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Analysis and Proposed Remedies for Power System Blackouts around the Globe †

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Abstract: Stable operation of power systems contributes towards the economic growth of developed and developing countries around the globe. Blackouts due to technical faults put the whole power system in danger. In this paper, a comprehensive analysis of power system blackouts, their root causes, and potential impacts on the economy of developed and developing countries around the globe is presented, along with possible approaches to avoid and resolve power system blackouts. The paper also proposes ways to avoid cascaded events in case of power system failure at a single point resulting in cascaded events and a complete blackout.

Keywords: frequent power outages; emergency blackouts; blackouts management; power system stability

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1. Introduction

The ability of power protection devices is to ensure stability and maintain a sustainable supply of electricity during the occurrence of any disruption in power systems. When a power blackout appears, the impacts are far reaching. Failure of control and protection systems, transmission line tripping or overloading, poor maintenance, lightning strikes, human mistakes, voltage collapse, equipment malfunction, cyberattacks, and other factors all contribute to power system blackouts [1]. Several power system failures have occurred since 2010, stranding millions of users for hours. For example, on 8 September 2011, a power blackout persisted for nearly 12 h in the Pacific Southwest, affecting 2.7 million people in four states in the USA [2]. The system failed as a result of a key transmission line tripping at peak load. On 4 February 2011, in the same year, a power system blackout happened in Brazil because of transmission line faults, lasting around 16 h. A total of 53 million customers were impacted [3]. A blackout impacting about 620 million people in north and east India happened on 30 July 2012, lasting roughly 15 h. This blackout occurred because the 400 Kilovolt Gwali–Binar transmission line was overloaded, which was scheduled for maintenance at that time [4]. The next day, the system collapsed again because of a demand–generation imbalance, which affected almost 32 giga watt of energy, and almost one million people were affected [4]. In terms of the number of persons affected, the Indian blackout is the biggest power outage ever recorded [4]. Fourteen power plants in the Philippines shut down in the same year, affecting roughly 40% of the Luzon islands and the capital city of Manila [5]. The estimated number of people affected in the Philippine blackout was around 8 million [5], and this blackout occurred due to a total voltage collapse in the system caused by the tripping of generators and transmission cables. In 2013, a lightning strike devastated Thailand's electricity grid, affecting over 8 million people in 14 provinces [6]. On 1 November 2014, Bangladesh's electrical system had a total system failure that lasted roughly 24 h. According to the findings, this was caused by an unexpected high voltage direct current station outage. The situation worsened further because some generators were undergoing maintenance at the time [7]. On 26 January 2015, a blackout appeared as a result of technical mistake at a power station in the Sindh region which affected almost all of Pakistan [8].

In light of these blackouts, a greater number of power outages are recorded in South Asia (1200), followed by 210 in Africa, 200 in East Asia, 50 in the Middle East and North America, 40 in Latin America and the Caribbean, and 250 in other countries till now [9]. The rate of power system blackouts is increasing continuously throughout the world, affecting social and economic activities in developed and non-developed countries.

This paper covers major reasons and potential impacts of power system collapse/blackout, which are given in Section 2. Section 3 presents a method for avoiding and resolving blackouts or cascading events around the globe. Section 4 describes research gaps and a conclusion is provided in Section 5.

2. Major Reasons and Potential Impacts of Power System Collapse/Blackout

Some of the well-known blackouts and cascaded occurrences of this decade are summarized in Table 1. The blackout with the longest duration, lasting 24 h, occurred in Bangladesh on 1 November 2014 [7]. The Indian blackout, which began on 30 July 2012, affected the greatest number of people in history [4]. Most blackouts (69%) appeared as result of poor protection and operational strategies, 18% of blackouts were due to over demand, 7% of blackouts were due to vehicle accidents, and 6% of blackouts were due to animals and bad weather condition [10].

Table 1. Major power system blackouts around the world.

