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Risk assessment of electrical power systems considering traffic congestion

Introduction

Electrified vehicles (EVs) are a promising technology for effectively relieving the environmental crisis and resources shortage [1,2]. The advantages offered by electrified vehicles is attracting more and more the attentions of governments and policies have been initiated to promote the use of EVs [3]. However, the sharp increase of charging demands of EVs is posing challenges to the existing electricity infrastructures. Especially, the advancement of EV battery and wireless charging technologies [4] further popularize the EVs and bring new threats to the stability of the power system.

Modelling

Transportation system -- Cell transmission model

$$n_i(t+1) = n_i(t) + f_i(t) - f_{i+1}(t)$$

Power system -- AC power flow model

$$PW^G_{k,t} - PW^B_{k,t} - PW^D_{k,t} = \sum_{j=1}^{N} |V_{k,t}||V_{j,t}|\left(G_{kj}cos(\theta_{k,t} - \theta_{j,t}) + B_{kj}sin(\theta_{k,t} - \theta_{j,t})\right)$$

EV charging demand

$$PW^D_{k,t} = \sum_{m=1}^{M}\sum_{n=1}^{N} \alpha \cdot r \cdot n_{m,n}(t)$$

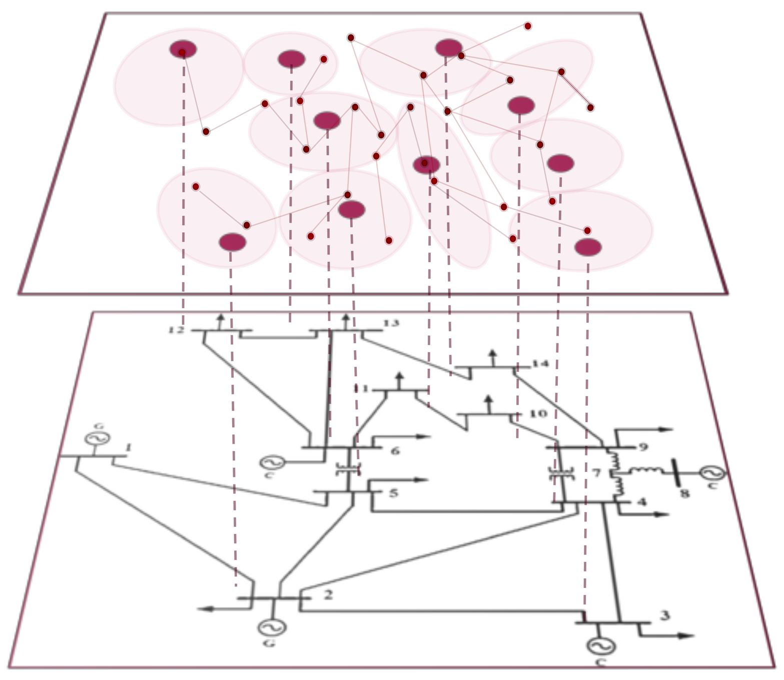


Fig. 1. The integrated systems.

Risk analysis

Modelling a traffic incident

Characteristics of an incident:

Incident duration d: the time period between the onset of incident and clearance of the incident.

Hazard based log-logistic distribution: $f(d) = \frac{(\lambda P)(\lambda d)^{P-1}}{1+(\lambda d)^P}$

Capacity reduction Q^p: the available capacity after an incident.

The doubly truncated normal distribution:

$$f_{DTN}(Q^p) = \begin{cases} 0 & Q^p < 0 \\ \dfrac{(Q^p)}{\int_0^Q f(Q^p)\cdot dQ^p} & 0 \le Q^p < Q \\ 0. & Q \le Q^p \end{cases}$$

Occurrence time**:** the time when an incident start

Post-incident duration d_p: the time period between when the incident is cleared and when all of the delayed vehicles have flowed out the road network.

