planning of its power system includes,

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[18] Under-frequency relays are used to automatically shed a portion of load whenever the system frequency falls to an undesirable level.

1. Forecast the demand for 24 hours,
2. Schedule the available generators.

3.2.1. Demand Forecast

The energy management division (EMD) performs the demand forecast to facilitate the preparation of generation schedule and load shed planning. Day ahead hourly demand forecast for next 24 hour is made considering season and weather condition, previous day's demand condition, working day or holiday, existence of any emergency/priority situation etc. EMD uses the e-terraplatform 2.3 software which can forecast demand using different methods based on regression, load shape, etc. EMD uses load shape-based demand forecasting. The data sources are historical load data from the archive, weather data from Bangladesh Meteorological Department and the internet, and special events from Bangladesh government calendar and daily newspaper.

3.2.2. Generator Scheduling

The generation schedule is the detailed description of the hourly loading status of the generating units which is made to facilitate improved performance in load dispatching. The EMD is responsible for preparing the generation schedule for the next 24 hours.

To prepare the generation schedule the following information is required,

- Available generation units of a power station for that day,
- Probable maximum generation of the machines for that day,
- Information about the limitation of generation,
- Probable time of synchronization/shutdown of the machines (if applicable).

Information on limitation in the transmission network, probable voltage problem in a zone due to MVAR[19] demand, limitation of natural gas/liquid fuel supply etc. are also needed. These data and information are not readily available.

Before scheduling, updated information regarding generator availability is required. This data is not readily available. Sometimes the availability information is collected real-time, and not before the scheduling.

Generation economic order is considered in preparing the generation schedule. Machines on/off conditions (unit commitment) are considered as well. BPDB prepares the economic order of generating units based on fuel cost for BPDB owned generators and fuel tariff of independent power producers (IPPs). Fuel cost is the weighted average fuel cost, calculated for a period of 365 days. Fuel tariff is defined in the "Power Purchase Agreement (PPA)" of a particular IPP, and the applicable rate is updated and circulated by IPP Cell of BPDB. BPDB reviews the economic order of generating units every few months.

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[19] MVAR (megavolts-ampere reactive) is a unit of measuring reactive power

The hourly generation schedule is prepared by engineers in EMD. Generation output level in the eastern and the western part of the system are derived separately with security constraints considered manually.

3.2.3. Load Allocation and Load Control

Load allocation planning is made based on available generation and forecasted demand in the system for the day. Limitation in the transmission network, priority in load allocation (irrigation load, special occasion in a particular area etc.) are considered. The estimated load is distributed among the different distribution zones proportionate to the demand of the respective zones as per load allocation plan and/or as per system condition.

Load control (load shed) is imposed in the system either partially or all over the county as necessary when total generation in the system is not enough to meet system demand, or if there is any limitation in transmission network, or if the grid voltage falls below controllable range due to excess MVAR demand. Depending on the condition, necessary load control is imposed in distribution zones.

3.3. Operational Management of the Transmission System Operator

The network operations division is responsible for operational management of the BPS. Functions of the network operations division include,

- Generation economic dispatch
- System frequency monitoring and control
- Voltage monitoring and control
- Line load monitoring and control
- Cross border import schedule implementation
- Load management
- Ensuring system stability

3.3.1. Generation Economic Dispatch

Generators are selected based on their “merit order”, i.e., full load average production cost (in Taka/kWh), availability, capacity, and predicted generation (MW output). A number of constraints are also considered in selection:

- Operational constraints of available generating units:
    - Maximum MW and minimum MW output levels,
    - Start-up and shut-down times,

    - Voltage support requirements (must run units).

- Operational limitations of generating units due to natural gas/liquid fuel supply.
- Available import from the interconnector with India,
- Limitations of the transmission network in evacuating the generation:
    - Thermal constraints,
    - Possible voltage problems in a zone due to MVAR demand.

In case a transmission circuit is likely to be overloaded, generation units already running in the neighborhood are instructed (via offline telecommunication) to reduce their outputs.

NLDC operators also try to ensure a small percentage of operational, e.g. spinning reserve, but it is not always available due to maintenance being undertaken on some units, inadequate gas pressure for gas-fired power plants or unscheduled outages.

The eastern and western parts of the Bangladesh power system are connected by two interconnectors. However, the generation schedule in the two areas is decided separately, with security constraints between the two considered manually.

The unit commitment and dispatching decisions are implemented by voice telephony as there has been no Automatic Generation Control (AGC)[20] system in Bangladesh. Primary control, for example, Free Governor Mode Operation (FGMO)[21] is implemented on a few large generation units.

3.3.2. Basic Principle of Loading Generator

The generators of the Bangladesh power system can be categorized according to the fuel used. The basic principle of loading different type of generators follows this categorization.

Except for dry season, available hydro units are run in such a way that the head water level of the Kaptai lake reservoir remains at or below the level of rule curve as far as possible. During rainy season, all the available hydro units are run round the clock at maximum load. In dry season, the available hydro units are generally run as a peaking machine.

In normal operating conditions, variable renewable energy (VRE) generators (e.g., solar PV, wind) are exempted to provide spinning and/ or standby reserves, and expected to generate according to the available primary resources. However, subject to primary resource availability, these units are required to follow dispatch instructions that include increase or decrease MW generation.

Liquid fuel-based units are fired mainly to meet the evening peak demand.

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[20] AGC is a system that adjusts the power output of multiple generating units located at different power plants depending on the changes in the load.

[21] In FGMO mode, the governor regulates the admitting of steam to vary the load on the generator if the system frequency changes.

Normally natural gas fired turbines having the least operating expenses are loaded to their maximum to meet the peak hour demand in the system. In the off-peak hours, depending on the demand in the system, they are run at a lower load or shut down.

Steam plants and combined cycle machines are run as base load plants. These units are loaded to their maximum to meet the peak hour demand in the system. In the off-peak hours, depending on the demand in the system, these are run at a lower load.

When the system demand becomes extremely low (as in the case of long holidays during the two Eid vacations, and severe storm condition), some selected steam and/or combined cycle units are kept shut down. Prior approval is needed for the shutdown of steam and combined cycle plants due to low system demand.

3.3.3. System Operation

A list of generators and the maximum output and potential output level of the generators at each hour of the day is prepared by the EMD and is available in the control room. System operators use an Excel spreadsheet-based tool to tune output levels for those generators on-line in accordance with the estimated demand level and merit order of the generators.

System operators use various communication media (IP phone/mobile phone etc.) to inform BPDB and private generation entities about the expected generation output level for each unit. If the available generation capacity cannot meet the estimated demand, a manual load shedding scheme is developed using the excel tool.

Generation reserve can be calculated using the excel tool as well if more generation capacity is available. However, system operators do not know how much reserve should be maintained for real time operation.

The Remote Terminal Unit (RTUs)[22] send operational information from RTU monitored power plants and grid substations. The operators use telephone to gather information from plants and substations without an RTU.

3.3.4. Coordinating Power Station Operation

The dispatcher in the NLDC control room has to ensure maximum power available to meet the demand while achieving the most possible economic generation and transmission of power. To accomplish the tasks, dispatcher maintains close contact to the power stations and monitor and guide the operation of the same.

With this information available, dispatcher calculates the generation available in the forthcoming hours. If there is a possibility of shortage, dispatcher imposes load control as required. When a machine is synchronized or goes for shutdown, the information described above helps dispatcher to control the system by varying the loads on other machines.

3.3.5. Load Allocation and Control

Load is allocated in proportion to the demand of the respective zones or as guided by the system condition. Dispatcher from NLDC control room informs area control centers over telephone about the load allocated for them. Dispatchers closely monitor whether the load

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[22] RTU is a microprocessor-controlled electronic device that interfaces power plant and grid substations to SCADA.

allocation is implemented properly or not by monitoring the load flow of different transmission lines with the help of SCADA system. If a zone does not carry out the given load control plan properly, first alerts are given to them and then forced load control is imposed by SCADA trip (remote operation from NLDC) of selected 33 kV feeders in grid substations feeding those areas.

3.3.6. Frequency Control

Frequency does not change significantly as long as there is a balance between load and generation. The NLDC is responsible for maintaining the system frequency at 50 Hz +/- 0.5 % to ensure quality power to the customer.

Only a few generators in BPS are operated in frequency control mode. Most of the generators are still operated in constant power control mode, which impose significant challenge on system operators to maintain system frequency within acceptable limits.

According to the Bangladesh Electricity Grid Code (BEGC), the NLDC should include allocated spinning reserve in the day ahead according to the hourly generation schedule. However, there is no specific limit of the required margin of spinning reserve that must be maintained.

Under normal operating conditions, the NLDC attempts to maintain frequency by a very sharp demand forecasting and committing units. If frequency falls below specified limit, the NLDC operators cut-off load automatically or command control posts to shed load and command a few chosen generators to increase production if they have sufficient spinning reserve. If there is steady rise in frequency, then the control operators command the chosen generators to decrease their production. This is a very slow and inefficient method to control frequency of a power system.

3.3.7. Voltage Control

Controlling voltage within desired level is required to ensure quality power. The NLDC control room operator directs the area control centers to take necessary actions for voltage control at the substation level. If required, the control room operator directs appropriate generating units to take action.

3.4. Emergency Operations

Emergency operations and control functions are carried out when system stability is at stake and likely to lead to a blackout. However, besides under-frequency-relays no other aid is available in BPS which is unfortunate.

In case of partial grid-failure, following things may happen

- One or more zones get full power interruption
- Almost all generating units in concerned zone gets tripped
- One or more transmission lines trips isolating affected zones from the national grid

- All power stations in the concerned zone lack auxiliary power supply.

Partial grid-failure may be apprehended, depending on generation, load condition and load flow through associated lines in the concerned area, when major generators in those areas trip or due to tripping of zone-interconnecting-lines. Dispatcher is immediately informed by the concerned grid substation and/or power stations where tripping has occurred or he contacts himself with them noticing no load-flow in lines in the SCADA mimic board or console. Apprehending a partial grid-failure, dispatcher immediately collects information confirming partial grid-failure and inform all concerned high officials (according to a list of priorities) about the partial grid fail. A suitable restoration method is devised with consultation of concerned officials to recover the failed zones. Following actions are then taken,

- Start and synchronize the generator tripped,
- Perform switching operations in association with the grid sub-station to resume the service of transmission lines and/or substation equipment tripped,
- Unification of grid zones running under island-mode with whole grid.

If restoration of power is not possible in a zone following the above-mentioned actions, power in that zone is restored from nearby area where power is available.

Before charging any equipment and/or transmission line, necessary checks are done to find out suitability of the equipment for charging and safety.

CHAPTER 4: STATUS OF GRID STABILITY

4.1. Classification of Operating States of BPS

The operating states of a power system can be generally classified into five states. Figure 4.1 shows the states and their correlation.

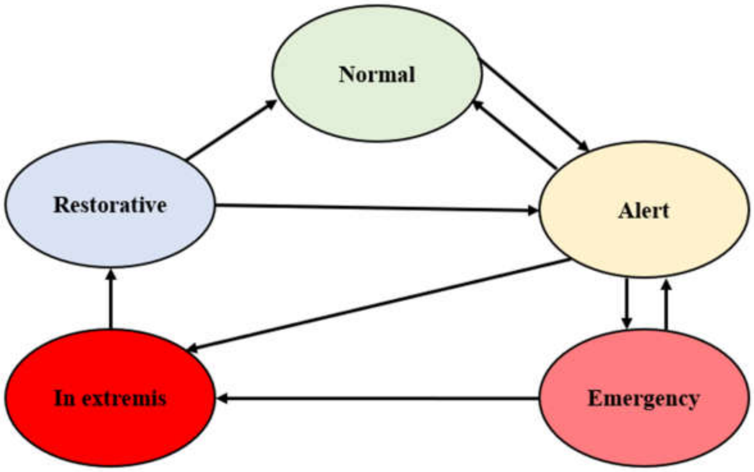

Figure 4.1: Operating states of a power system

A brief description of the different states follows.

1) **Normal state**, in which all system variables are within the normal range and no network component is overloaded. In this state system operates in a secure manner and is able to withstand a contingency without violating any constraints.

2) **Alert state**, in which the security level of the system falls below a certain level or possibility of a disturbance increases because of adverse weather conditions such as the approach of severe storms. Though all system variables are still within the acceptable range and no constraints are violated, the security margin of the system at the operating point reduces. A contingency may cause overloads of network components, voltage violations, or even system instability.

3) **Emergency state**, in which voltages at many buses are low and/or and equipment are overloaded beyond emergency ratings. System still intact and may be restored to alert state by the initiating of emergency control actions: fault clearing, excitation control, fast-valving, generation tripping, generation run-back, HVDC modulation, and load curtailment

4) **In extremis state**, in which cascading outages and possibly isolation or shutdown of a major portion of the system has taken place due to ineffective control actions during the emergency state period.

5) **Restorative state**, in which the designed control actions are taken step by step to reconnect the network components and restore power supply to those customers who were affected in the extremis state.

The operating states of BPS are not well defined. The normal operating conditions are well defined by the Bangladesh Electricity Grid Code (BEGC). However, the other operating states are not clearly defined. Since the operational objectives for each state are not identical, standard operating procedures (SOPs) should be clearly articulated. This is not, unfortunately, the case for BPS.

4.2. Topological Analysis of the BPS Network

The transmission system of BPS has formed an integral grid of three voltage levels of 132 kV, 230 kV and 400 kV. It supplies electricity to the whole country, geographically divided into three regions by the mighty rivers Padma and Jamuna, identified by red lines in Figure 4.2. The Eastern region can be further divided into four major 'load regions,' identified by green lines. That is, the transmission system has number of 'islands' (marked a, b, c) and 'load regions' (marked 1, 2, 3, 4) connected through tie lines. The system operator typically maintains load and generation balance in each 'island' and 'load region'. Central to this network in terms of connectivity is the 'load region 1.' There is a certain radiality in the grid that renders the BPS network weakly mashed and inherently less resilient.

