RESEARCH

Resilience in the Age of Connected Infrastructures: Preventing Cascading Disruptions

Researchers explore how traffic disruptions can put unexpected strain on the power grid, and how EV charging at workplaces and offices can be a compelling solution for greater grid stability amid increasing solar penetration.

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As cities increase the adoption of electric vehicles (EVs) and solar energy, new challenges arise at the intersection of urban and energy infrastructure. A recent study by researchers at the Future Resilient Systems programme (FRS) at the Singapore-ETH Centre explores how **traffic disruptions** can put unexpected **strain on the power grid**, and how **EV charging at workplaces** and offices can be a compelling solution for **greater grid stability** amid increasing solar penetration. Their findings include actionable strategies to manage hidden risks and ultimately ensure resilience across interconnected systems.

– Previously, FRS researchers have highlighted the **stress to EV charging infrastructures** due to **concurrent EV arrivals** after a disruptive event[1], and proposed solar powered carparks[2] as a possible solution to increase the sustainability and reliability of EV charging infrastructures.

– This study complements their findings by analysing the **impact** of **accident-induced congestion** on solar-powered **workplace EV charging**.

– Simulations show that **major accidents** can cause a **sharp increase in power costs** – but integrating **real-time accident alerts** can help significantly **reduce** these **unexpected costs** by **up to 50 percent**.

– Maintaining **10%-15% additional charging capacity** enables EVs to still retain their function as a **buffer to absorb shocks to the grid**, even when multiple vehicles arrive at charging stations at the same time due to major highway accidents.

The Risk of Cascading Disruptions

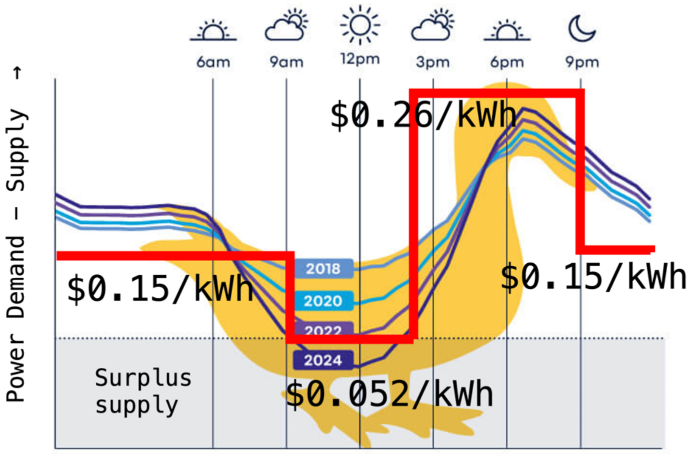
Urban infrastructures are becoming increasingly interconnected, elevating the risk of cascading disruptions. A road accident, for instance, can trigger a surge in workplace EV charging demand if delayed vehicles arrive all at once. In such cases, even the best power pricing models or charging schedules may fail, causing unexpected strain on the grid and increased costs for everyone involved.

This study uses large-scale, data-driven simulations based on a dataset from Minneapolis, USA, to examine how traffic accidents on freeways affect EV charging, and how cities can buffer against these unexpected impacts. As expressways constitute a large proportion of Singapore's road network, rerouting after an expressway accidents is extremely challenging. Given Singapore's similarities to Minneapolis in terms of its dense highway and transport networks, the insights from this study prove highly applicable to the Singapore context.

Why Workplace Charging Matters

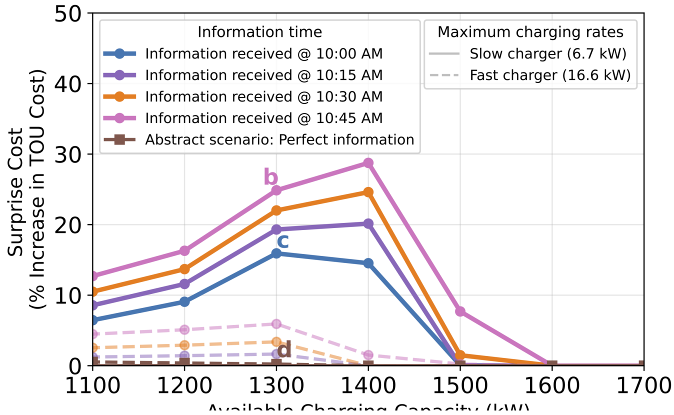
Electric vehicles are a fundamental lever for the global transition to low-carbon transport systems. However, they remain so insofar as:

