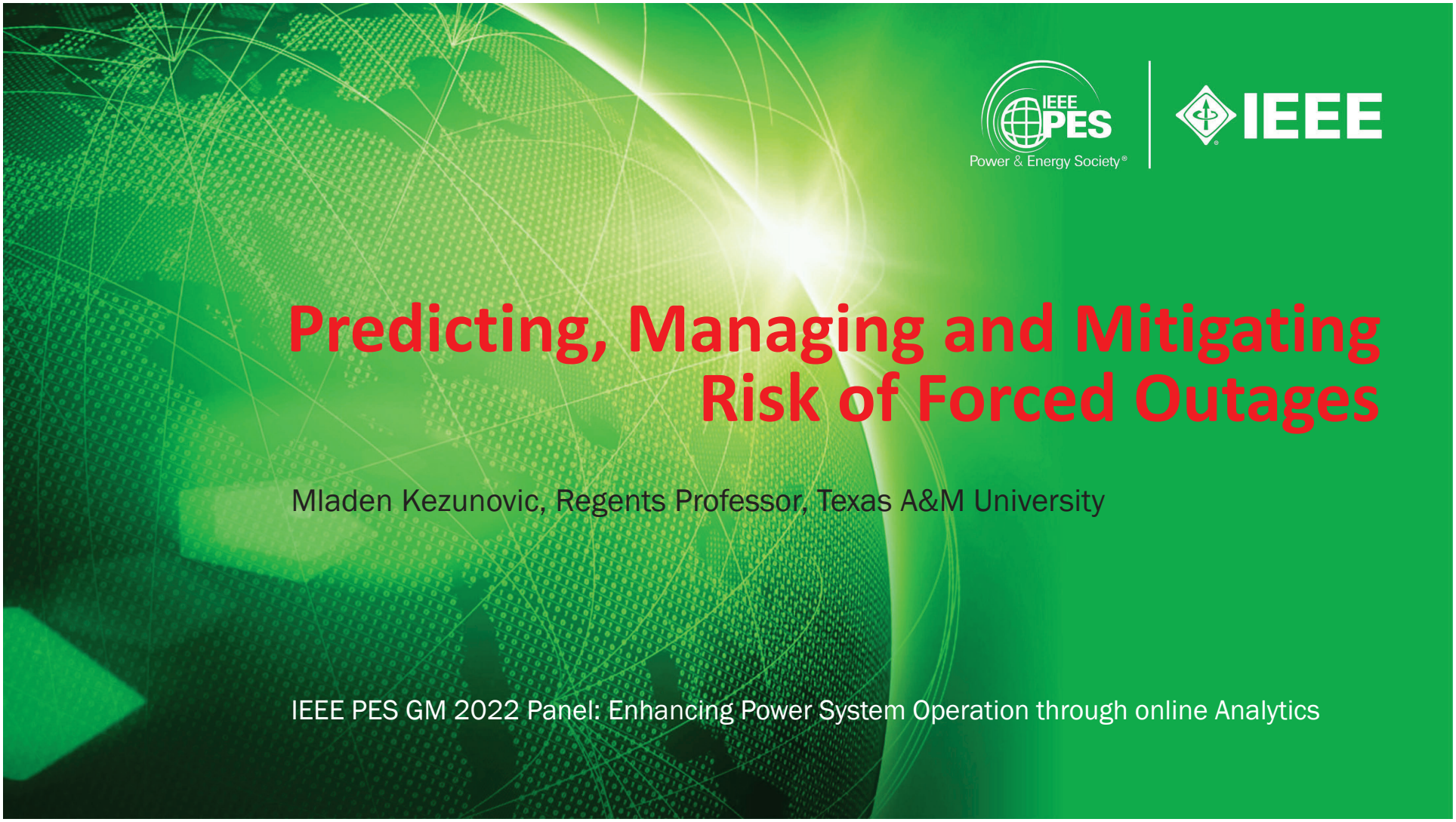


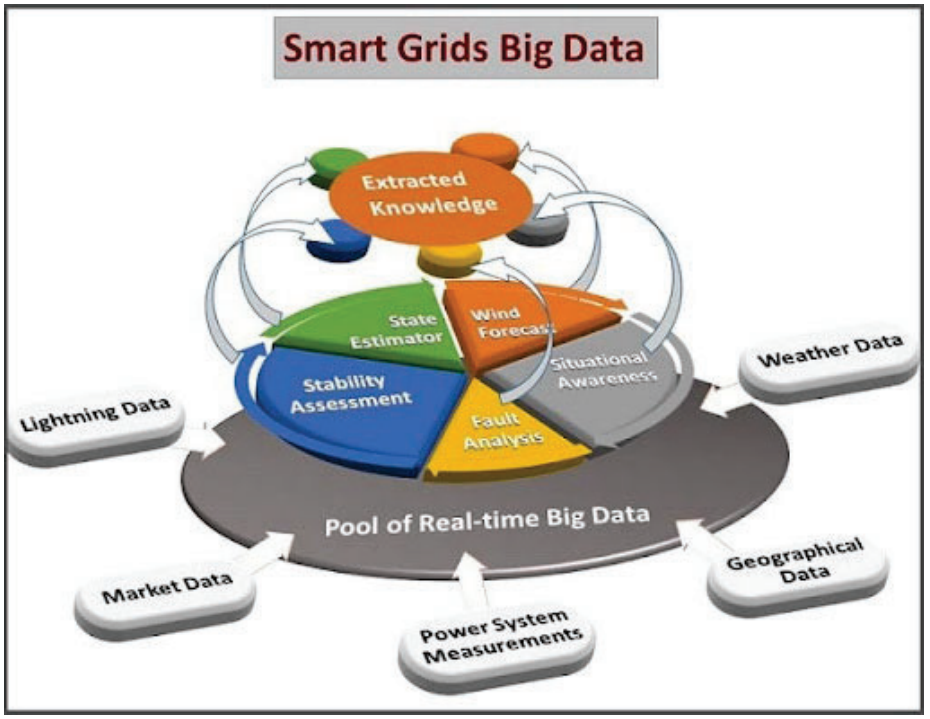
Predicting, Managing and Mitigating Risk of Forced Outages

Mladen Kezunovic, Regents Professor, Texas A&M University

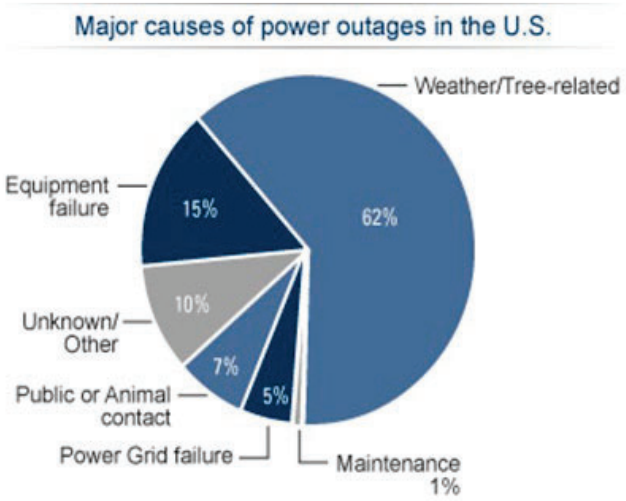
IEEE PES GM 2022 Panel: Enhancing Power System Operation through online Analytics