Blackout Occurred in	Blackout Date	Blackouts Causes and Affects
Pakistan [10]	2021 (9 January)	Failure of bus bar protection caused blackout for twelve hours.
Canada [11]	2018 (12 December)	Too windy season caused the failure of power lines. Blackout remained for four hours and it affected six people.
Brazil [12]	2018 (3 March)	Failure of large transmission line caused blackout for one hour and affected ten million people.
Uruguay [13]	2017 (26 August)	Cascading failure appeared as a result of bad weather conditions. Blackout remained for four hours.
Australia [14]	2016 (28 September)	Transmissions lines were damaged due to a huge wind storm. Blackout remained for six hours and it affected one and half million people.

When multiple faults appear in the system, it leads to longer cascading events. If these faults are not properly managed, the system will experience a blackout. On the other hand, faults such as animals causing shorting, operational faults, poor weather, and technical defects are considered the main causes of power system failure. A deficit between generation and demand arises whenever a power system disturbance occurs, resulting in insecure system operation. This results in overloading of transmission lines and generators, lowering voltages and system frequency at individual levels. Ultimately, emergency load tripping is carried out via relay action to keep the frequency and voltage within permissible limits. If the relay function is delayed due to technical reasons, generators and transmission lines will trip automatically. The problem will quickly escalate into a series of events, and if this is not addressed, the system collapses. Major reasons for system failures are overloading of transmission line or tripping of generators, a rise or drop in the system frequency, voltage failure, and loss of synchronism.

Electricity cuts out when unplanned disturbances appear in the power system, and this affects economic, social, and political aspects of human life. These breakdowns have negative consequences for various sectors, including educational, medical, testing laboratories, industries, water supply pumps, banks, small and large business centers, and almost every walk of life, creating a huge toll on social, political, and economic activities, which at times are irreversible. Backup generators, which require continuous maintenance, have a heavy financial impact, adding to the already high costs of everything in general and medical emergencies in particular.

Internet disruption due to power breakdown can result in enormous economic losses. Since industries are dependent on electricity, manufacturing and production work is affected very badly due to the absence of electricity, despite the fact that industries have generators. Shipment of goods through seaports, airports, roads, and rail is delayed. Refrigerator items such as fruits, vegetables, and meat can perish. The slow process of loading and offloading important things such as medicines and oil can have a negative effect on human life and market. Organizations that maintain data are also affected. They are likely to lose their crucial data and state-of-the-art systems because of sudden power outage, incurring a huge loss not only for their companies, but also the centers associated with them. This hampers the provision of quality and timely services to customers. Thousands upon thousands of dollars can be lost in commercial centers that are linked to the stock market due to the process of buying and selling that takes place every moment.

3. Proposed Model to Minimize the Chances of Power System Collapse/Blackout

Aiming to solve problems related to power system collapse/blackouts, the scientists of Oak Ridge National Laboratory United States have discovered a power system blackout model with the name "ORNL-PSerc-Alaska (OPA)". However, a limitation of this model is that the results in simulations are not accurate in terms of the practice for cascading failure and for the outages in the transmission lines. In this regard, an improved OPA model is designed to cater to the limitations of the OPA model. The applications of the designed model can be implemented on a complicated large power system and take into consideration the various aspects of power systems, such as power planning, communication, dispatching, relay protection, automation, and sustainable operation mode. In addition, a qualitative blackout risk assessment is possible in this designed model with the help of Value at Risk (VR) and Conditional Value at Risk (CVR). Risk minimization factors are investigated based on the various choices of VR and CVR. The designed model consists of two loops. The first loop (inner side) simulates the fast dynamics of cascading failure and power flow (power communication, dispatching and relay protection). The second loop (outer side) simulates the slow dynamics of power system evolution (power planning and sustainable operation mode). Normally, one day is taken for the slow dynamics, upon which the fast dynamics are activated. The steps of the designed model are described below:

1. a = 0, starting.
2. Find out load shedding amount through the process of fast dynamics on day "a".
3. If $a = a_{max}$ then stop the program and go back to step number 2. The equation a = a + 1 is used for the slow dynamics. A flow chart of the proposed blackout model is shown in Figure 1.