4.3. Generation Capacity of BPS

The total installed generation capacity connected with the grid as on April 2022 stands at 22,348 MW which includes an import capacity of 1,160 MW[3]. Table 1.2 in Chapter 1 presents the installed generation capacity with fuel types and percentage share of each fuel type. From that table, it can be seen that more than 50 percent of the generation capacity is dependent on natural gas followed by 33 percent dependence on liquid fuels. Share of the grid-connected renewable energy sources is barely above 2 percent, of which only 1.03 percent comes from solar.

It is to be noted that natural gas provided for nearly 88 percent of the generation capacity at the time when the first Perspective Plan 2010-2021 was prepared. The Plan decided for a more balanced fuel-mix to ensure energy security by 2021. The dependency on natural gas has now been reduced through increased generation using liquid fuel and coal. This will reduce even further in the coming years with increased coal-based power generation and introduction of nuclear power.

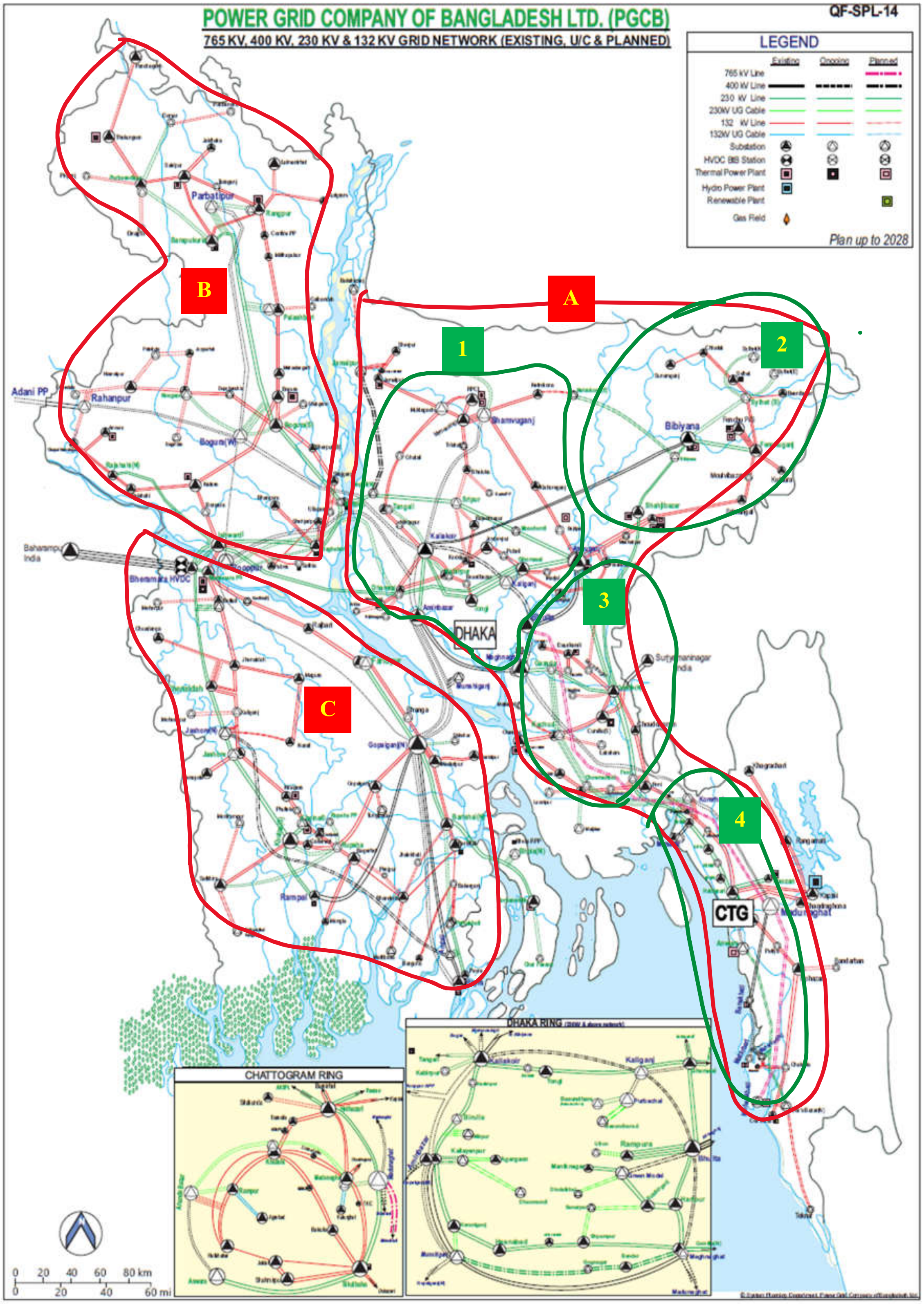

Figure 4.2: 'Islands' and 'load regions' of BPS

4.4. Generation System Inertia of BPS

Frequency at its nominal value reflects balance in supply and demand. Sudden loss of supply or demand will result in frequency deviation from the nominal frequency. The sudden disconnection of an active power source will initially produce rotor swings in the remaining generating units. The amplitude of the rotor oscillations of any given generator will depend on the amount of lost generation it picks up immediately after the disturbance occurs. The share of any given generator in meeting the lost load will depend on its electrical distance from the disturbance. The situation only last for a few seconds before the power imbalance causes all the generators in the system to slow down and the system frequency to drop. Then the active power share of any one generator in meeting the power imbalance depends solely on its inertia and not on its electrical distance from the disturbance. The rate of change in frequency due to imbalance depends on the system inertia. System inertia is directly proportional to synchronously rotating mass in the system.

The relationship between the initial frequency behaviors after a power imbalance is determined by the behavior of the rotating masses of the system, the bulk of which is provided by spinning generators, via their stored kinetic energy, i.e., rotational inertia.

Low levels of rotational inertia in a power system have implications on frequency dynamics and can influence the whole power system, in the worst case ending in fault cascades and blackouts. They are becoming faster in power systems with low rotational inertia. This can lead to situations in which traditional frequency control schemes become too slow with respect to the disturbance dynamics for preventing large frequency deviations and the resulting consequences. The loss of rotational inertia and its increasing time-variance lead to new frequency instability phenomena in power systems.

Typically, smaller system inertia is observed during off-peak periods in BPS compared to peak periods because of less synchronously rotating mass online. Since small engines have low rotating mass, they can store low kinetic energy and goes out-of-step after certain time because of post disturbance dynamic oscillation, although the frequency tries to rise before a blackout.

Table 1.1 presents the generating plant type and installed capacity in BPS. It shows that nearly 37% of the installed capacity is reciprocating engines that have very low inertia. Sometimes that actual generating capacity come is more than that. Hence, BPS operates at low inertia during certain period of time.

4.5. Frequency Response Characteristics of BPS

System frequency is the most important indicator of the operating condition of a power system. One of the main concerns in power systems is that the amount of active power consumed plus losses should always be equal to the amount of the active power produced. If more power is produced than it is consumed the frequency would rise and vice versa. Even small deviations from the nominal frequency value would affect the performance of synchronous machines and other equipment.

Frequency requirements are an essential part in the Bangladesh Electricity Grid Code (BEGC). The updated BEGC specifies a normal frequency range of 49.5 to 51.5 Hz (i.e. ±1%). However, it is yet to be achieved and will require detailed planning.

The National Load Dispatch Centre (NLDC) is responsible for demand-generation balancing and regulation of system frequency.

4.5.1. Frequency Characterization of BPS

A study on frequency characterization of BPS is the only such work published in Bangladesh.[23]

Frequency data plot of BPS with statistical parameters presented in the publication shows the mean, 50 Hz baseline and boundaries of first and third standard deviation as shown in Figure 4.3. The system is seen to have frequency above 50 Hz value most of the time. From numerical calculations, the mean and standard deviation were found out to be 50.470174 Hz and 0.459404 Hz, respectively.

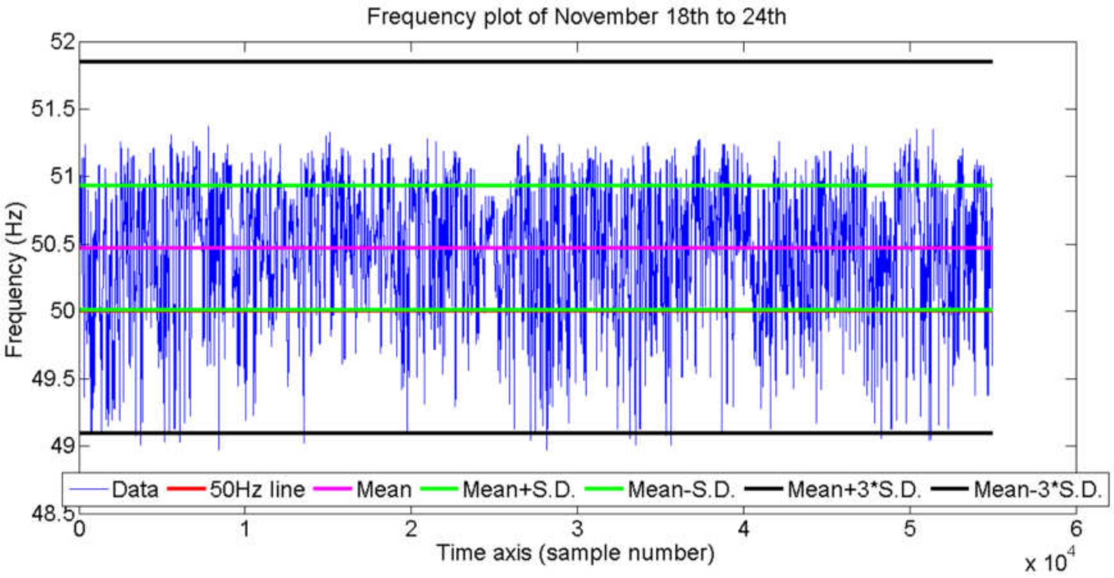

Figure 4.3: Frequency data plot of BPS with statistical parameters

The graph of rate of change of frequency (ROCOF)[24] presented in Figure 4.4 shows the out of bound rate of change of frequencies. It is seen to have more upward deviations while fewer but prominent downward spikes.

The distribution of the data was compared to that of the standard normal distribution shows that the data is positively skewed with respect to mean or base line and does not follow Gaussian approximation (Figure 4.5).

PGCB employs frequency threshold-based under-frequency load shedding to stabilize system frequency and prevent blackouts. The number of trips an under-frequency relay would make

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[23] Md. Rifatul Haque, A. H. Chowdhury, “Frequency Characterization of Bangladesh Power System,” 9th International Conference on Electrical & Computer Engineering (ICECE), Dec. 2016, Dhaka, Bangladesh, pp. 341-344.

[24] ROCOF is the time derivative of power system frequency, i.e., the rate of change of frequency.

when it encounters frequency below a threshold value was calculated by the referred study[22]. Figure 4.6 presents the frequency threshold versus numbers of under-frequency relay trips.

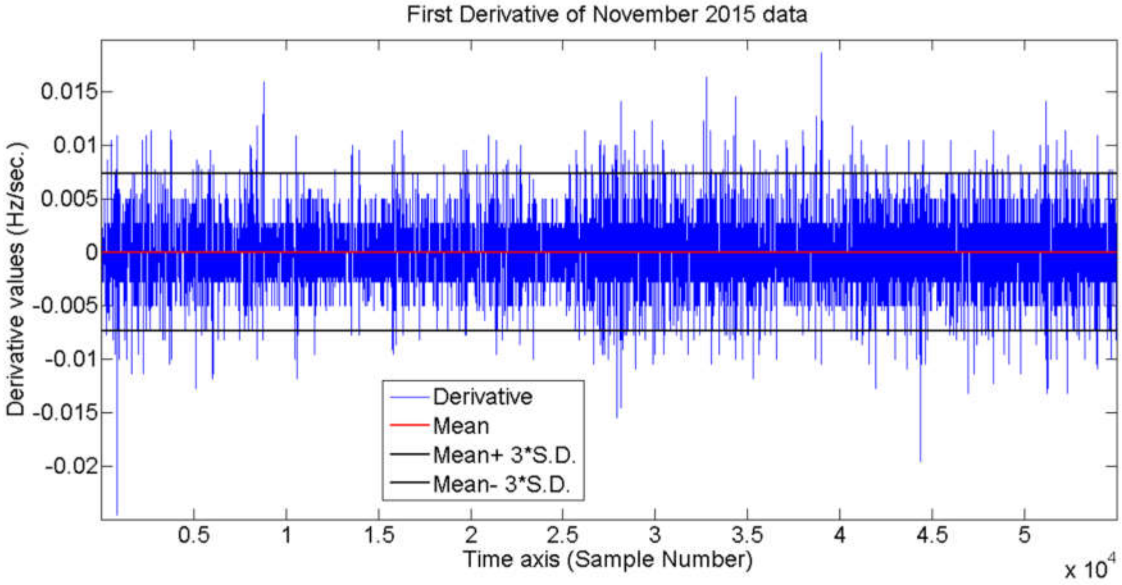

Figure 4.4: First derivative of frequency with statistical limits

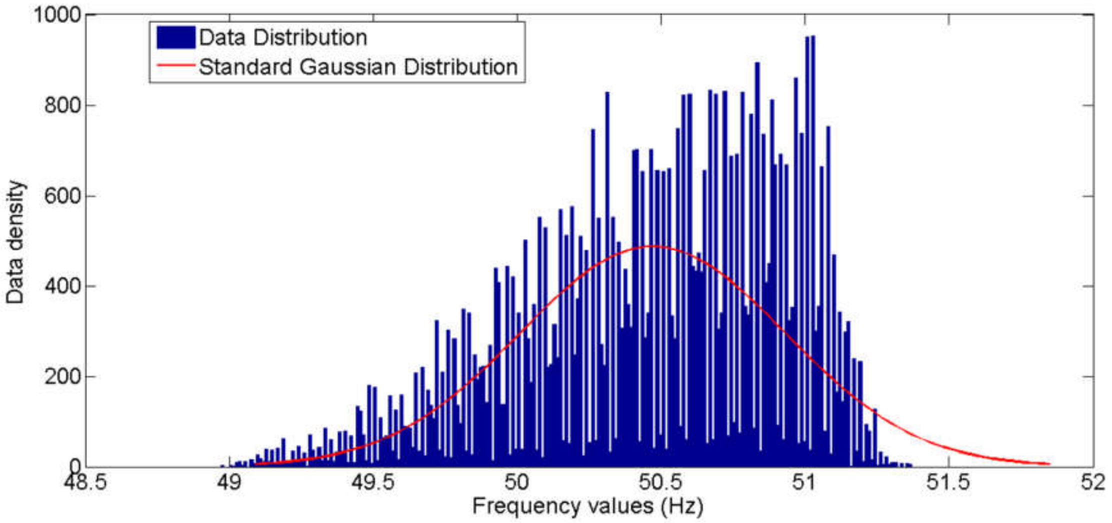

Figure 4.5: Frequency data density compared to Gaussian approximation

It is seen that zero relay trips would occur if relay were set to trip at 49 Hz, which is much lower than the standard limit. The number of trips that would occur is seen to rise exponentially with a rise in trip frequency setting. This is indicative of the problem of under-frequency load-shedding scheme in BPS. Because of *frequency instability*, even though rotor angle stability is not in the offing, under-frequency load shedding relay will activate and shed load.