Observation duration T: incident duration + post-incident duration ($T = d + d_p$)

Severity quantification

The severity of the consequences on the power system is formulated as:

$$\max_{t\in T}(Sev_t(d, Q^p|C_i)) = \max_{t\in T}\left(\sum_b SevOL_{b,t}(d, Q^p|C_i)\right) + \max_{t\in T}\left(\sum_k SevLV_{k,t}(d, Q^p|C_i)\right)$$

Severity of low voltage :

$$SevLV(V_k) = \begin{cases} \dfrac{0.95 - V_j}{0.95}, & V_k \le 0.95 \\ 0, & V_k > 0.95 \end{cases}$$

severity of overload:

$$SevLV(V_k) = \begin{cases} \dfrac{0.95 - V_j}{0.95}, & V_k \le 0.95 \\ 0, & V_k > 0.95 \end{cases}$$

References

- [1] R. Sioshansi, R. Fagiani, and V. Marano, “Cost and emissions impacts of plug-in hybrid vehicles on the ohio power system,” *Energy Policy*, vol. 38, no. 11, pp. 6703–6712, 2010.
- [2] T. R. Hawkins, O. M. Gausen, and A. H. Strømman, “Environmental impacts of hybrid and electric vehiclesa review,” *The International Journal of Life Cycle Assessment*, vol. 17, no. 8, pp. 997–1014, 2012.
- [3] C. E. M. IEA, E. V. Initiative, *et al.*, “Global ev outlook 2017.” https://www.iea.org/publications/freepublications/publication/GI obalEVOutlook2017.pdf, 2017.
- [4] M. Yilmaz and P. T. Krein, “Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles,” *IEEE Transactions on Power Electronics*, vol. 28, no. 5, pp. 2151–2169, 2013.

Numerical Example

Simulation procedures

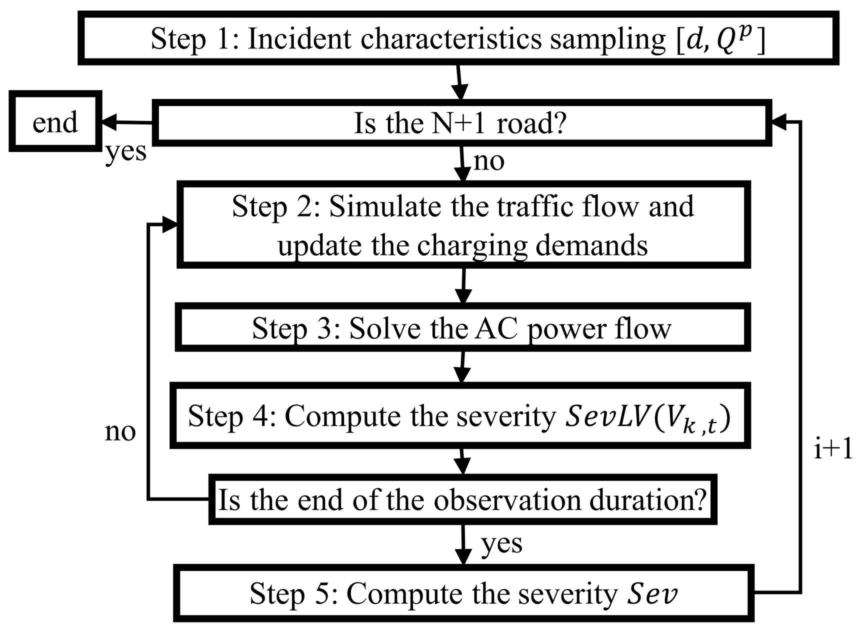
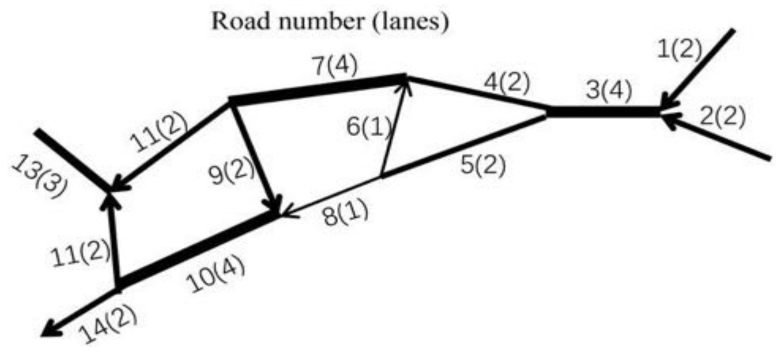
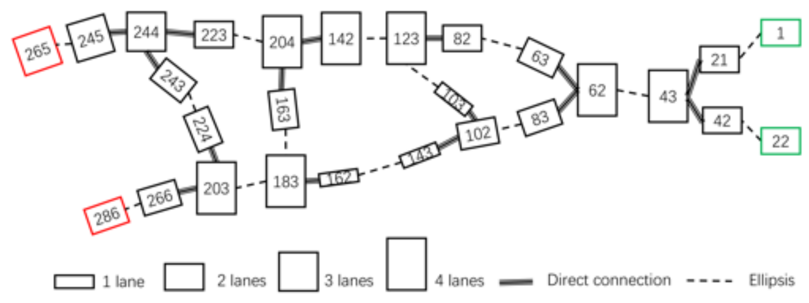


Fig. 2. Flow chart of a single MC run.