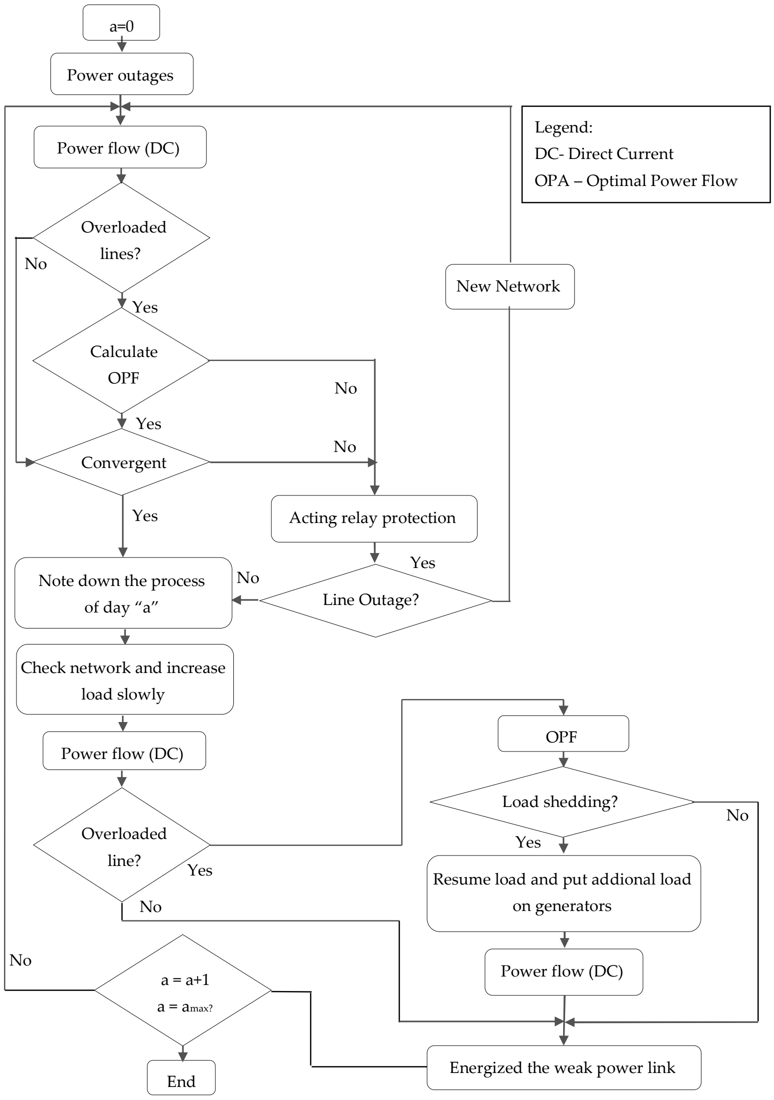

Figure 1. Flow chart of OPA model for power system blackouts.

4. Research Gaps

Some gaps have been identified in the research which will keep causing challenges such as electricity breakdowns in the existing power system in future smart grids if they are not addressed effectively and in a timely manner. These gaps are as follows:

- Required proper planning of the power system protection schemes.
- Increasing protection against cyber issues.
- Study of new protective techniques that are or could be used in technologies using a wide area measurement system (WAMS).
- Control schemes that use online coordination to reduce power outages should be further studied.
- Protective functions that use online coordination and that effect directly the frequency of blackouts should be studied.
- An extensive investigation of the technologies that monitor power-related emergency situations in real time should be carried out so that better decisions can be made in such situations.
- A study of damping coefficient is necessary, as it fluctuates during peak loads. Further study is also needed regarding a renewable energy resource that can not only generate energy extensively but could also supply power evenly during blackouts.

5. Conclusions and Recommendations

Global power system blackouts are reviewed successfully for the purpose of identifying their root causes and their potential impacts on the economic development of countries. One of the major causes of power system collapse is bad weather conditions. Other reasons, including human error, faulty equipment, and overloading, are the main causes of power system blackouts. Weather forecasting and the use of modern control and protection devices would help to achieve stability in power systems. Management of load at peak demand times is also crucial and must engage customers in managing the emergency demand response. Maximizing the use of energy storage devices under peak load demand can reduce such shutdowns. Power system managers and planners need to conduct pre-disturbance studies to prevent emergency situations.