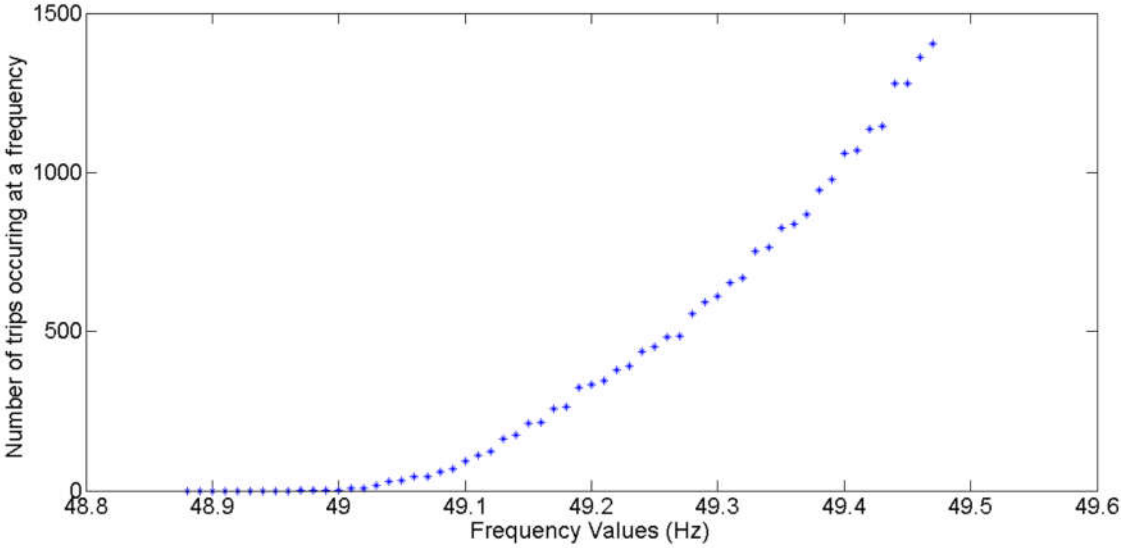

Figure 4.6: Number of trips of under-frequency relay with change in frequency threshold

4.5.2. Frequency Control Requirements

According to Bangladesh electricity grid code, during rising frequency conditions, NLDC issues instructions to generators to reduce generated output. When frequency falls below specified limit, NLDC operators are required to cut-off load automatically or command control posts to shed load.

In case of low frequency situation, under-frequency load-shedding scheme is followed. There are no provisions to monitor how fast the frequency has declined, only the system frequency is monitored by the traditional load-shedding scheme, not the rate of change of frequency (ROCOF). Furthermore, it should be noted there is no grid integration scheme for BPSN in current under-frequency scheme.

4.6. Present Practice of Frequency Control

4.6.1. Frequency Control under Normal Operating Condition

Due to lack of modern dynamic control over the system, the frequency of BPS varies significantly. Currently, the governor control mechanism of most of the generators in the BPS has been disabled and there is no secondary or AGC control implemented. Only a few generators are operated using frequency control mode. Most of the generators are still operated at constant power control mode, which impose significant challenge on system operators to maintain system frequency within acceptable limits. Hence, the frequency is very unstable and frequently violates the nominal limits.

If system frequency goes above the allowable range, the control room operator generally follows the following steps,

1. Switch on the feeders in stages, as needed, that tripped (if any) under the "under-frequency load-shedding scheme".
2. Switch on the feeders that were manually switched off temporarily to control the load. (Except those switched off due to the capacity limitation of transmission line and/or transformer.)
3. Withdraw the load shedding as required in stages (if any).
4. Generation of the running generating units is reduced as per economic order of generation and/or operating conditions of the generators.
5. Check the frequency status for the conformity with the requisite condition after each stage of operation.
6. If steps 1 to 4 is not enough, generating units are given instruction for shut down on temporary basis to ensure the conformity with the requisite condition.
7. Record the activity in the shift register.

If system frequency goes bellow allowable range the control room operator generally follows the following steps,

1. Generation of the generating units from a preselected list are increased (if spinning is available) as per economic order of generation and/or operation conditions of the generators.
2. Switch off the feeders temporarily to control load by manual intervention.
3. New generators are added in the system (if standby generation is available).
4. Check the frequency status for the conformity with the requisite condition after each stage of operation.
5. If steps 1 to 3 are not enough, load control is imposed all over the country in proportionate of demand of the respective areas.

4.6.2. Frequency Control under Emergency Conditions

Emergency load-shedding for preventing frequency degradation is an established practice all over the world. The objective of load shedding is to balance load and generation. Since the amount of overload is not known at the instant of disturbance, the load is shed in blocks until the frequency stabilizes. Different techniques are available for implementing the load shedding scheme. The three main categories of load shedding schemes are[25],

1) Traditional;
2) Semi-adaptive;
3) Adaptive.

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[25] Md. Quamrul Ahsan, Abdul Hasib Chowdhury, S. Shahnawaz Ahmed, Imamul Hassan Bhuyan, Mohammad Ariful Haque, and Hamidur Rahman, "Technique to Develop Auto Load Shedding and Islanding Scheme to Prevent Power System Blackout," *IEEE Transactions on Power Systems*, Vol. 27, No. 1, Feb. 2012.

Traditional load-shedding scheme sheds a certain amount of load when the system frequency falls below a certain threshold. If this load-drop is sufficient, the frequency will stabilize or increase. If this first load-shed is not sufficient, the frequency keeps on falling at a slower rate. When the falling frequency reaches a second threshold, a second block of load is shed. This process is continued until the overload is relieved or all the frequency sensitive (FS) relays have operated. The values of the thresholds and the relative amount of load to be shed are decided offline, based on experience and simulations.

Traditional load shedding schemes usually have conservative settings because of the lack of information regarding the magnitude of the disturbance. Although this approach is effective in preventing inadvertent load shedding in response to small disturbances with relatively longer time delay and lower frequency threshold, it is not able to distinguish between the normal oscillations and the large disturbances of the power system. Thus, this approach is prone to shedding lesser loads at large disturbances.

The semi-adaptive load shedding scheme uses the frequency decline rate as a measure of the generation shortage. The activation of this scheme depends on the rate of change of frequency (ROCOF) when the system frequency reaches a certain threshold. According to the value of ROCOF, a certain amount of load is shed. That is, this scheme checks the speed at which the threshold is exceeded: the higher the speed, the more load is shed. Usually, the measure of the ROCOF is evaluated only at the first frequency threshold, the subsequent ones being traditional. In this scheme, the ROCOF thresholds and the size of load blocks to be shed at different thresholds are decided offline on the basis of simulation and experience. But the scheme adapts to the system disturbance as the actual amount of load blocks to be shed is decided by the frequency droop (FD)[26] relay depending on the rate of frequency change.

Adaptive load shedding schemes also estimate power disturbance magnitude by using the frequency gradient (i.e., df/dt). However, the amount of load to be shed at different thresholds are decided online on the basis of real time measurement of feeder loads.

PGCB employs frequency dependent load shedding scheme to stabilize system frequency under emergency conditions. The relays used by PGCB for this purpose can operate based on both frequency threshold and ROCOF. Currently only the traditional underfrequency load shedding scheme is implemented by PGCB.

4.7. Voltage Profile Assessment and Reactive Power Management

Voltage stability of a power system is concerned with the ability of the system to maintain acceptable voltages at all buses in the system under normal conditions and after being subjected to a disturbance. A system enters a state of voltage instability when a disturbance, increase in load demand or change in system condition causes a progressive and uncontrollable decline in voltage. The main factor causing instability is the inability of the power system to meet the demand for reactive power.

Closely related to voltage instability is voltage collapse. Voltage collapse is the process by which the sequence of events accompanying voltage instability leads to a low unacceptable voltage profile in a significant part of the power system. When the voltage control equipment

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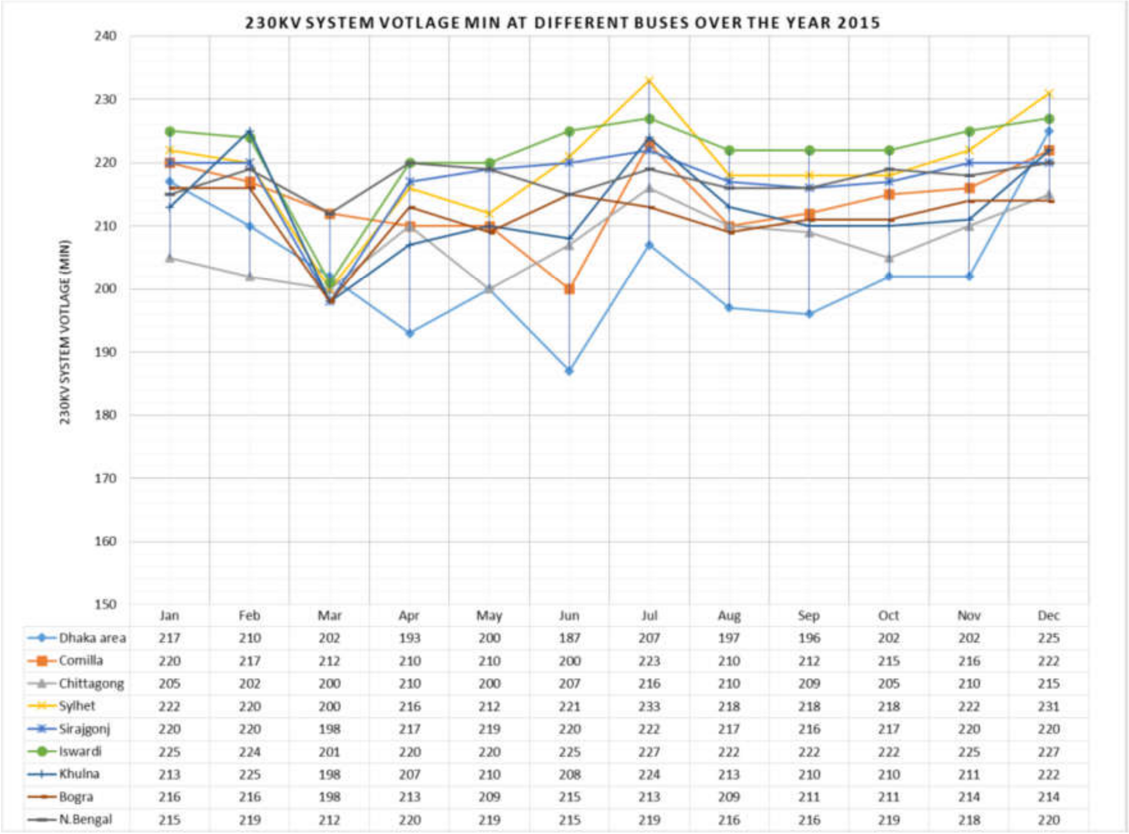
[26] In droop mode, a generator's output is inversely proportional to frequency.

is inadequate, it may not be possible to maintain the same voltage at different points of the grid at all times, and poor voltage conditions may develop and persist over extended periods. Prolonged low voltage on the grid may create problems in starting and running large-capacity motors, particularly those of nuclear power plants.