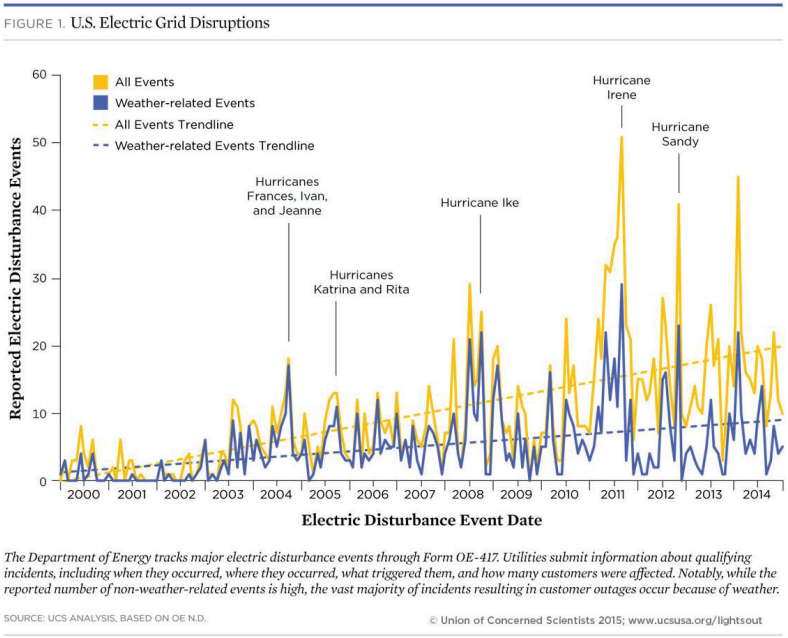
Outline

- ***Outages:*** how do they occur and what is their impact?
- ***State of Risk (SoR) Predictions***: Why the outage risk assessment matters
- ***Example #1***: SoR Prediction and management of component outages
- ***Example #2***: SoR prediction and management of system-wide outages



Outage causes, weather in particular

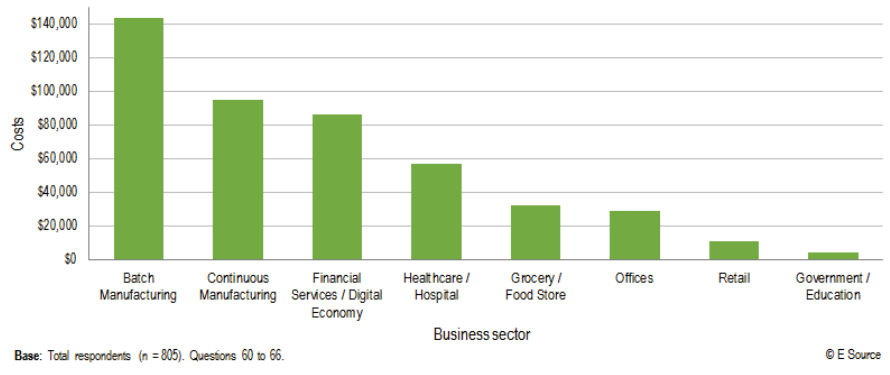


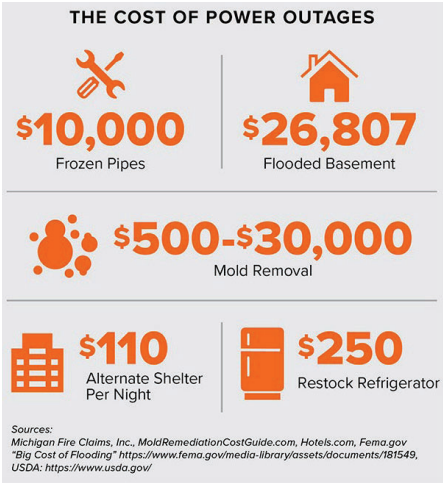


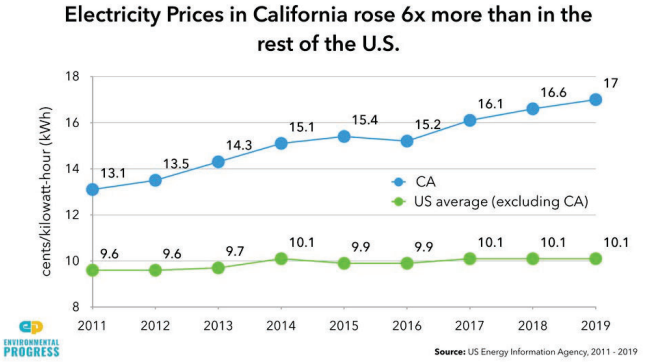
M. Kezunovic and T.J. Overbye, "Off the Beaten Path: Resiliency and Associated Risk," IEEE Power and Energy Magazine, Vol. 16, No. 2, March/April 2018