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References

1. Alhelou, H.; Hamedani-Golshan, M.; Zamani, R.; Heydarian-Forushani, E.; Siano, P. Challenges and Opportunities of Load Frequency Control in Conventional, Modern and Future Smart Power Systems: A Comprehensive Review. *Energies* **2018**, *11*, 2497. [CrossRef]
2. September 2011 Southwest Blackout Event. Nerc.com. 2011. Available online: https://www.nerc.com/pa/rrm/ea/Pages/September-2011-Southwest-Blackout-Event.aspx (accessed on 2 August 2021).
3. Chen, Q.; Mili, L. Composite Power System Vulnerability Evaluation to Cascading Failures Using Importance Sampling and Antithetic Variates. *IEEE Trans. Power Syst.* **2013**, *28*, 2321–2330. [CrossRef]
4. Raza, M.; Khatri, K.; Israr, A.; Ul Haque, M.; Ahmed, M.; Rafique, K.; Saand, A. Energy demand and production forecasting in Pakistan. *Energy Strategy Reviews* **2022**, *39*, 100788. [CrossRef]
5. Dobson, I.; Newman, D. Cascading blackout overall structure and some implications for sampling and mitigation. *Int. J. Electr. Power Energy Syst.* **2017**, *86*, 29–32. [CrossRef]
6. Annual Report 2013. Eaton B.T. United States. 2013. Available online: https://www.annualreports.com/HostedData/AnnualReportArchive/e/NYSE_ETN_2013.pd (accessed on 14 July 2022).
7. Raza, M.; Khatri, K.; Memon, M.; Rafique, K.; Haque, M.; Mirjat, N. Exploitation of Thar coal field for power generation in Pakistan: A way forward to sustainable energy future. *Energy Explor. Exploit.* **2022**, *40*, 1173–1196.
8. Raza, M.; Khatri, K.; Rafique, K.; Saand, A. Harnessing Electrical Power from Hybrid Biomass-Solid Waste Energy Resources for Microgrids in Underdeveloped and Developing Countries. *Eng. Technol. Appl. Sci. Res.* **2021**, *11*, 7257–7261.
9. Raza, M.; Khatri, K.; Hussain, A. Transition from fossilized to defossilized energy system in Pakistan. *Renew. Energy* **2022**, *190*, 19–29. [CrossRef]
10. Raza, M.; Khatri, K.; Ul Haque, M.; Shahid, M.; Rafique, K.; Waseer, T. Holistic and scientific approach to the development of sustainable energy policy framework for energy security in Pakistan. *Energy Rep.* **2022**, *8*, 4282–4302. [CrossRef]
11. Haes Alhelou, H.; Hamedani-Golshan, M.; Njenda, T.; Siano, P. A Survey on Power System Blackout and Cascading Events: Research Motivations and Challenges. *Energies* **2019**, *12*, 682. [CrossRef]
12. Hunt, J.; Stilpen, D.; de Freitas, M. A review of the causes, impacts and solutions for electricity supply crises in Brazil. *Renew. Sustain. Energy Rev.* **2018**, *88*, 208–222. [CrossRef]
13. *From Subsidy to Sustainability: Diagnostic Review of Sudan's Electricity Sector*; The World Bank: Washington, DC, USA, 2019. Available online: https://openknowledge.worldbank.org/bitstream/handle/10986/33702/From-Subsidy-to-Sustainability-Diagnostic-Review-of-Sudan-Electricity-Sector.pdf?sequence=1&isAllowed=y (accessed on 14 July 2022).
14. Lucas, A. Confected conflict in the wake of the South Australian blackout: Diversionary strategies and policy failure in Australia's energy sector. *Energy Res. Soc. Sci.* **2017**, *29*, 149–159. [CrossRef]