4.7.1. Voltage Control Requirements

Maintaining a proper voltage regulation limit is important to ensure proper utilization of a grid system's total installed capacity. If voltage regulation is poor, equipment cannot run at full power rating despite generation being sufficient. According to the Bangladesh grid code (BEGC), voltage variation on the transmission system shall normally be ± 5% for 400 kV, ± 6% for 230 kV and 132 kV bus during normal operations, and ± 10% at 400 kV, + 10/-15% for 230 kV, 132 kV bus during emergencies. All generating units of BPSN are required to have automatic voltage regulator (AVR)[27] in service.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dhaka area	217	210	202	193	200	187	207	197	196	202	202	225
Comilla	220	217	212	210	210	200	223	210	212	215	216	222
Chittagong	205	202	200	210	200	207	216	210	209	205	210	215
Sylhet	222	220	200	216	212	221	233	218	218	218	222	231
Sirajgonj	220	220	198	217	219	220	222	217	216	217	220	220
Iswardi	225	224	201	220	220	225	227	222	222	222	225	227
Khulna	213	225	198	207	210	208	224	213	210	210	211	222
Bogra	216	216	198	213	209	215	213	209	211	211	214	214
N.Bengal	215	219	212	220	219	215	219	216	216	219	218	220

Figure 4.7: 230 kV system minimum voltage of different buses over the year 2015

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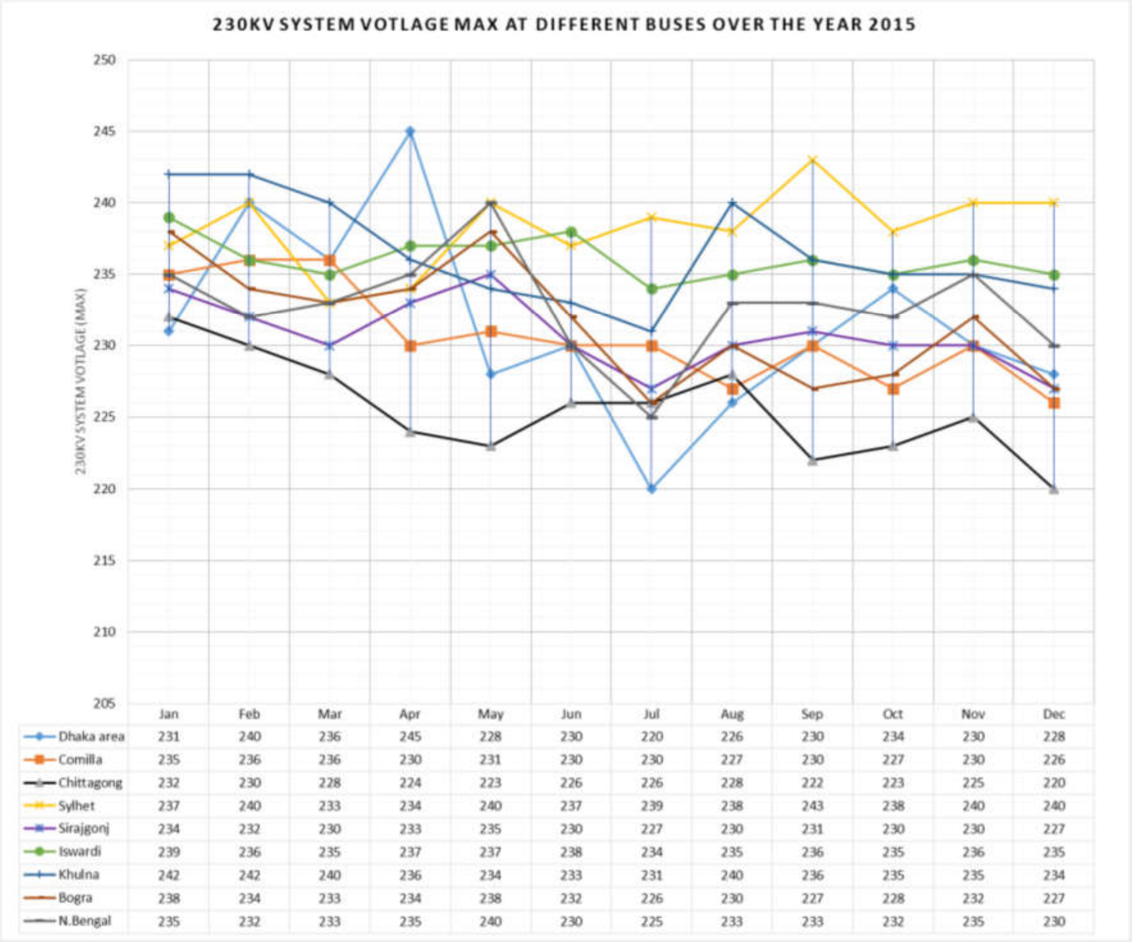
[27] AVR is an electronic device that maintains a constant voltage level of equipment.

4.7.2. Low Voltage Problem of BPS

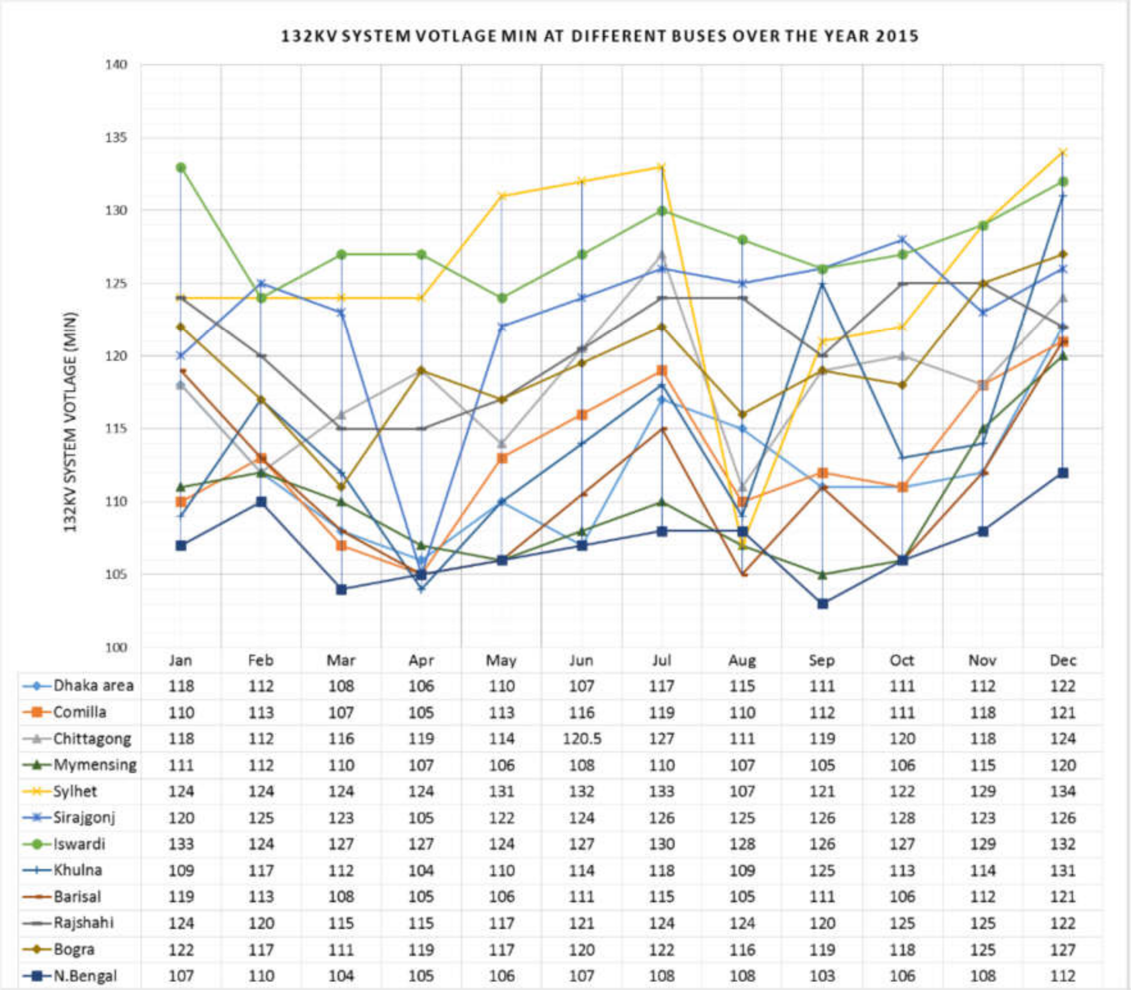
Bangladesh power system historically experienced low voltage problem throughout the grid. The problem is particularly pronounced in the Western part of the grid, i.e., in North Bengal and South Bengal.

Voltage and load profile of BPSN have been studied from operation data of PGCB and BPDB. A study on voltage data for the whole year of 2015 observed that the 230 kV level voltage varied from a minimum of 187 kV to a maximum of 245 kV at different buses. In Figure 4.7 it is seen that all the observed buses had a voltage dip in March 2015. Sylhet, Sirajganj and Iswardi buses had good voltage stability over the year. Dhaka and Chittagong were stressed areas as most of the industrial loads are in these two areas. Figure 4.8 shows the maximum voltages at the same buses over the whole year of 2015.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dhaka area	231	240	236	245	228	230	220	226	230	234	230	228
Comilla	235	236	236	230	231	230	230	227	230	227	230	226
Chittagong	232	230	228	224	223	226	226	228	222	223	225	220
Sylhet	237	240	233	234	240	237	239	238	243	238	240	240
Sirajgonj	234	232	230	233	235	230	227	230	231	230	230	227
Iswardi	239	236	235	237	237	238	234	235	236	235	236	235
Khulna	242	242	240	236	234	233	231	240	236	235	235	234
Bogra	238	234	233	234	238	232	226	230	227	228	232	227
N.Bengal	235	232	233	235	240	230	225	233	233	232	235	230

Figure 4.8: 230 kV system maximum voltage of different buses over the year 2015



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dhaka area	118	112	108	106	110	107	117	115	111	111	112	122
Comilla	110	113	107	105	113	116	119	110	112	111	118	121
Chittagong	118	112	116	119	114	120.5	127	111	119	120	118	124
Mymensing	111	112	110	107	106	108	110	107	105	106	115	120
Sylhet	124	124	124	124	131	132	133	107	121	122	129	134
Sirajgonj	120	125	123	105	122	124	126	125	126	128	123	126
Iswardi	133	124	127	127	124	127	130	128	126	127	129	132
Khulna	109	117	112	104	110	114	118	109	125	113	114	131
Barisal	119	113	108	105	106	111	115	105	111	106	112	121
Rajshahi	124	120	115	115	117	121	124	124	120	125	125	122
Bogra	122	117	111	119	117	120	122	116	119	118	125	127
N.Bengal	107	110	104	105	106	107	108	108	103	106	108	112

Figure 4.9: 132 kV system minimum voltage of different buses over the year 2015

The 132 kV buses that were monitored were highly stressed and had less regulation. Figures 4.9 and 4.10 show that 132 kV level voltage varied from a minimum of 103 kV to a maximum of 152 kV at different buses. Figure 4.9 presents the low voltages. It can be seen that North Bengal, Khulna, Barisal, Mymensingh, Comilla and Dhaka areas were mostly affected. Average minimum voltage of all buses was about 115 kV, 12.9% less than nominal[28].

That the low voltage problem in the BPS grid persists can be observed in Figure 4.11. The figure shows the daily maximum and minimum voltages presented in an ascending manner for the period from 1 June 2019 to 31 May 2020, at the Jaldhaka 132 kV substation in Rangpur district in the North Bengal.

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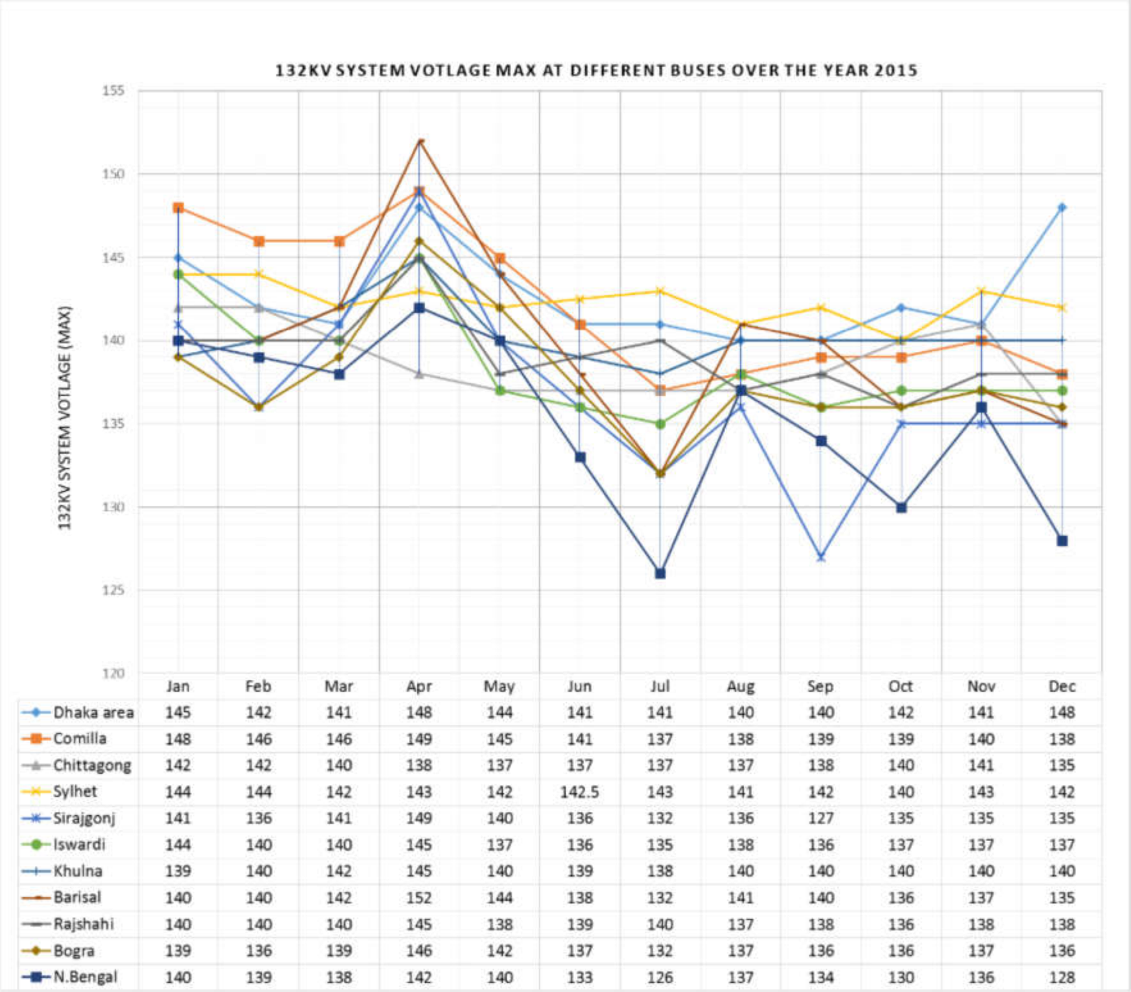
[28] A T. M. Mustafizur Rahman, Reactive Power Reserve Management to Prevent Voltage Collapse in Bangladesh Power System [MSc. Thesis], Bangladesh University of Engineering and Technology, 2016. [Online]. Available: http://lib.buet.ac.bd:8080/xmlui/ bitstream/handle/123456789/4506/Full %20Thesis.pdf?sequence=1&isAllowed=y.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dhaka area	145	142	141	148	144	141	141	140	140	142	141	148
Comilla	148	146	146	149	145	141	137	138	139	139	140	138
Chittagong	142	142	140	138	137	137	137	137	138	140	141	135
Sylhet	144	144	142	143	142	142.5	143	141	142	140	143	142
Sirajgonj	141	136	141	149	140	136	132	136	127	135	135	135
Iswardi	144	140	140	145	137	136	135	138	136	137	137	137
Khulna	139	140	142	145	140	139	138	140	140	140	140	140
Barisal	140	140	142	152	144	138	132	141	140	136	137	135
Rajshahi	140	140	140	145	138	139	140	137	138	136	138	138
Bogra	139	136	139	146	142	137	132	137	136	136	137	136
N.Bengal	140	139	138	142	140	133	126	137	134	130	136	128