(a) they **do not strain the grid** and inadvertently **drive up charging costs** and
(b) are as **green as the power that charges them**.
Currently, most EV charging takes place overnight, which presents a missed opportunity to capitalise on the abundance of cheap, surplus solar energy available during the day. Workplace charging offers a promising solution to this mismatch. By encouraging daytime charging, it can help stabilise the grid and reduce the midday energy surplus known as the *duck curve*.



Electricity prices vary during the day, with solar power becoming increasingly cheaper year-on-year during periods of peak sunlight.

Additionally, the integration of previously independent systems (specifically, transport infrastructure and the power grid) creates a need for inter-infrastructure contingencies for "shock absorption". This ensures that systems remain resilient to cascading disruptions across systems.
Simulations for Real-World Conditions
The study models real-life urban conditions in Minneapolis—a city with a high reliance on private car travel—to examine how traffic incidents can disrupt EV charging patterns. By simulating a wide range of accident scenarios with varying severity, timing, and clearance durations, the research captures the complex interplay between transport disruptions and power grid stress.
While based on Minneapolis data, the findings are highly applicable to Singapore, where a high percentage of highway travel and a national push toward full EV adoption by 2030 create similar interdependencies and vulnerabilities.
To explore solutions, the team focused on workplace EV charging as a key lever for grid stability in an era of growing solar power. They developed a scalable **Cell Transmission Model (CTM)** based on Open Street Maps to simulate detailed traffic dynamics, and integrated it with **ACN Sim ↗** from Caltech to model EV charging operations. Using this coupling of simulators, the researchers were able to assess how disruptions in traffic flow influence electricity demand in real-time. The pipeline is open-sourced for the EV research community, and a **user-friendly web demo ↗** based on a lightweight version of the simulator is available for all other stakeholders.
Together, these tools offer a robust platform for understanding and mitigating cascading disruptions between urban transport and energy infrastructures.
While optimisation is essential for efficiency, over-optimising across interconnected systems can create unintended vulnerabilities. When tightly coordinated systems—such as traffic flow and EV charging are disrupted by unexpected events like a highway accident, the results can be destabilising.
For example, a simulated 10AM accident near a downtown district in the city of Minneapolis led to a wave of EVs arriving simultaneously once the road was cleared, which then overwhelmed charging infrastructure. In such scenarios, some vehicles risk being undercharged, while the microgrid itself may face unprecedented strain.



Available Charging Capacity (kW)

An accident was simulated on the highway leading to the downtown office area of the city of Minneapolis, USA. The accident occurs at 10AM and lasts 45

minutes before it is fully cleared. This figure shows the surprise costs due to impact of concurrent arrivals of EVs.

Key Recommendations

Given the governmental push for sustainable energysolutions by leveraging the high solar insolation in Singapore[3] , this study presents a strong case for smart-charging based workplace EV charging infrastructures that can leverage cheaper and sustainable electricity during mid-day.

To reduce risk and ensure resilience in future-ready cities, the study recommends:

1. **Integrating real-time traffic data** into charging operations to anticipate and respond to demand shocks
2. **Building a 10–15% capacity buffer** compared to historical average workday to absorb unexpected peaks
3. **Deploying fast-charging solutions** to quickly serve delayed vehicles
4. **Using subscription-based pricing models** to protect EV users from unforeseen events beyond their control

Toward Smarter, Safer Systems

As the boundaries between transport and energy systems blur, urban resilience will increasingly depend on our ability to anticipate and manage cross-domain disruptions. This study demonstrates that workplace EV charging, when intelligently designed and supported by real-time data, can serve as a powerful buffer—both absorbing shocks from traffic events and stabilising the grid in an era of rising solar energy use.

By adopting the strategies outlined in this research, cities such as Singapore can ensure that their clean energy future is also a resilient one.

Full study available here: https://www.sciencedirect.com/science/article/pii/S1361920925002792?via%3Dihub ↗

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