(a) A part of national highway system of New York State.



(b) Extracted topological structure of



(c) Cell representation of the study network

Figure 4: The test transportation network

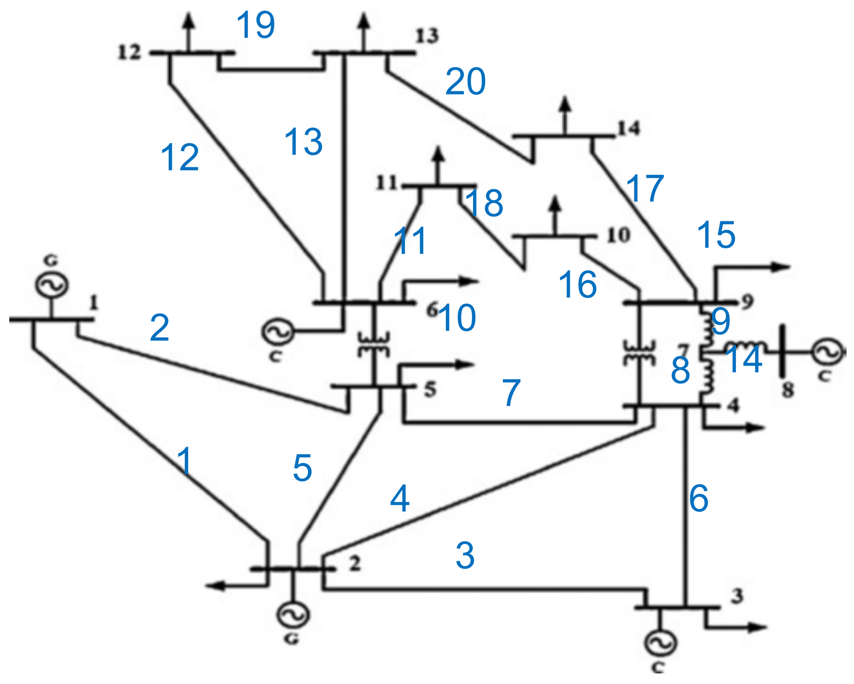


Figure 3: IEEE 14-bus system model

Results and conclusion

EV penetration

Increasing penetration of EVs, as expected, more negative impacts on power system would be cased including more severe extend of low-voltage and line overload problems and more bus and branches being involved in such problems.

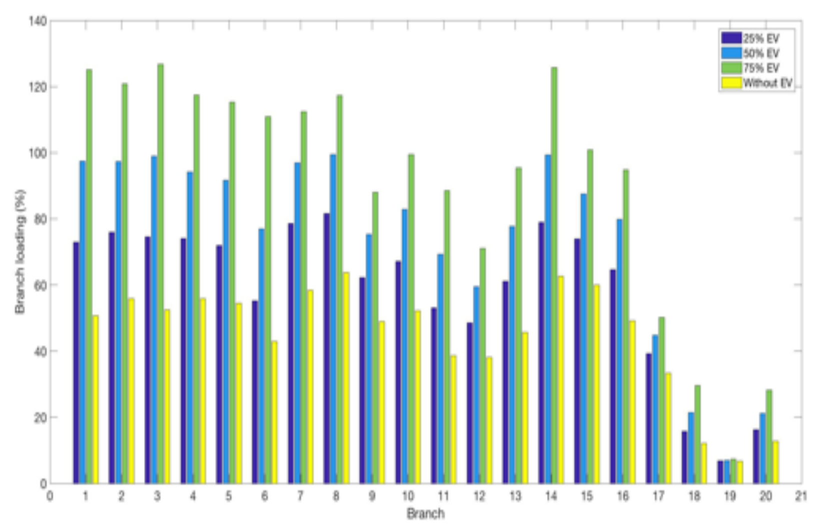


Figure 5: Branch loadings at the peak load times.