Figure 4.10: 132 kV system maximum voltage of different buses over the year 2015

4.7.3. Reactive Power Management

The BEGC requires the users to improve load power factor by providing reactive power compensation at load end. The BEGC specifies that users shall not depend on the grid for reactive power and shall install facilities for maintaining power factor.

According to the BEGC, all generating units are required to notify NLDC of its reactive power capability (MVAR) in the range 0.95 leading to 0.85 lagging power factor. There are no specific limits for capacity as to which the generation plants should be obliged to provide reactive power compensation or the amount of compensation.

Reactive power reserve (RPR) is not maintained at any generating unit in BPS. Generators do not have sufficient RPR to respond to system voltage deviation for better voltage stability. Most of the power plants run in fixed active power with obligatory fixed power factor.

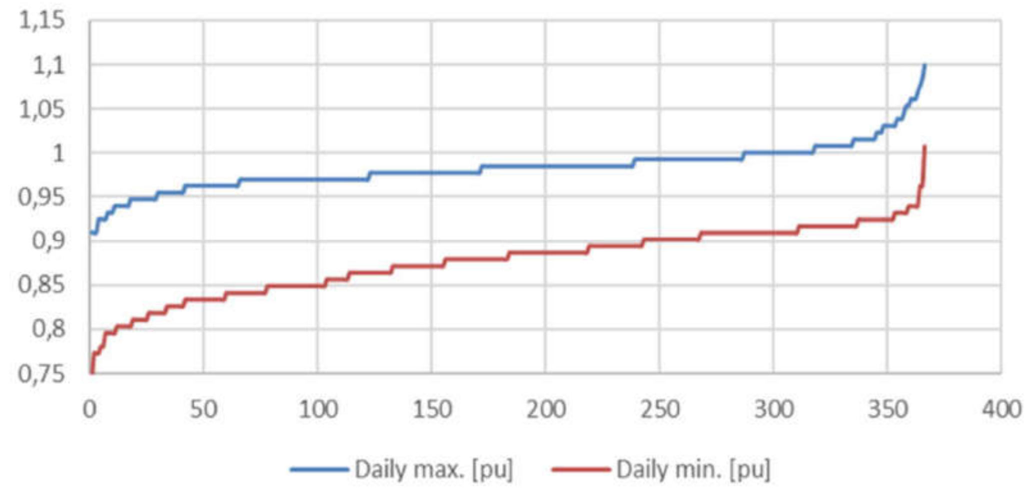


Figure 4.11: Daily maximum and minimum voltages presented in an ascending manner for the period from 1 June 2019 to 31 May 2020, at the Jaldhaka 132 kV substation.[29]

The BEGC does not require Static VAR compensators (SVC) implementation to provide necessary reactive power to maintain system stability at points where bus voltage levels are poor. The existing reactive power compensators in substations are not sufficient. Load buses of the BPS, which have been identified as the most vulnerable ones to voltage collapse phenomenon, are not provided with enough reactive power support.

4.8. Present Practice of Voltage Control

The NLDC control room operator directs the area control centers to take necessary actions for voltage control at the substation level. If required, the control room operator directs appropriate generating units to take action.

If grid voltage comes down below the required level following steps are followed,

1. Capacitor banks which are connected with 33 kV bus are switched on automatically (as applicable).
2. If step 1 is not enough, capacitor banks which are connected with 33 kV bus are switched on manually to raise the voltage.
3. If steps 1 and 2 are not enough generation of MVAR of the running generating units are increased.
4. NLDC control room operator and/or area control center operator check the voltage status for the conformity with the requisite condition after each stage of operation.

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[29] A Hasib Chowdhury, Bangladesh Power System - Issues and Concerns, Seminar organized by Power Division Ministry of Power, Energy and Mineral Resources, Bijay Hall, Bidyut Bhaban, Dhaka, November 8, 2020

5. If steps 1 to 3 are not enough, load control is imposed in the respective areas where voltage is low.

If grid voltage goes high beyond the required level following steps are followed,

1. The capacitor banks connected with 33 kV bus are automatically switched off (as applicable).
2. If step 1 is not enough, MVAR generation of the running generating units is reduced.
3. If steps 1 and 2 are not enough, the capacitor banks connected with 33 kV bus are switched off manually to lower the voltage.
4. NLDC control room operator and/or area control center operator check the voltage status for the conformity with the requisite condition after each stage of operation.
5. If steps 1 to 3 are not enough, related transmission lines are switched off to control voltage.

4.9. System Restoration Management

PGCB has an instruction manual on procedures for restoration from partial or complete grid. It specifies the conditions for apprehending a partial or complete grid fail, immediate actions to be taken by the NLDC dispatcher. The document also specifies the actions to be taken for unit restoration in case of partial grid failure. The document further specifies primary actions to be for black start restoration, i.e., restoration from complete grid fail, particularly for the generating plants that have black start facilities, for the grid substations, and for the NLDC control room. However, this restoration procedure document was adopted in February 2006, when the BPS was much smaller.

There is no comprehensive restoration plan for the present system and the restoration process after a system disturbance is carried out based on operational experience.

CHAPTER 5: GRID INSTABILITY AND BLACKOUTS

5.1. Analysis of Cases of Countrywide Blackout

Case 1 – First Countrywide Blackout on 16 November 2007

The first two failures occurred in the same day, in the morning and in the evening of November 16, 2007, the next day of the occurrence of tropical cyclone Sidr.

Sidr was an extremely severe tropical cyclone that resulted in one of the worst natural disasters in Bangladesh. It formed in the central Bay of Bengal, and quickly strengthened to reach peak 1-minute sustained winds of 260 km/h, making it a Category-5 equivalent tropical cyclone. The storm made landfall in Bangladesh on the night of November 15, 2007. Power distribution utilities switched off almost all the 33 kV distribution feeders throughout the country prior to the land fall, and the load demand came down to a few hundred MWs. However, the remaining system could weather the storm. In the morning as the system was being restored to its normal capacity, at around 7:50 am the system frequency started to fall and within a few minutes a complete failure of the grid occurred.

Figure 5.1 presents the frequency during the first grid failure on 16 November 2007 as recorded by digital fault data recorder (DFDR).[30] It was a failure during system restoration. A major generation and load mismatch occurred during system restoration; load being switched-on at a faster rate than generation increase. This is reflected in the frequency curve.

At 07:52:43 hrs system frequency was 49.01 Hz, it increased to 49.29 Hz at 07:54:25 hrs, but fell to 49.04 Hz at 07:56:04 hrs. The frequency fell to 48.49 Hz at 07:57:00 hrs. At this point two generating units, Siddhirganj 210 and Barapukuria-2, tripped showing low frequency. This indicates that an auxiliary system failure occurred in these two units. This increased the generation-load mismatch, further aggravating the situation. The frequency continued to fall, and within three minutes complete blackout of the system occurred.

The reason of failure is two folds: i) poor co-ordination between the NLDC, which was commanding the generation, and the load centers controlled by the utilities, and ii) auxiliary system failure of some of the generating units. The frequency curve further indicates under-frequency load shedding scheme did not perform the intended task of shedding enough load to stabilize frequency decline. This is expected as there was not enough load available for shedding at the time.

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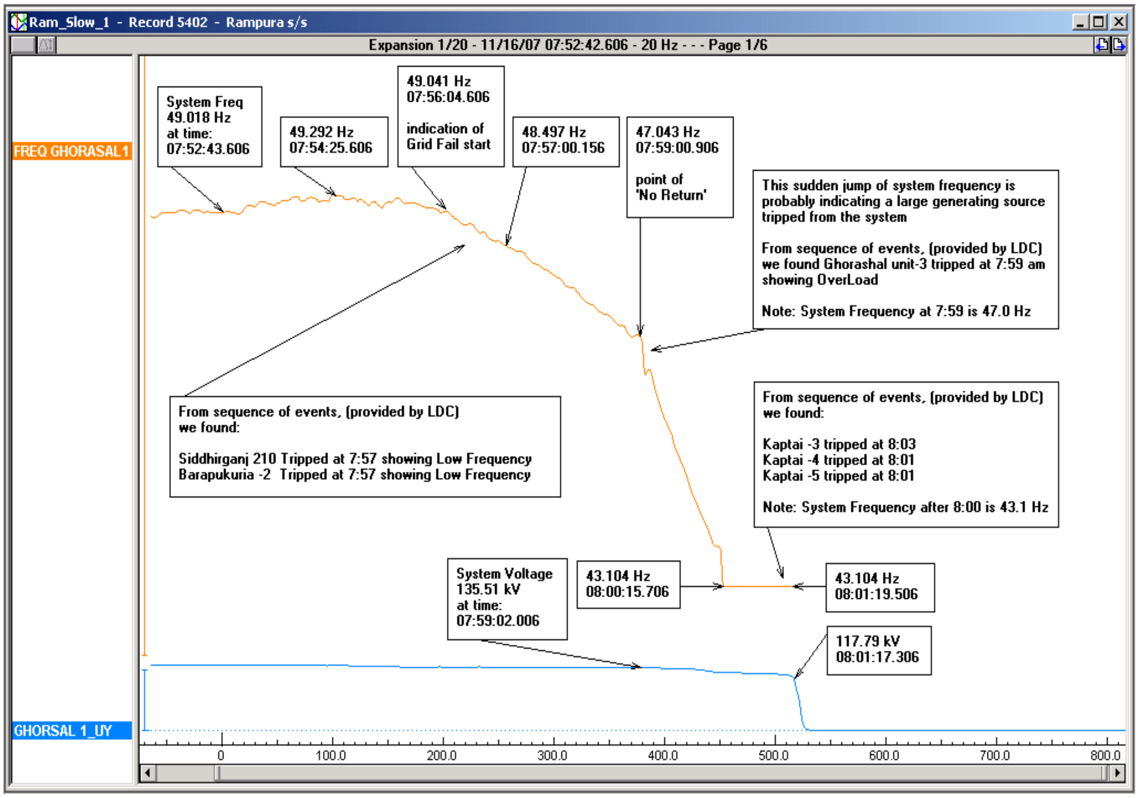
[30] Recorded data from Digital Fault Data Recorder (DFDR) at Rampura 230 kV substation.



System Freq
49.018 Hz
at time:
07:52:43.606

49.292 Hz
07:54:25.606

49.041 Hz
07:56:04.606

indication of
Grid Fail start

48.497 Hz
07:57:00.156

47.043 Hz
07:59:00.906

point of
'No Return'

This sudden jump of system frequency is probably indicating a large generating source tripped from the system

From sequence of events, (provided by LDC) we found Ghorashal unit-3 tripped at 7:59 am showing OverLoad

Note: System Frequency at 7:59 is 47.0 Hz

From sequence of events, (provided by LDC) we found:

Siddhirganj 210 Tripped at 7:57 showing Low Frequency
Barapukuria -2 Tripped at 7:57 showing Low Frequency

From sequence of events, (provided by LDC) we found:

Kaptai -3 tripped at 8:03
Kaptai -4 tripped at 8:01
Kaptai -5 tripped at 8:01

Note: System Frequency after 8:00 is 43.1 Hz

System Voltage
135.51 kV
at time:
07:59:02.006

43.104 Hz
08:00:15.706

43.104 Hz
08:01:19.506

117.79 kV
08:01:17.306

Figure 5.1: Frequency curve during the first grid failure on 16 November 2007

Case 2 – Second Countrywide Blackout on 16 November 2007

After the 'first grid failure' the system was getting restored gradually. Up to 17:00 hrs the following machines got synchronized with the system: Ashuganj GT-1, Haripur SBU, NEPC, Shahjibazar-4, 5 & 6, RPCL-1, 2, 3 & 4, KPCL, Bheramara, Baghabari-100 MW, Westmont & Kaptai-2, 3, 4 & 5. At that time total generation was 630 MW. At about 17:25 hrs the grid system failed again.

