Policy Brief

Understanding Blackouts: Technical Perspectives and Solutions

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Executive Summary

A blackout is defined as a complete loss of electrical power to an area and represents the most extreme form of power outage that can occur in a power system[1]. This paper investigates the technical aspects of blackouts in Pakistan, meticulously examining their root causes and cascading effects on individuals, businesses, and the overall economy. It identifies the primary drivers behind power outages, such as outdated infrastructure and mismanagement, and highlights the significant economic losses incurred due to these disruptions. The study underscores the urgent need to address the challenges associated with power restoration after blackouts, offering a comprehensive set of recommendations to strengthen Pakistan's power grid infrastructure and enhance management practices

To minimise the frequency and severity of blackouts, the paper advocates for the adoption of advanced technologies, such as high voltage transmission lines, static var compensators, and storage batteries. It also emphasises the importance of real-time disturbance tracking and automatic response systems to isolate and address issues before they escalate. Additionally, the paper calls for the establishment of clear restoration procedures, improved data collection, and the implementation of a robust maintenance regime to ensure the reliability and resilience of the power grid.

By implementing these action-oriented recommendations, policymakers can take decisive steps towards creating a more stable and efficient power system in Pakistan. These measures will not only mitigate the adverse economic consequences of blackouts but also enhance the quality of life for Pakistani citizens. The findings of this paper provide valuable insights into the vulnerabilities of Pakistan's power grid and serve as a strategic guide for making informed decisions to ensure a sustainable and secure energy future.

[1] Parihar, Manish, and M.K. Bhaskar. "Review of Power System Blackout." International Journal of Research and Innovation in Applied Science 3 (2018): 8-12.

Introduction

Electricity is the backbone of every society, and significant losses occur when a power cut happens. While short power outages may not have a substantial negative impact, large-scale blackouts, where power is completely off for an extended period, have a significant impact on a country's economy. Blackouts typically occur due to an imbalance between power generation and consumption, resulting in the complete loss of power in a particular area[2]. Some key factors that play a vital role in power stability are Thermal limitation, Voltage Limitation, Frequency control and Rotor Angle Stability.

To avoid blackouts, selective power cuts must be carried out to shut down the power supply in the area where the fault occurred. Faults in the power grid can cause problems that spread to other parts due to power system instability issues. Restoring power after a blackout is complicated, as utilities and power stations need to identify and fix the initial problem, which can take a long time depending on the electrical network configuration[3].

Blackouts are distinct from localised power outages that might occur during a storm when heavy winds topple an electricity pole near your home, and a repair crew arrives to fix the damage. In these cases, the power outage is confined to a small part of the overall electricity grid. However, large-scale blackouts are a nightmare scenario for grid operators. These are cascading failures that render the grid incapable of supplying its users, plunging an entire region into darkness. The national grid operator (NPCC/SO) is responsible for managing the vast array of components that make up our electrical transmission infrastructure and ensuring that electricity supply always meets demand and the system remains stable.

Matching electricity supply to demand keeps the grid frequency—the rate at which the alternating electrical current in the grid changes direction—at exactly 50 Hz. This allows the generators in power plants to spin in unison throughout the grid, keeping the entire system synchronised and stable. Typically, a blackout begins with an unplanned event such as a component failure in a large generating plant or transmission line, which "trips" or disconnects from the grid for safety reasons. This creates a sudden mismatch in supply and demand and an

[2] Matthewman, Steven, and Hugh Byrd. "Blackouts: a sociology of electrical power failure." (2014).
[3] Generator Source. "The Many Causes of Power Failures." Generator Source. Accessed June 28, 2024. https://www.generatorsource.com/Causes_of_Power_Failures.aspx.

instantaneous change in system frequency. If the grid operator cannot correct this frequency imbalance within seconds, there is a risk of a series of cascading failures, leading to a blackout.

Due to the large geographical area, the chances of power failure and faults increase in Pakistan. New technology has been developed globally to address blackout issues, and it is improving day by day. Still, there is a chance of such events occurring, but at a relatively low capacity, as new technology decreases their likelihood.[4]

In Pakistan, the National Transmission and Distribution Company (NTDC) is unable to upgrade its technology and utilising techniques such as Inertia, Frequency, Voltage, Thermal, constraints…these are just a few of the factors that go into the highly complex process of balancing the grid. Moreover, employing proper operation and maintenance activities in foggy areas, replacing all disc insulators with polymer types or applying anti-corrosion coatings to reduce tripping of main lines in the winter season is delayed.