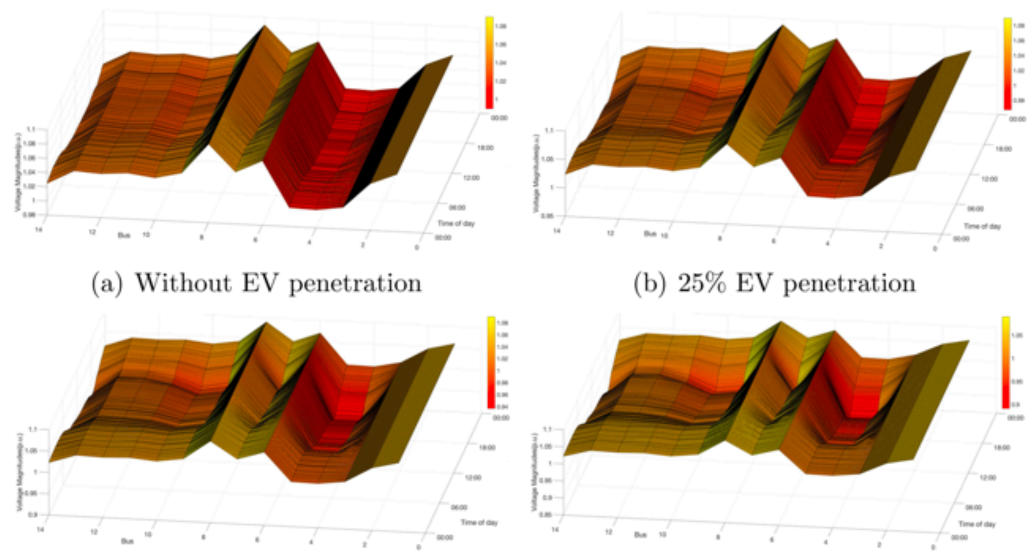


Figure 6: Nodal voltage magnitudes of bus bars

Occurrence time

Traffic incidents happening around the peak time would cause more severe severity of low voltage and of overload.