During this second grid failure Ashuganj GT-1 tripped due to auxiliary system failure. Haripur SBU, NEPC, Baghabari 100 MW and Westmont tripped due to low frequency. RPCL-1, 2, 3, & 4, and Shahjibazar-4 went floating. Shahjibazar-5, 6 tripped due to reverse power. KPCL tripped due to over voltage. Kaptai-2, 3, 4 and 5 were not tripped and were running with Chittagong and Cumilla zones.

Figure 5.2 presents the frequency during the second grid failure on 16 November 2007[30]. From this curve it is seen that at 17:19:04.69 hrs system frequency was 49 HZ, which slowly declined to 48.492 Hz at 17:25:04.69 hrs. After that the grid suddenly failed within 7 seconds.

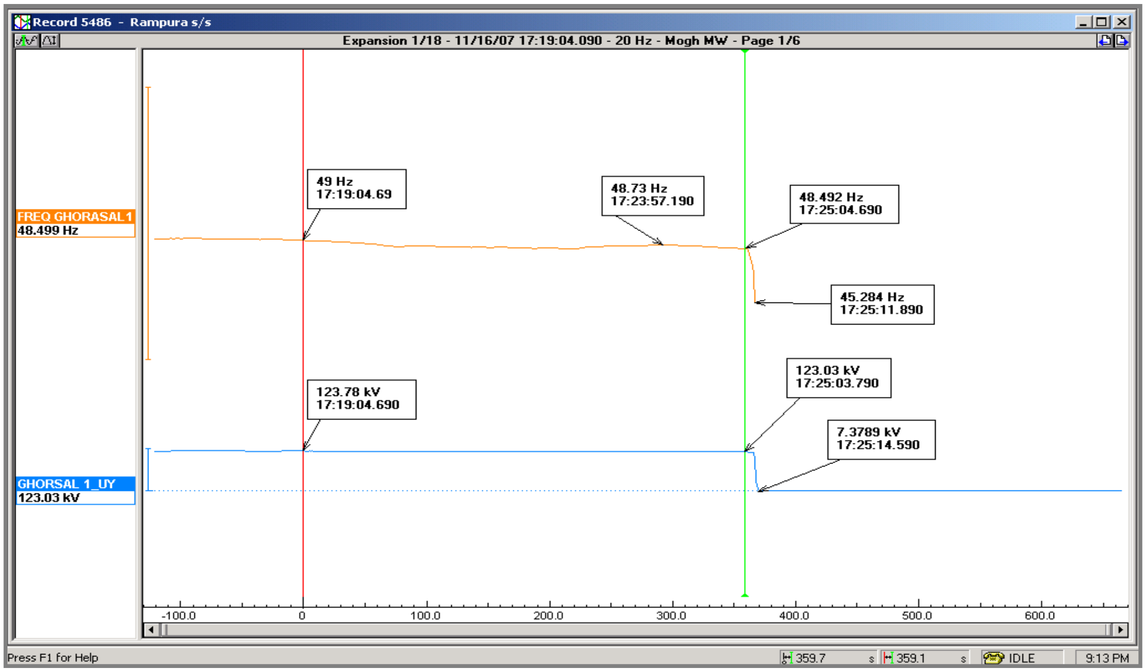


Figure 5.2: Frequency curve during the second grid failure on 16 November 2007

Records show number of transmission lines tripped at around 17:25 hrs. A few of those lines tripped due to over/under voltages, but reasons for most of the line tripping could not be ascertained.

Poor co-ordination between generation and load increase, during the period when the system was being restored after the first grid failure on that day, may have been the main cause of the second grid failure. Under-frequency load shedding scheme failed to stabilize the frequency decline. The system was a much reduced one, and there was not enough load available for shedding at the time.

Case 3 - Countrywide Blackout on 15 December 2007

A countrywide grid failure occurred at 11:42 am on 15 December 2007. At that time the people working in Ashuganj power generating station heard a very loud sound. Three workers were filling SF6 gas in the 230 kV circuit breaker of unit #3 at that time; they heard the sound and saw smoke in the middle (blue) phase of 132 kV bus and also saw a partially burnt bird on the ground just below the location of smoke. Within minutes the total grid system was out of operation.

Figure 5.3 presents the frequency during the grid failure on 15 December 2007.[31]

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[31] Md. Quamrul Ahsan, Abdul Hasib Chowdhury, S. Shahnawaz Ahmed, Imamul Hassan Bhuyan, Mohammad Ariful Haque, and Hamidur Rahman, "Technique to Develop Auto Load Shedding and Islanding Scheme to Prevent Power System Blackout," *IEEE Transactions on Power Systems*, Vol. 27, No. 1, Feb. 2012.

Figure 5.3: Falling frequency during blackout on 15 December 2007 from DFDR records.

A team of experts from BUET investigated through EMT simulations to identify whether the root cause of the flashover at Ashuganj 132 kV bus was due to a surge from probable switching events or a lightning surge likely to result from the presence of charged clouds in the vicinity of the Ashuganj switchyard. It was concluded that no switching event could cause the flashover and that a lightning surge from the presence of charged clouds may have caused the flashover.[32]

The flashover at the Ashuganj power station switchyard caused a bus fault. This led to tripping of the generators one by one in the Ashuganj power generating station. Ashuganj power station is one of the important nodes of BPS, being connected to the Ghorashal PS, Shahzibazar PS, Cumilla North and Kishorganj buses. A bus fault in this power plant impacted the first ring buses leading to cascading outages, and the eventual failure of the complete gid.

The frequency curve shows that under-frequency load shedding could arrest the fast-falling frequency a little over 48.2 Hz, then the frequency increased and stabilized over 48.5 Hz for about 10 seconds. After that it again slowly started to decline and finally a complete system blackout occurred. The load shedding amount was not sufficient and there was very little spinning reserve, if at all. The sudden fall of frequency at a later stage may be indicative of generating unit tripping throughout the system due to the operation of volt/Hz protection at a lower frequency. This may also be due to the low frequency trip setting of some of the generators defined at a higher value than specified in the grid code.

Case 4 – Countrywide Blackout on 1 November 2014

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[32] Report on Power System Stability Study and Electromagnetic Transients (EMT) Study During the Occasion of Grid Failure on 15th December 2007, Dept. of EEE, BUET, Feb. 2008.

Bangladesh power system experienced a countrywide blackout on 1 November 2014. On that day at 11:27:28:344 hours the 500 MW HVDC station at Bheramara that draws power from India experienced a forced outage leading to a complete blackout of BPS.

The frequency disturbance events recorded by DFDR is presented in Figure 5.4.[33]

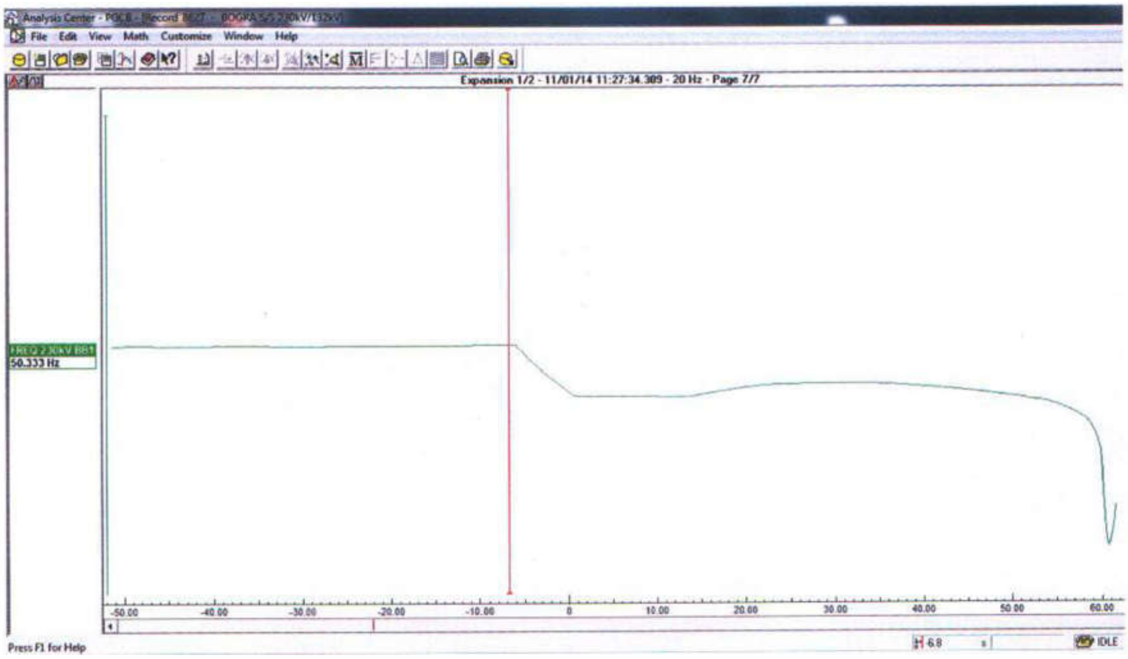

Figure 5.4: Frequency transient during blackout on 1 November 2014.

From the recorded frequency transients shown in Figure 5.4, it is observed that prior to HVDC station tripping, the network frequency was 50.327 Hz and total generation was 4674 MW. Due to tripping of HVDC at 11:27:28.16 hrs, import of 438 MW stopped. This caused a generation shortfall of 9.37% of total generation at that time. In the absence of spinning reserve, the system frequency started to decline and fall to 48.654 Hz within 6.8 sec. The fall in frequency was arrested because of the activation of the under-frequency load-shedding scheme. The frequency remained between 48.631 Hz to 48.691 Hz and then started rising and reached 49.066 Hz. The frequency sustained above 49.0 Hz for 18.3 seconds. Tripping of the HVDC station also resulted in low voltages in 230 kV buses connected to Bherama causing under-voltage tripping of some 230 kV transmission lines. Finally, the frequency started to decline again eventually leading to system blackout. From fault inception at HVDC station to complete blackout took approximately 59 seconds[33].

The under-frequency load shedding scheme operating at that time and the actual load shed as reported by PGCB is presented in Table 5.1.

The actual load-shed amount was approximately 415 MW. The first stage load-shed of 23 MW could not affect the system frequency significantly. Subsequent load-shedding could only arrest the falling frequency, but it was not sufficient to raise it.

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[33] Power Grid Company of Bangladesh, “Report on the Power Grid Failure on 1st November 2014,” Dec. 2014.

The generation from reciprocating engines were 996 MW, which was the 21.3% of total generation at the time. The inertia constants of these units are very small and these are highly susceptible to dynamic oscillations in the system that is expected in such a situation.

The above analysis indicates that there was not enough load to shed to stabilize the frequency at the nominal value of 50 Hz, that there was not enough inertia to sustain the stabilized frequency at a lower value, and that there was a deficiency of reactive power to hold the voltage within the rated limits.

Table 5.1: Under-frequency load-shedding scheme

Sl. no.	Stage setting, Hz	Expected load shed, MW	Actual load shed, MW	% Load shed
1	48.9	69	23	33.33
2	48.8	356	152	26.39
3	48.7	576	240	41.67
Total load shed		1001	415	41.45

5.2. Overview of Main Causes of Grid Instability

Based on the above case studies, present practice of generation scheduling and operations planning, and the analysis of status of grid stability presented in earlier chapters the main causes of BPS grid instability are summarized below.

1. The spinning reserve is not sufficient during normal operating conditions.
2. There is a deficiency of reactive power to hold the voltages within the rated limits.
3. In absence of security constrained generation dispatch, share of reciprocating engine-based generation sometimes reaches levels that make the system less resilient, making the system vulnerable to large transients.
4. The under-frequency load shedding scheme does not include enough load available for shedding, particularly during off-peak hours than is required to stabilize the frequency under emergency conditions.
5. The under-frequency load shedding scheme does not consider rate of change of frequency, and as such fails to adapt to different load scenario.
6. There is not enough inertia in the system to sustain the frequency stabilized at a lower value through underfrequency load shedding.
7. The volt/Hz protection of generating units may not be properly coordinated with the system frequency response characteristics.
8. Some of the generating units may have low frequency trip setting set at a higher value than stipulated in the BEGC.
9. Poor communication link between the NLDC and the generating stations and the grid substations.
10. The SCADA system does not connect to all the generating units and grid substations.
11. The NLDC does not have the data, models, and tools necessary for security constrained generation dispatch.
12. The BEGC does not clearly define all the five system states, the operating modalities for each state, and the operators at the NLDC control room are not sufficiently trained for all five states.
13. The distribution system is susceptible to inclement weather.

CHAPTER 6: ASSESSMENT OF GAPS AND OUTLINES OF SOLUTIONS

6.1. Technological, Policy and Operational Gaps

This study identifies technological gaps, policy gaps and operational shortcomings that renders the Bangladesh power system less resilient and prone to instabilities and blackouts. These identified gaps are presented below under separate sub-headings:

A. Technology gaps

A1. Some of the recently commissioned power stations and grid substations do not have remote terminal units (RTUs) or equivalent equipment. These power stations and grid substations remains outside of direct monitoring from the NLDC except via phone call. All power stations and grid substations should be connected to the SCADA system.

A2. Every generating unit in a power system has its own characteristics. The generating unit database of BPS is not complete and comprehensive. Since the unit steady state and dynamic modelling parameters are not comprehensive, any dynamic study of the BPS is a broad approximation only.

A3. The energy management division (EMD) of NLDC performs the demand forecast using e-terraplatform. The present version of e-terraplatform does not include integration of renewable and distributed energy resources into the grid.