The control system is not sufficient to track disturbances in real time or respond automatically to isolate problems before they snowball. No redesigning of the system for installing phaser measurement units. The lack of upgrades in the transmission system has more to do with non-professional management of affairs than with funds[5].

Major breakdowns in the country usually occur due to system disturbances in 500 kV and 220 kV transmission lines and tripping in unstable power swing mode, causing a separation of the South and North zones. The separation of the North causes cascade tripping, unbalancing generation and connected load in both zones. Automated generation control is only available on major hydel plants such as Tarbela, Mangla, and Ghazi Barotha. Due to the minimum load in winter on these plants, the frequency control of the system becomes weak. As required in the Grid Code, the spinning reserve is not maintained. Due to nominal hydel generation in the North in winter, power generated in the South flows to the North to meet the load requirement in the North and Centre. Consequently, any generation loss causes the frequency to decline below the tripping limits of generators, resulting in cascade tripping and blackout. The outdated mechanisms and procedures contribute to not only major blackouts but also several hours required to restore the system in Pakistan. Even after many years, power plants are not developed with a black start facility to restart parts of the power system after a blackout. Grid

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[4] Malik, Afia. "Power System and Blackouts." Business Recorder, 2023.
[5] Malik, Afia. "Power System and Blackouts." Business Recorder, 2023..

stations and power stations lack real time synchronisation devices; many power plants and grid stations are not integrated with system operator control rooms.

Why Are Blackouts So Dangerous?

One of the key issues with blackouts is that they are difficult to fix quickly. In worst-case scenarios, outages can affect areas for several days if the damage to facilities or equipment is severe enough. Not having power for several hours or days can affect our modern lives in ways we might not even think about. Most people might consider not being able to charge their phones, but access to clean water is restricted without power. People dependent on refrigerating medication or electrical health devices are at risk. Electric stoves cannot prepare food, and modern transportation systems run on electricity. Airports and air traffic control can be halted, and much more. In this era of information and fake news, one can imagine the effects of fake news on such scenarios and its impact on people and the country[6].

Date	**Population Affected (Million) and Economic Cost**	**Reason**	**Details**
Jan 23, 2023	230 (99%), approx. Rs100 billion loss	Frequency variation and voltage fluctuation	In winter, electricity demand lessens nationwide; hence, temporary closure of power generation is common. When the plant was turned on, frequency variation and voltage fluctuation were observed in southern Pakistan. Subsequently, power-generating units shut down one by one, following the cascade effect.
Oct 13, 2022	2009, no financial loss estimated	Grid failure	Sindh, Balochistan, and parts of Punjab remained without power for several hours after a grid failure shut down several power stations. Disruption occurred in two 500 kV transmission lines in the south of Karachi.

[6] Cheema, Tahir Basharat, Nadeem Ul Haque, and Afia Malik. Power sector: An enigma with no easy solution. Pakistan Institute of Development Economics, 2022.

Jan 9, 2021	200 (90%), financial cost over Rs120 billion	Engineering fault	A technical fault at one of Pakistan's biggest power plants sparked a massive grid breakdown, plunging the entire country into darkness. Seven employees of the Guddu plant were suspended for negligence over the blackout, which lasted around 18 hours in most areas.
Jan 26, 2015	140 (80%), approx. Rs20 billion loss	Grid damaged by explosion in militant attack	The outage started after midnight when a transmission line connected to the national grid was damaged in an explosion. Authorities blamed the attack on a separatist group in Balochistan. The blowing up of two power pylons in Naseerabad created a backward surge, affecting the system.

Effects of Blackouts

Blackouts result in significant disruptive effects, causing damage to individuals, businesses, and the community. Economically, blackouts lead to productivity losses and financial setbacks for businesses, as machinery, lighting, and communication systems are rendered inoperative. Additionally, city-wide blackouts can destroy perishable items such as food and medicine stored in fridges and freezers, posing serious health risks from spoilage and contamination. Patients relying on electrically operated medical equipment face severe difficulties, necessitating backup sources or alternative setups for survival[7].

The elderly, those with existing medical conditions, and individuals living alone may experience increased anxiety and stress due to blackouts. Regulatory authorities and power agencies must consider their well-being. Blackouts can also lead to traffic system disruptions, resulting in uncontrolled intersections, increased accidents, and injuries. Large-scale blackouts may contribute to social disorder, public frustration, anger, social unrest, and damage to essential services and communication channels.

