Super typhoon Yagi's impact on power systems and insights for enhancing system resilience

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THE STRONGEST TYPHOON IN AUTUMN

On September 6, Typhoon Yagi made landfall in the coastal area of Wenchang City, Hainan Province, marking the strongest autumn typhoon in China since 1949. At the time of landfall, the wind speed near the center reached level 17 (62 m/s). After traversing through Wenchang City and entering Haikou City, the typhoon exited Hainan Island at 4:12 AM on September 7. The intense winds and heavy rainfall inflicted severe damage on various types of infrastructure, including electrical equipment. Consequently, water supply, communication, and power supply were disrupted in Wenchang, Haikou, and other areas, prompting the entire Hainan Province to declare a state of emergency.

DAMAGE TO POWER SYSTEMS

Typhoon Yagi inflicted significant damage on the energy system, with the power system experiencing the most severe impact. The interruption of power supply to numerous users severely disrupted daily life and production activities. The excessive wind speed, turbulence, and heavy rainfall associated with the typhoon compromised the operation of generators, transformers, and power lines, leading to short circuits and seriously causing permanent equipment damage.

Typhoon Yagi significantly impacted the operation of various types of power plants. In thermal power plants, it caused damage to equipment such as transformers or lead to water supply interruptions, both of which may result in a substantial loss of power generation capacity. In recent years, China has been rapidly developing new energy sources, including wind power and photovoltaics, to facilitate the low-carbon transformation of the energy system. However, the typhoon's effects were particularly pronounced in areas where these new energy projects are underway. For instance, several onshore