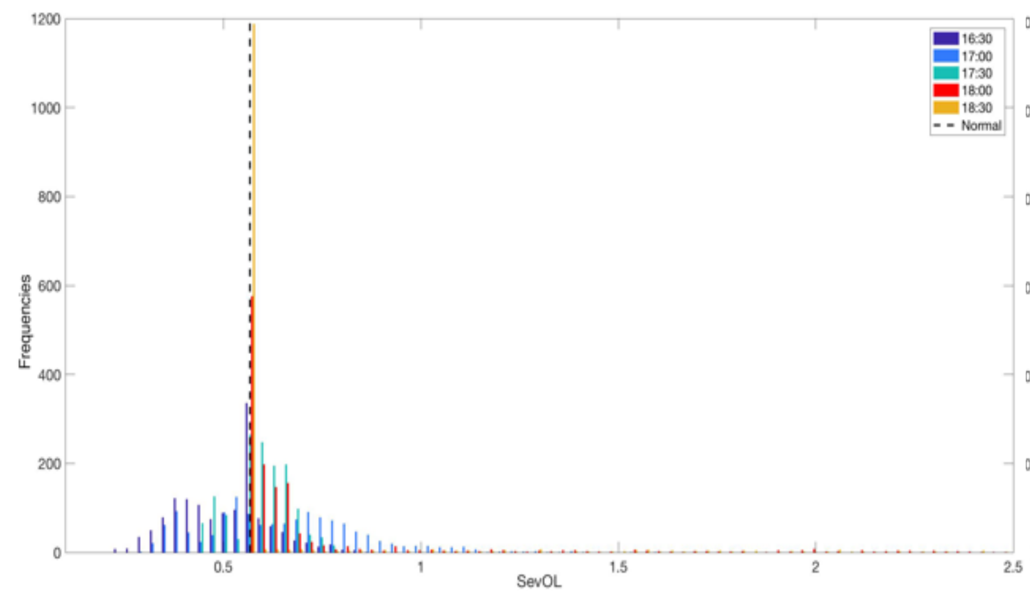


Figure 7: The distribution of *SevOL* at different occurrence time

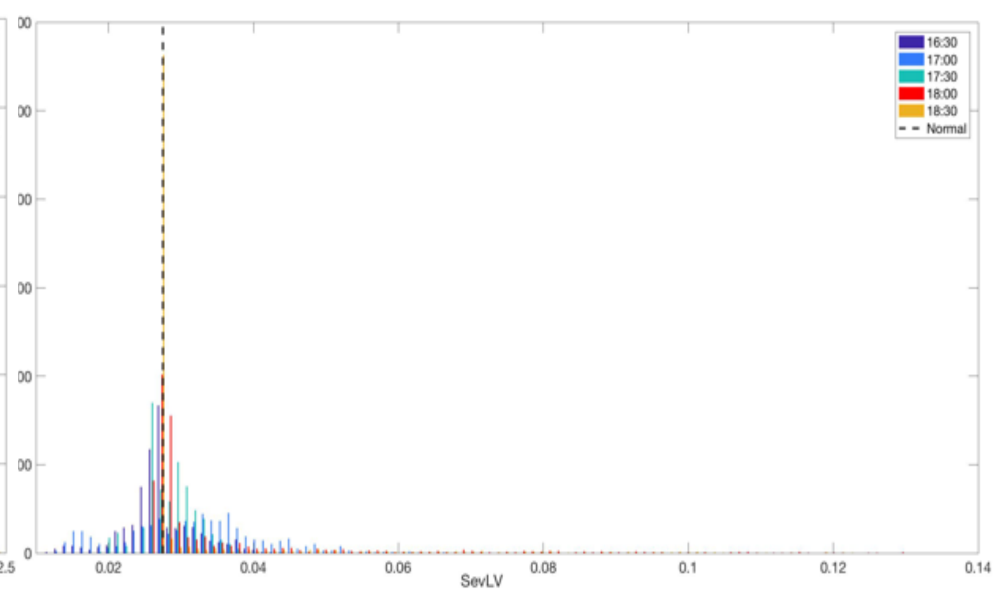


Figure 8: The distribution of *SevLV* at different occurrence time

Location of traffic incidents

Traffic incidents happened on exit roads and roads with high flow rate cause more severe consequences (of low voltage and line overload).

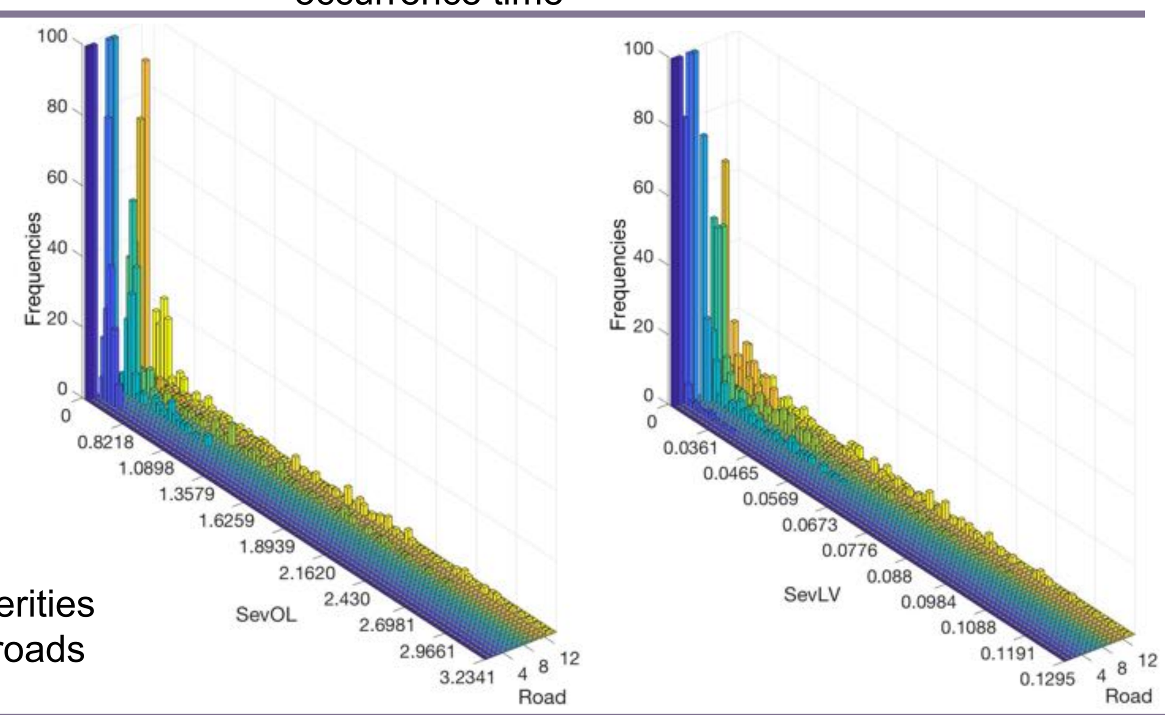


Figure 9: Distributions of the severities with traffic incidents on different roads