[7] Hussnain, Hossam. Blackout power system causes and effects: Best Solutions. accessed on 27 June 2024

The internet, crucial in modern life, is also affected by blackouts, leading to communication challenges. This disconnect affects not only individual communication but also the operations of commercial banks and other essential services[8]. Large-scale blackouts remind us of our dependence on electricity and underscore the importance of comprehensive power grid efforts to minimise outages and ensure the safety and smooth operation of critical infrastructure[9].

Procedure of Blackouts in Pakistan

Pakistan faces numerous power generation challenges due to mismatched power needs (demand and supply) from generating and transmission points of view. Limited capacity links the Hydropower plants in the North to the wind/coal power stations in the South. System failure is inevitable due to high volumes of energy and unprofitable use of system capacity. Developing new berths, widening lanes, and studying tread limits are essential solutions. Additionally, research on local wind corridors and infrastructure extension would enable the grid to manage power more efficiently and support robust industrial operations.

Phases of the Collapse of the Power Grid & Restoration Process

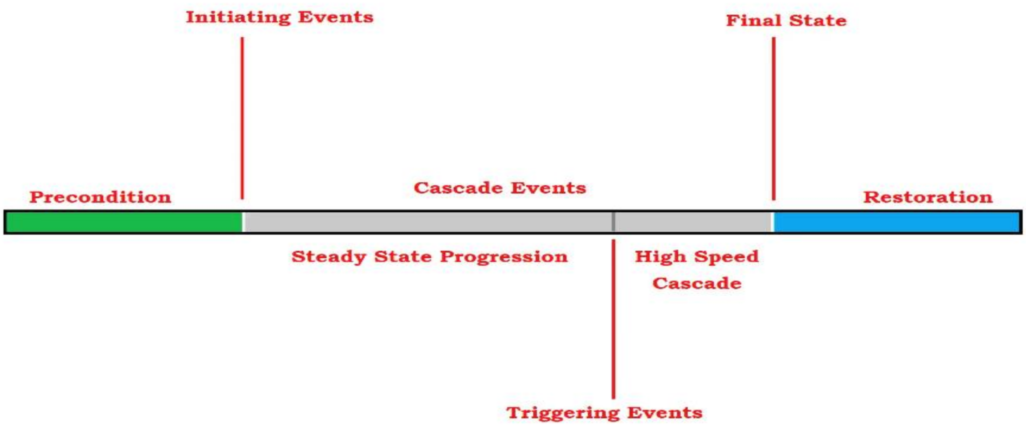

Figure 1: Phases of the Collapse of the Power Grid

Source: Instrumentstool.com[10]

There are three phases: utterance, threshold progression, and ultimate effect.

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[8] Capital, F. "The Impact of Power Outages on Communities and Businesses." Faster Capital. Accessed June 07, 2024. https://fastercapital.com/topics/the-impact-of-power-outages-on-communities-and-businesses.html.
[9] Roy, Saptarshi. "Blackout Prevention Methodologies: A Burning Topic of Research." (2021).
[10] Kumar, Shiv. "What Happens When the Power Plant Blackout?" Inst Tools. Accessed June 21, 2024. https://instrumentationtools.com/what-happens-when-the-power-plant-blackout/.

1. **Initiation**: This phase involves circumstances that precede a blackout, such as equipment failure (e.g., transformer, power line), sudden loss of production (e.g., power station going offline), surge in demand (e.g., during a heatwave), or cyberattack disrupting power operations.
2. **Steady State Progression**: During this phase, the imbalance in the system grows, leading to further deviation from required voltage and frequency values.
3. **High-Speed Cascade**: In this final phase, the imbalance becomes critical, causing machinery to fail under operational load, leading to a complete system collapse.