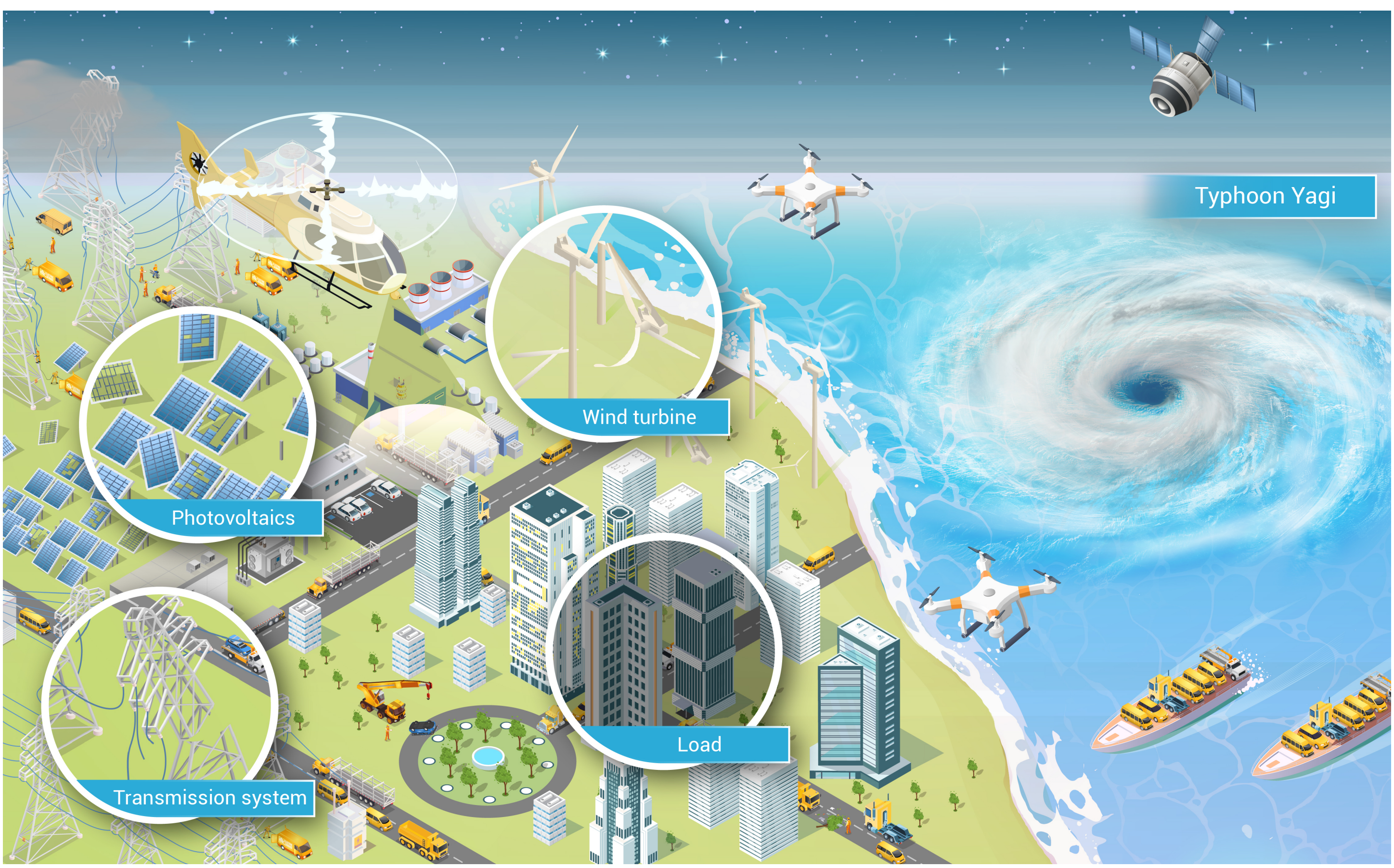

Figure 1. Facilities repair and system restoration following the typhoon's passage

wind turbines are under construction near Yulan Bay in Wenchang City, the typhoon's landing site. The wind farm, located near the landing point of Typhoon Yagi, suffered significant damage. Since the project had not yet been energized, the yaw system was not operational, and the anti-typhoon strategy could not be implemented, resulting in the collapse of eight 6.25 MW wind turbines due to lateral wind forces. Furthermore, photovoltaic power stations in Wenchang, Xuwen, and other regions were also adversely affected. The most direct impact of the typhoon on these stations was the severe oscillation of components, which made each connection vulnerable to the typhoon's force, leading to the detachment or destruction of photovoltaic panels. Additionally, the typhoon may have caused internal cracks, short circuits, and other detrimental effects on the photovoltaic systems.

The impact of typhoons on transmission and distribution networks is more severe than their effect on power supply systems. The primary mechanism of disaster involves typhoon wind speeds exceeding the maximum design wind speed of infrastructure components, leading to structural failures, particularly in towers and overhead lines. The mechanical stress and severe vibrations caused by strong winds can result in tower collapses, short circuits, disconnections of overhead lines, and transformer failures. For instance, Typhoon Yagi significantly affected the main transmission network in Hainan Province, with 68 towers with voltage levels of 110 kV and above were damaged. Furthermore, the damage to the distribution network was extensive, with 61,487 towers operating at voltage levels of 35 kV and below being affected. Additionally, 14,203 kilometers of transmission lines sustained damage. The impact extended to 28,220 distribution transformers, which directly serve users, were shut down, accounting for 63.94% of the total, leading to substantial power outage losses and increased repair demands. These power outages further disrupt the normal operation of communication, water supply, and gas supply systems. In Wenchang, the most severely affected city, the power failure rate of communication base stations reached 82.3%, and 8 out of 11 water plants suspended water supply due to power outages, resulting in significant economic and social impacts on the region. Figure 1 illustrates the post-disaster power grid recovery process.

IMPROVEMENT PATH OF POWER SYSTEM RESILIENCE

According to the China Meteorological Administration, an average of 7 to 8 typhoons make landfall on the Chinese mainland each year between 1949 and 2023. The rapid increase in sea surface temperature and sea level has diminished the South China Sea's capacity to buffer against these typhoons.[1] Consequently, coastal provinces along the South China Sea have experienced an elevated risk of typhoon-related impacts in recent years. Therefore, it is crucial to investigate strategies for enhancing the resilience of the power systems and mitigating the effects and damage caused by super typhoons, such as Yagi, on the power systems.