A4. Unit commitment in Bangladesh is currently not carried out using the classical principles. NLDC does not have the customized software which considers generation unit commitment and transmission network constraints in the BPS, and there is also a lack of data required for such a software tool. An optimization tool for unit commitment which comprises security constrained unit commitment (SCUC) and security constrained optimal power flow (SCOPF) and takes into consideration the given characteristics and limitations of fuels, will support more secured, efficient and effective generation dispatch. Such a tool should be developed and implemented for the system operators at the NLDC.

A5. BPS grid has almost no active spinning reserve because FGMOs (free governor mode operation) are not active in most of the generating unit. There is no formal provision for spinning reserves to be maintained in our electrical grid in accordance with Bangladesh grid code. Moreover, units having the FGMO facility are not generally operated in the FGMO mode.

A6. Bangladesh power system does not have automatic generation control (AGC). Without units in FGMO mode and without LFC, AGC control alone will be of little use for frequency control.

A7. The scope of energy storage systems for frequency stabilization remains to be explored.

A8. The distribution system of the country is susceptible to inclement weather.

B. Operational gaps

B1. The information management division (IMD) of PGCB carries out the post-dispatch tasks and prepares various reports for operational planning, project planning and policy making. System operations, projects, and policy, all three affects the system resiliency and stability from short term to long term horizons. It is imperative the input data and information to the IMD should be accurate, comprehensive, and up to date. To that end automation is required in IMD.

B2. NLDC does not have comprehensive database and software tools necessary for automation of generator scheduling. The merit order for scheduling the available generators considers the weighted average fuel cost, evacuating lines' limits, and voltages. The actual fuel consumption curves of different generators are not available.

B3. Currently, generating units are scheduled on an hourly-basis. NLDC should have capabilities for scheduling every half-an-hour for proper generation-load balancing. Considering greater integration of renewable energy resources in the future, these capabilities should be expanded to scheduling generating units every five minutes.

B4. Due to lack of data needed for a standard suite of software, NLDC is performing many steps of load dispatch just based on experience and intuitions.

B5. Although generation redispatch is practiced to avoid equipment overload, security constrained dispatching is not practiced in general. NLDC does not have suitable and sufficient tools and data available for that.

B6. Not all generating units have the load frequency control (LFC). Moreover, units having these facilities have never been tested while connected to the power system.

B7. Governor 'deadband' of generating units are not comprehensively identified. Because of the presence of 'deadbands,' the governor ignores frequency error until it is beyond a threshold. When frequency error exceeds the threshold, the governor becomes active. Legacy mechanical-style governors in the Bangladesh power system have larger dead band.

B8. Under rising frequency conditions, NLDC issues instructions to generators to reduce generated output. When frequency falls below specified limit, NLDC operators are required to cut-off load automatically or command control posts to shed load. This is a primitive and inefficient method to control frequency of a power system.

B9. PGCB uses traditional under-frequency load shedding in an emergency state to prevent power system blackout. Only the system frequency is monitored by the traditional load shedding scheme, not the ROCOF. The amount of load-shed does not depend on the ROCOF but only on the frequency magnitude. This approach is effective in preventing inadvertent load shedding in response to small disturbances with relatively longer time delay and lower frequency threshold. However, it is prone to shedding lesser loads at large disturbances.

B10. Clock time of individual RTUs of various power stations and grid substations are not synchronized with the NLDC event recorder and DFDR times. There is no facility for recording which relay tripped when at different power stations and grid substations. This makes it difficult and sometimes outright impossible to ascertain event sequence in case of a grid failure incident.

B11. NLDC does not have real-time network stability applications necessary for blackout prevention from the operational side. There is an absence of complete suite of AGC software at the NLDC as well as the power plant sides.

C. Policy gaps

- **C1.** All the system operating states are not clearly identified and defined. The normal-, emergency-, and restoration states are identified in the Grid Code. However, the boundary parameters of these states are not sufficiently defined. Other power system states that include alert- and extreme emergency states are not identified. Operational objectives and procedures of all five power system states needs to be clearly defined. A comprehensive training program for the system operators on the state objectives and operational procedures needs to be established.
- **C2.** The BEGC requires that the NLDC produce a day ahead hourly generation schedule by the generators which should include allocated spinning reserve, but there is no specific limit of the required margin of spinning reserve that must be maintained.
- **C3.** The BEGC has a provision for under-frequency relays for emergency load shedding. However, no requirement for rate of change of frequency (ROCOF) relays is specified. There are no provisions to monitor how fast the frequency has declined. There is no requirement of assessment of the event causing the system frequency fall and how fast the frequency declines.
- **C4.** Currently in BPS under-frequency scheme, there is no grid disintegration scheme as a last defense of countrywide blackout. The current load-shedding scheme is not adequate to arrest the frequency decay during low inertial reserve of BPS; instead, it may create a state of blackout by iterative loss of generators.
- **C5.** Most of the power plants in BPS run with fixed active power with an obligatory fixed power factor. Reactive power reserve (RPR) is not kept at any generating unit. Generators do not have sufficient RPR to respond to system voltage deviation for better voltage stability. There are no specific limits for capacity as to which generation plants should be obliged to provide reactive power compensation or the amount of compensation. All generating units are required to notify NLDC of its reactive power capability (MVAR) in the range of 0.95 leading to 0.85 lagging power factor.
- **C6.** Power purchase agreements (PPAs) and implementation agreements (IAs) with IPPs do not include any ancillary services option. IPPs are not obliged to provide frequency and voltage support.
- **C7.** There is a lack of trained manpower for the operation and control of the grid.

6.2. Outline of Technical and Operational Solutions

6.2.1. Theoretical Background

A power system is a very dynamic (highly nonlinear) system that operates in a constantly changing environment. The load, generation and transmission equipment availability are both variable and unpredictable. Since the load of any electrical system change continually, the generation output must also change to balance closely the changing load demand.

Figure 6.1 presents generation-load balancing and frequency control in time (the control continuum) using different resources that have some overlap in timeframes of occurrence. A primary focus of the controls is to maintain nominal frequency under all conditions. No single equipment can carry out this task. With a change in frequency the various control elements act to recover the frequency to nominal. The initial response comes from system inertia. The rotating mass in a synchronous generating unit holds large amount of stored energy, a part of which is transferred into the system. Consequently, the frequency starts to drop but not as much as it would if no stored energy is transferred into the system. Primary frequency response includes governor control and demand response. Under-frequency load shedding falls in this category. Primary control only arrest and stabilize the frequency. Other control elements are used to restore frequency to nominal.

Secondary control operates in the minute time frame and maintains the generation-load balance under normal operating state. During emergency state, e.g. during a frequency disturbance, secondary control returns the frequency to nominal once primary control has arrested and stabilized it. Secondary control is provided by operating reserve and accomplished using automatic generation control (AGC). Manual actions by the dispatcher provide additional adjustments at this stage. Fast-start generation unit can also act as non-spinning reserve.

Figure 6.2 presents typical frequency trend for the loss of a generating unit and the role of various control elements. In the figure point A is the pre-disturbance frequency, point C is the maximum deviation due to loss of generating unit, point B is the stabilizing frequency, and point D is the time the system frequency starts to recover.

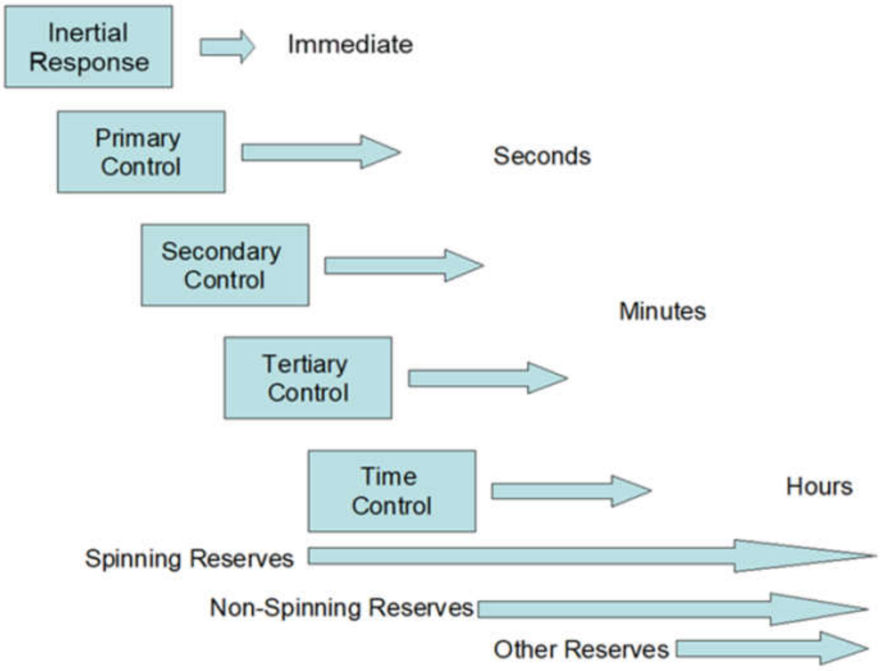

Figure 6.1: Frequency control continuum in power system[34]

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[34] NERC Balancing and Frequency Control Reference Document (2021)

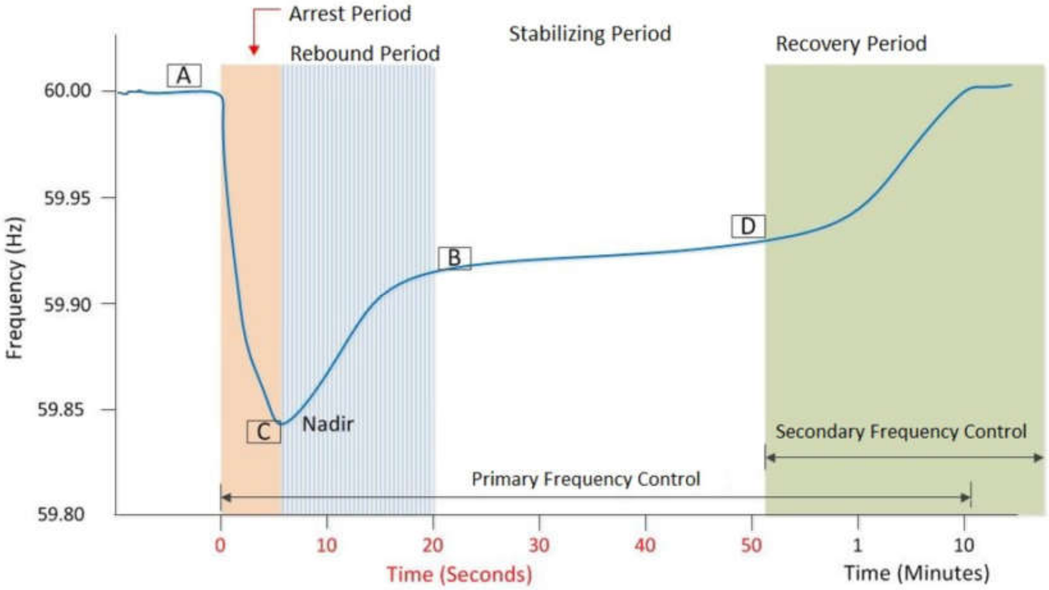

Figure 6.2: Typical frequency trend for the loss of a generating unit[34]

6.2.2. Outline of Technical and Operational Solutions

Considering the theoretical background presented above and the technology gaps and requirements of the BPS grid, an outline of technical and operational solutions to prevent power system blackout is presented below.

S1. Update the Bangladesh Electricity Grid Code to define the various states of the grid and the operational requirements.

S2. Connect all power stations and grid substations to the SCADA system.

S3. Develop a comprehensive and updated generating unit database that includes the steady state and dynamic modelling parameters as well as the generation characteristics of all generating unit.

S4. Automation of generator scheduling at NLDC and generation scheduling for every half-an-hour.

S5. Adopt security constrained generation dispatch.

S6. Use updated version of e-terraplatform that include integration of renewable and distributed energy resources into the grid, and online network stability applications to prevent blackouts.

S7. Develop a model for assessing the spinning reserve requirements. Activate FGMO for major generating units in each ‘island’ and load regions.

S8. Implement automatic generation control (AGC) for major generating units in each 'island' and load regions.

S9. Automation of loading dispatch and load control.

S10. Implement semi-adaptive under-frequency load shed scheme.

S11. Implement grid disintegration scheme as a part of the under-frequency load scheme that will act as the last defense of countrywide blackout.

S12. Consider using battery energy storage system (BESS) to provide frequency stabilization and recovery support for 1 to 2 minutes.

S13. Develop and implement a reactive power management plan.

S14. Develop a comprehensive restoration plan.

S15. Update power purchase agreements (PPAs) and implementation agreements (IAs) to ensure frequency and voltage support by IPPs.

S16. Training program for capacity development.

S17. Synchronization of RTUs, NDCL event reader and DFDR.

S18. Establishing a real-time communication link between NDCL and all generating stations and grid substations.

S19. Strengthening of the power distribution network.

The following Table 6.1 represents the mapping of the proposed solutions to specific technological, operational and policy gaps identified in the previous section. From the table, it may be observed that each proposed solution addresses one or more technological, operational or policy gap.

Table 6.1. Mapping of technical and operational solutions

Solution	Technology Gap								Operational Gap											Policy Gap						
	A1	A2	A3	A4	A5	A6	A7	A8	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	C1	C2	C3	C4	C5	C6	C7
S1														√						√	√	√				
S2	√												√													
S3		√		√					√	√		√			√											
S4											√										√					
S5													√													
S6			√	√																						
S7					√																√					
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S16																				√						√
S17																		√								
S18	√															√										
S19								√																		

6.2.3. Mapping of potential role of relevant stakeholders

Table 6.2 presents mapping of all relevant stakeholders and how they can play a role in overcoming the existing limitations of BPS. From the table, it may be observed that a collaborative effort is necessary to implement the technical and operational solutions suggested in Section 6.2.2.