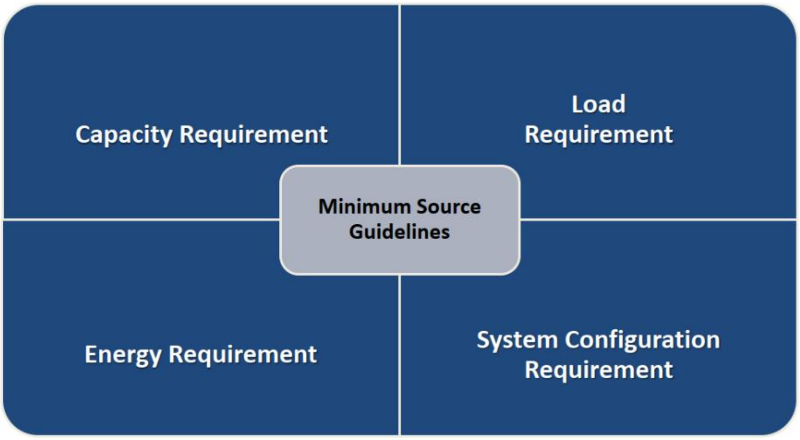

Figure 2: Minimum Source Guidelines

One should be clear about their system's capacity requirement (CR) and energy requirement (ER). The amount of energy a system needs to run for CR should be ascertained, while ER contains the amount of energy needed for production purposes. The Watt-hour requirement refers to the units of power that the system will produce to meet the demand. The text says that the planning capacity and the load capacity are the same, which suggests that the system's power to perform work and the energy required to meet the load put on the system are the same. Therefore, the approximation shows that it is a necessity to have sufficient power system capacity befitting the load to maintain stability and avoid possible collapses due to insufficient amount of energy produced.

Methods of System Restoration

Bottom-Up Approach[11]: This approach begins at the lowest part of the system and progresses upwards. The transmission operator energises a lower voltage part of the network (Zone A), which is then connected to adjacent higher voltage zones until the whole system is fully restored. This method ensures each component is stable before integrating it into the next one.

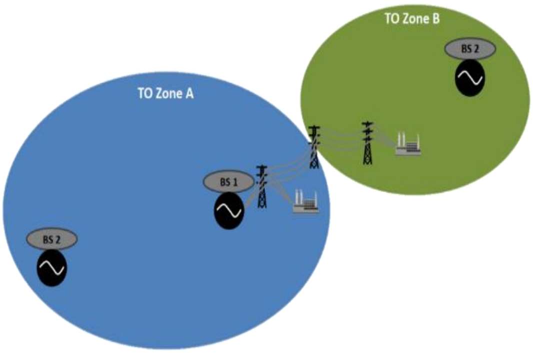

Figure 3: Bottom-Up Approach

Top-Down Approach[12]: This approach starts with the strongest and most stable part of the power system and progresses downwards. It begins with a stable voltage source, which could be a neighbouring electricity system or a reliable zone within the grid. Weaker sections are connected progressively, stabilising the grid through shared infrastructure.

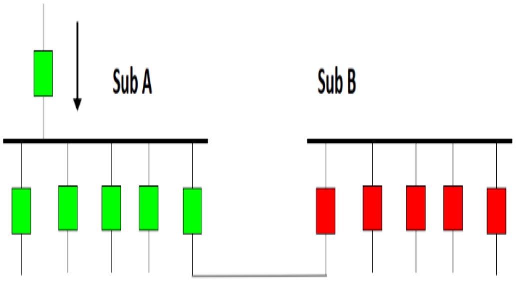

Figure 4: Top-Down Approach

Combination Approach[13]: This hybrid strategy uses both bottom-up and top-down methods, depending on the specific conditions in different zones. The approach ensures a flexible and fast-responsive restoration, leading to a stable and effective overall recovery.

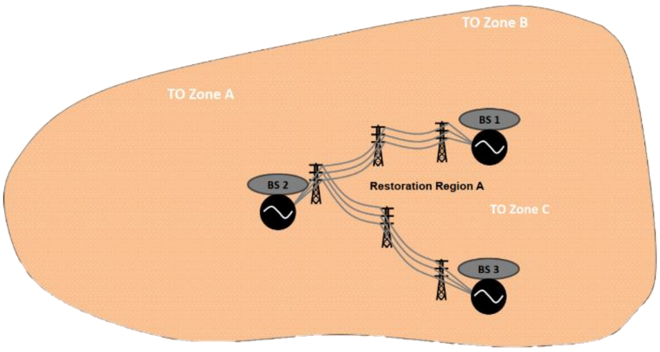

Figure 53: Combination Approach

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[11] Ranjith, Simi, and Sanjay Jain. "Overview of Challenges in Securing a Cognitive Radio Network." 2016.
[12] Desfray, Philippe, and Gilbert Raymond. "Chapter 5 - Key Modeling Techniques." In Modeling Enterprise Architecture with TOGAF, edited by Philippe Desfray and Gilbert Raymond, 67-91. Morgan Kaufmann, 2014
[13] Bhave, Ajay Gajanan, Ashok Mishra, and Narendra Singh Raghuwanshi. "A combined bottom-up and top-down approach for assessment of climate change adaptation options." Journal of Hydrology 518 (2014): 150-161.