To enhance the resilience of power systems against typhoons, both long-term planning measures and short-term adjustment strategies should be implemented.[2] In terms of long-term measures, replacing critical and vulnerable overhead transmission and distribution lines with cables can significantly reduce the risk of collapse during typhoons.[3] Additionally, enhancing the typhoon resistance of new energy units is crucial. Increasing energy storage capacity and incorporating Flexible AC Transmission Systems (FACTS) can further improve the reliability of power supply to essential loads and enhance the system's power flow adjustment capabilities. On the other hand, short-term strategies should be informed by meteorological predictions and typhoon path analyses to develop tailored planning and disaster prevention plans. This involves optimizing the load distribution in anticipation of the predicted typhoon path and affected areas. Furthermore, it is essential to reserve adequate emergency repair equipment and materials in advance and to optimize protective measures in critical areas. Trimming vegetation that is prone to collapse around power lines can also enhance the grid's preventive measures and rapid response capabilities.

During the process of a typhoon making landfall and moving, it is crucial for the emergency center to dynamically assess the fault risk of power grid components. This assessment should be based on the multi-time scale prediction data provided by the meteorological department. Consequently, the emergency plan for power grid operations must be updated in real-time, incorporating measures such as adjusting the grid's operational mode,[4] implementing under-frequency load shedding, and executing controlled islanding. New energy sources, particularly wind turbines, are highly susceptible to typhoon impacts. Therefore, a differentiated and grouped orderly tripping scheme for these new energy units should be developed. This scheme should consider the typhoon's path, wind field position, wind circle range, and duration of influence to prevent sudden large fluctuations in system power and frequency instability. Additionally, the operation mode of various units in key areas should be arranged according to the principle of regional balance, maintaining 'spark power supply', and preparing for a black start in the event of a complete shutdown of the entire island grid. Historical events underscore the importance of these measures, Typhoon Damrey of 2005 caused a total blackout of the Hainan power grid, and the landfall intensity, wind speed, and extreme rainfall of Typhoon Yagi even exceeded those of Damrey.

After the typhoon has passed, the focus shifts to the efficient and coordinated development of emergency repairs for disaster-affected equipment and the functional recovery of transmission and distribution systems. Temporary support for critical lifeline loads should be provided by distributed energy sources and mobile power vehicles. For high-voltage transmission networks, it is essential to devise a repair resource allocation scheme and a coordinated system power supply restoration plan. This should be approached from a global perspective, considering the restoration income of the entire system, and the operation mode should be updated in a rolling manner to ensure the safe and stable operation of the transmission system with time-varying topology[5] and the orderly pickup of power loads. Technologies like UAV-based disaster surveys and satellite communication enable real-time disaster assessments and precise identification of repair sites. The swift restoration of power supply depends on the optimal allocation of emergency repair resources, such as personnel, vehicles, emergency power generation vehicles, and helicopters. To effectively mitigate the impact of secondary natural disasters, such as strong winds, rainstorms, storm surges, floods, landslides, and mudslides, that often follow extreme typhoons, it is essential to focus on the restoration of systems and the collaborative repair of equipment. From the perspective of a secondary disaster chain, this approach is particularly crucial when considering the interconnected nature of multi-type power supplies, power loads, power grids, and even communication systems.

By September 28, Hainan had successfully restored electricity in the areas affected by Typhoon Yagi. Tropical storms are not a specialty of Asia. Shortly thereafter, on October 9, Hurricane Milton struck Florida, resulting in power outages for at least 3.2 million people. Afterwards, in less than a month, Hurricanes Rafael and Oscar both caused significant Cuba's nationwide blackout just 200 kilometers from Florida. From a resilience perspective, it is never too early to conduct assessments and summarize experiences after extreme disasters in preparation for potential risks in the coming year. Enhancing the power system's resilience to severe tropical storms is a crucial long-term challenge for humanity.

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DECLARATION OF INTERESTS

The authors declare no competing interests.