Table 6.2 identifies major tasks for the system upgrade for normal operation, emergency situation handling, restoration and maintaining proper health of the electricity grid. The key stakeholders are BPDB and PGCB. Though they are under the same ministry and division (power), their roles are different. PGCB of course takes the greater burden, since it is the sole grid operator. BPDB through its sister concerns (power cell) could play necessary roles in supplementing the greater effort played by grid operator PGCB. Also, since BPDB owns most of the generation companies under the public sector, it also becomes a natural key player. Other generation companies are also identified for important role plays, since how they operate their machines crucially impact the grid during emergencies. Distribution companies also play a major role since shedding of loads requires their involvement and support. Regarding operational practice updates, reactive power reserve management, grid disintegration scheme planning, restoration plans should be taken with full involvement of the generation companies (public and private) and distribution utilities. Involving the IPPs through mandatory requirements are sometimes needed and that should be coordinated by the power ministry and power cell. Finally, for capacity development, local academia can be consulted. Funding agencies can and should actively consider financing capacity building, formulating regulations on frequency stabilization, reactive power management, automation and updated software implementation, maintaining updated databases and implementing full SCADA. Full automation of NLDC operation is a must-action that the funding agencies can pursue through PGCB. Major industrial consumers are a stakeholder through many secondary and tertiary levels, but their main involvement is through grid code upgrade and SCADA, since they own some captive generators and also their single load consumption hampers the grid frequency. One of the main tasks is the review and update of the grid code which falls under BERC jurisdiction, but it touches all other stakeholders in various levels. Other important tasks, where a majority of the stakeholders are involved, are the tasks involving the connecting of the generators and grid substations to a SCADA, maintaining an updated generation unit database, and capacity building.

Table 6.2 also proposes tentative implementation time-frames within which the tasks should be completed. These three time-frames have been considered based on the urgency of implementation as well as the technical and financial requirements; 3 years, 5 years and 7 years.

Table 6.2: Potential role of stakeholders

Tasks	Stakeholders										Implementation Time Horizon		
	Power Division, MPEMR	Power Cell	BPDB	PGCB	BERC	SREDA	Gen. Co.	Dis. Co.	Major Industrial Consumers	Funding Agencies	3yrs	5yrs	7yrs
1. Update the Grid Code		√	√	√	√		√	√	√		√		
2. Comprehensive automation of NLDC				√						√		√	
3. Automation of IMD				√						√		√	
4. Connecting all power stations and grid substations to the SCADA system			√	√			√	√	√	√		√	
5. Complete and comprehensive generating unit database of BPS	√	√	√	√			√			√	√		
6. Security constrained half-hourly generation scheduling			√	√			√				√		
7. FGMO for major generating units in each 'island' and load regions	√		√	√			√			√	√		
8. Complete automation of load dispatch and control			√	√				√		√		√	
9. Updated version of e-terraplatform for			√	√		√	√			√	√		

Tasks	Stakeholders										Implementation Time Horizon		
	Power Division, MPEMR	Power Cell	BPDB	PGCB	BERC	SREDA	Gen. Co.	Dis. Co.	Major Industrial Consumers	Funding Agencies	3yrs	5yrs	7yrs
renewable-integrated grid analysis													
10. Develop a spinning reserve model; ensure spinning reserve	√		√	√			√				√		
11. Ensure LFC in generating units			√	√			√					√	
12. Implement AGC			√	√			√					√	
13. Identification of governor deadbands			√				√				√		
14. Update operating practices at NLDC for different system states			√	√			√	√			√		
15. Implement reactive power reserve management	√		√	√			√	√		√			√
16. Develop grid disintegration scheme			√	√			√	√					√
17. Implement semi-adaptive load shedding scheme			√	√				√		√		√	
18. Consider using BESS for frequency stabilization			√	√				√		√			√

Tasks	**Stakeholders**										**Implementation Time Horizon**		
	Power Division, MPEMR	**Power Cell**	**BPDB**	**PGCB**	**BERC**	**SREDA**	**Gen. Co.**	**Dis. Co.**	**Major Industrial Consumers**	**Funding Agencies**	**3yrs**	**5yrs**	**7yrs**
19. Develop a comprehensive restoration plan	√		√	√			√	√			√		
20. Ensure frequency and voltage support by IPPs	√	√	√	√			√					√	
21. Provide capacity development training	√		√	√			√	√		√	√		
22. Strengthen the distribution network								√		√			√

CONCLUSIONS

This report is prepared and submitted for the fulfillment of the Terms of Reference (ToR) of the contract agreement signed between the European Union, represented by the Delegation of the European Union to Bangladesh and the Bureau of Research, Testing and Consultation (BRTC), Bangladesh University of Engineering and Technology (BUET) on 12th December, 2021. The study was conducted by the Institute of Energy and Sustainable Development (IESD), BUET, formerly known as the Centre for Energy Studies (CES), starting from 2nd January, 2022. A kick-off meeting was held on 23rd January, 2022 at the office of the Delegation of the European Union to Bangladesh where different aspects of this project were discussed by both sides. An inception report was submitted on 2nd February, 2022 to outline the proposed methodology and output indicators.

Although the initial timeframe was agreed to be eight months, the progress of the study was slowed down by Covid-19 pandemic. As a result, a review meeting was held on 6th July, 2022 at the office of IESD, BUET. In the meeting, both sides came to an agreement that the project duration may be extended on a "no-additional charge" basis. A formal letter for extension was submitted on 20th July, 2022 and the contract signing for the time extension of three months was done 14th August, 2022. The first draft of the report was submitted on 31st August, 2022. A follow-up review meeting was held on 4th September, 2022. The second draft of the report was submitted on 2nd October, 2022. A dissemination workshop was held on 8th January, 2023 at the office of the European Union Delegation to Bangladesh.

The study aims to assess the power grid stability in Bangladesh through analyses based on recorded available data, official and technological reports and studies, published scholarly papers, etc. At first, the study presents a clear overview of Bangladesh Power System (BPS) and its ancillary services i.e., frequency response, voltage management, reserve power, black start, etc. The study also realizes the importance of different stakeholders in the overall development of BPS. Therefore, the study presents a brief description of all the major stakeholders in this sector such as government organizations, regulatory bodies, generation companies, transmission company, distribution utilities, private organizations, major consumers, funding agencies, etc. At the same time, an overview of the national grid of Bangladesh is provided. The acts and policies that may have direct or indirect impact on the stability of the grid are also identified and presented in this report. Finally, the quantitative indicators for power system reliability analysis are listed and the current practices in the country to evaluate system performance are mentioned.

This study has also conducted various surveys through questionnaires to a set of stakeholders. It was generally found that the response has been very lukewarm. Some institutions showed data-blackout other than a regulator authority. However, we did get some information from one generating company and one utility company. The two responses have been added in the Addendum.

The study also presents the system operational setup of PGCB, the sole transmission company of Bangladesh. The roles of different circles and divisions within PGCB are specified. The basic steps for generation scheduling and operations planning are discussed in detail. Load control method imposed by PGCB is also explained. Different operational management practices such as generation economic dispatch, system frequency monitoring and control, voltage monitoring and control, line load monitor and control, load management, etc. are discussed in detail.

The frequency response characteristics and voltage data are analyzed and a correlation between the two is investigated. At the same time, active power spinning reserve and load-shedding schemes are taken into account to realize the stability and resilience of the power grid of Bangladesh. After that, the current practices of grid operation and maintenance are analyzed to identify the root causes of grid instability and blackouts that have occurred in the recent past. The topological weaknesses of the grid network are also investigated. Finally, the technological and data gaps are identified based on the analyses performed in the study and an outline of the technical and operational solutions is provided based on theoretical knowledge to improve the reliability of BPS grid.

This study also discussed the grid instabilities and blackouts and causes and ways of prevention. The main causes of vulnerabilities of Bangladesh Power Grid were outlined. A few case studies have been discussed – the blackouts in 2007 and 2014. The frequency curves of each incident have been analyzed. Poor coordination between the NLDC and the distribution utilities has been repeatedly noted. In the case of November 2014, this report found that, "there was not enough load to shed to stabilize the frequency at the nominal value of 50 Hz, there was not enough inertia to stabilize the frequency at a lower value, and there was a deficiency of reactive power to hold the voltage within the rated limits." These aspects of the grid need to be addressed by the operators to avoid future blackouts which will have devastating consequences, since nuclear power, VRE and an increasingly complex industrialization is being envisaged in the coming future.

Finally, this report assesses the technical, policy-related and operational gaps that has been observed through our study of the meta-data about the BPS. Recommendations are provided which will lead to overall grid stabilization. This report also suffices the technical and operational solutions to these problems. Nineteen recommendations towards possible solution to the grid stability problem has been proposed and a mapping has been provided that links these recommendations / solutions to the identified gaps. Thus, each proposed solution covers one or more gaps, and by following the table one can initiate any corrective procedure. Updating the grid code, automation through unified SCADA, automation of generation scheduling, automation of load dispatch and load control, semi-adaptive load shed scheme, grid disintegration scheme to prevent nation-wide blackout, adoption of reactive power management plan, ensuring sufficient spinning reserve, incorporation battery energy storage system etc. has been suggested. A mapping of role-plays on part of the stakeholders has been identified. This matrix will help policy makers and investors to identify specific tasks and track these to the relevant stakeholders to have a meaningful impact. This matrix will also help the operator and the stakeholders to become self-aware of the responsibilities and roles they have. The matrix also includes a time-frame for possible implementation of the suggested tasks. This will help prioritize actions to be taken.

The analyses of Bangladesh Power System presented in this study is performed on the basis of metadata and information available in published literature and reports. The study identifies that there is extensive data gap that needs to be addressed so that proposed solutions may be implemented successfully and meaningfully. Overcoming these data gaps is beyond the scope of this study. Further study may be conducted to identify and eliminate the existing data gap and build a comprehensive database that each component of the BPS may utilize.

ADDENDUM-I

Survey Responses

Survey Questionnaire (EUD Grid Study)
For Distribution Utility

Google form: https://forms.gle/xy3c3JXAfMzieXVT6

Basic Information:

1. Name: Engr. Md Moinuddin Khan

2. Designation: Superintending Engineer

3. Organization: Dhaka Electric Supply Company Limited

4. Key Responsibilities: Grid, System Protection and Energy Audit

5. Telephone/Cell No: +8801713443043 6. Email: moinudduin@desco.org.bd

Technical Questions:

7. Do you have SCADA system? Does it cover all the substation buses and feeders?

Yes, a SCADA Project is going to completed very soon and it will cover all substation buses and feeders

8. Do you have distribution management system (DMS)?

Not Yet

9. Do you have substation automation system (SAS)?

Yes, we have functioning substation automation system

10. Do you maintain equipment failure data? If yes, what are the parameters?

Not yet from my division but may be centrally maintain.

11. How often do you experience transformer or line overload?

It's very rare.

12. What problems does inclement weather create for your systems operation?

Normally overhead line failure.

13. If you are asked to participate in an emergency or forced load-shedding for stabilizing the frequency, will you comply?

Yes, definitely we shall comply

14. Is frequency fluctuation a problem for you? Elaborate, if yes.

This type of problem we don't face

15. Do you have voltage fluctuation problem? How much do they fluctuate? What problems do you face due to voltage fluctuation?

Voltage fluctuation problem in our system is negligible

16. Have your organization ever assessed distribution system resilience?

No

Survey Questionnaire (EUD Grid Study)

For Generation Company

Generation Company: https://forms.gle/4keHa7hZuZzAPXoD7

Basic Information:

1. Name: Mohammad Anwar Hossain
2. Designation: Project Director (Superintending Engineer), Sonagazi 50MW Solar Power Plant Construction Project.
3. Organization: Electricity Generation Company of Bangladesh Ltd. (EGCB)
4. Key Responsibilities: I was Maintenance Engineer (Electrical) at **Haripur 412MW CCPP, Bandar, Naranyanganj** from 2014 to 2018.
5. Duration of service: About 15 years in Power Sector.
6. Cell No: 01755645627
7. Email: anwar.hossain@egcb.com.bd

Technical Questions:

8. Do you have automatic generation control system installed in your units?

Yes, EGCB has 3(three) units (Haripur 412MW CCPP, Siddirganj 335MW CCPP and Siddirganj 2x120 MW PPP). All units are operating in FGMO mode as requested by NLDC.

9. Do you have any issue regarding low/high voltage in the system? Please elaborate, if yes.

Not now. But sometimes voltage fluctuation may be occurred during bad whether condition like storm.

10. Do you have any issue regarding system frequency fluctuations? Please elaborate, if yes.

No. There is very low frequency fluctuation within reasonable limit.

11. Have you suffered stability problem in any of your unit(s)? Please elaborate, if yes.

No.

12. Do you maintain equipment failure data? If yes, what are the parameters?

Yes. Failure Data for all Major equipment such as Turbine, Generator, Fuel Gas Compressors, Feed Water pumps, Circulation Water pumps, All MV motors, High pressure Valves etc. are properly maintained. Besides, hourly Log book for operational Data is also maintained.

13. What are the availability of your units?

Average 90%

14. If you are asked to participate in system frequency control what are the issues you will be concerned about?

a) Adequate fuel supply with required pressure.
b) All generating units to be operated in frequency control mode.
c) It is always desire for stable grid i.e. frequency and voltage.

15. Do you maintain any GHG emission data?

Yes. Nox, CO, CO2, O2, Moisture Content etc. emission data are recorded.

16. Do you experience any fuel supply problem?

Yes. Sometimes, it is observed low pressure and dust in Gas.