Conclusion and Recommendations

Blackouts in Pakistan are a recurring problem with significant economic consequences. Frequent outages disrupt businesses, damage perishable goods, and hinder productivity. The outdated infrastructure and poor management practices of the power grid contribute to these blackouts. Implementing the recommendations outlined in this paper, such as upgrading the transmission system, improving data collection, and establishing clear restoration procedures, can help Pakistan reduce blackouts and create a more reliable and efficient power grid. This will benefit the economy and improve the quality of life for Pakistani citizens.

- The System Operator (SO) and Transmission Network Operator (TNO) need to further analyse system vulnerabilities using contemporary equipment, such as EMT analysis. Based on this analysis, precautionary and efficient management measures should be communicated.
- To strengthen the network, Pakistan should establish individual network boundaries for districts like KP, Dera Ismail Khan, Quetta, Muzaffarabad, and Karachi. In the event of a blackout, localised power generation should be used to restore parts of the grid, reducing overall restoration time.
- The N-1 contingency approach should be employed to prevent system collapse by preventing single-line failures. The TNO must draft a plan to upgrade the existing power infrastructure to prevent future blackouts.
- Accurate data collection processes are essential. TNO must strengthen NEPRA regulations to ensure reliable data, as system stability and economic growth depend on it. Penalties should be imposed on TNO for inaccurate system readings and blackout events.
- Customers should receive compensation based on the frequency of power outages they suffer. The penalty should be paid in the form of substantial fines levied by both distribution companies and the NTDC (National Transmission and Despatch Company).

Action Matrix

Action Area	Pathways to Solution	How to Implement Each Solution	Actor Responsible	Implementation Timelines
System Vulnerability Analysis	Use contemporary equipment like EMT analysis to identify system vulnerabilities	Conduct regular EMT analysis and communicate precautionary and efficient management measures	System Operator (SO), Transmission Network Operator (TNO)	6-8 Months
Strengthening Network Boundaries	Establish individual network boundaries for districts to localise power generation and reduce restoration time	Develop a plan to establish network boundaries for KP, Dera Ismail Khan, Quetta, Muzaffarabad, and Karachi. Implement localised power generation solutions	Government, TNO, Local Authorities	1-2 Years
N-1 Contingency Approach	Employ the N-1 contingency approach to prevent system collapse	Draft and implement a plan to upgrade existing power infrastructure to prevent future blackouts	TNO	2-3 Years
Accurate Data Collection	Strengthen regulations to ensure reliable data collection and impose penalties for inaccuracies	Enhance NEPRA regulations, implement robust data collection processes, and impose penalties for inaccurate readings and blackout events	TNO, NEPRA	1-2 Years
Customer Compensation for Power Outages	Provide compensation to customers based on the frequency of power outages	Develop a compensation plan and implement substantial fines for distribution companies and NTDC based on outage frequency	Distribution Companies, NTDC, Regulatory Authorities	2-3 Months

About the Authors

Dr Aneel Salman holds the distinguished OGDCL-IPRI Chair-Economic Security at the Islamabad Policy Research Institute (IPRI) in Pakistan. As a leading international economist, Dr Salman specialises in Monetary Resilience, Macroeconomics, Behavioural Economics, Transnational Trade Dynamics, Strategy-driven Policy Formulation, and the multifaceted challenges of Climate Change. His high-impact research has been widely recognised and adopted, influencing strategic planning and policymaking across various sectors and organisations in Pakistan. Beyond his academic prowess, Dr Salman is a Master Trainer, having imparted his expertise to bureaucrats, Law Enforcement Agencies (LEAs), military personnel, diplomats, and other key stakeholders furthering the cause of informed economic decision-making and resilience.

Farhan Ahmad is an electrical engineer with a decade and a half of international and national expertise, he has designed high-voltage substations, managed assets, and overseen projects for OEMs (original equipment manufacturers), clients, and consultants in numerous national and multinational corporations. Farhan, who has experience in Pakistan, Saudi Arabia, and the UK power sector, now oversees multidisciplinary teams involved in the feasibility, design, and construction of high-voltage substations in the United Kingdom. Farhan is a member of the Institution of Engineering and Technology (IET), UK, the Saudi Council of Engineers (SCE), Saudi Arabia, and the Pakistan Engineering Council (PEC).

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