Outage Impacts

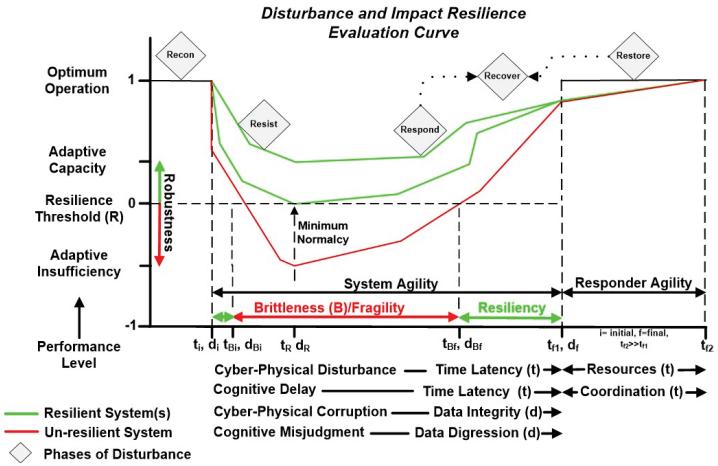
Scenario	Damage	Estimated Cost (USD)	Customers Effected	Typical Outage Duration
Low Impact	• Blown single phase Sectionalizing Fuse on the circuit • Recloser Operation	0 – $250	Less than 50 residential customers	**Fuse:** 1 hour or less **Recloser:** Momentary
Moderate Impact	• Recloser Lockout • Blown 3 phase Sectionalizing Fuse on the circuit (requires a patrol)	$100 – $500	50 – 500 customers	1 – 2 hours
High Impact	*Moderate Substation Damage* • Damaged Circuit Breakers • Damaged equipment bushings, warped bus work	$10,000 – $100,000	500 – 2500 customers	1 day – 1 week
Catastrophic Impact	*Heavy substation damage* • Requiring major reconstruction or long lead time item replacement	$100,000 – $1M+	2500 or greater	Multi day or greater
Catastrophic Plus Impact	*Major or Complete Rebuild* • Requiring major reconstruction or long lead time item replacement such as regulators and transformers, maybe taking years before complete restoration	$1M+ and greater	2500 or greater	Weeks to Months

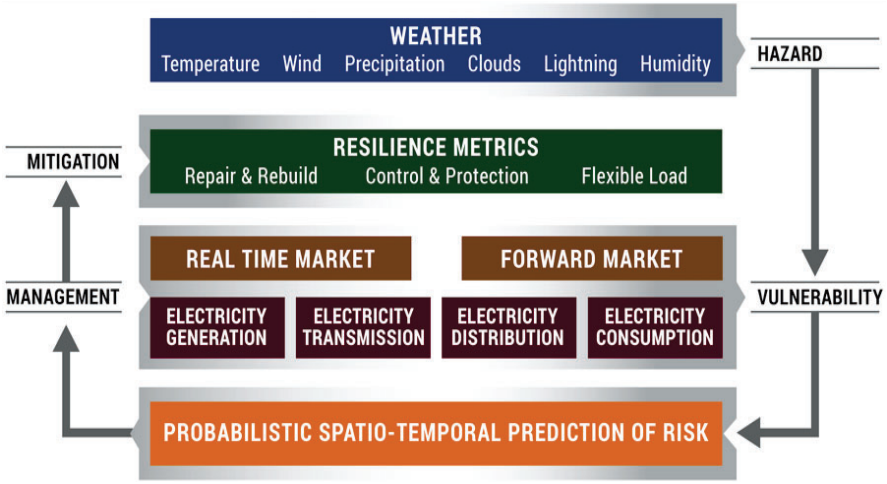






Improving resilience through risk prediction

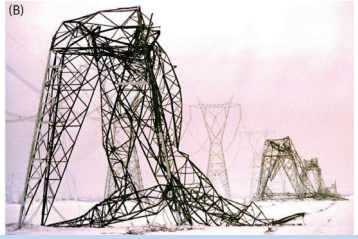


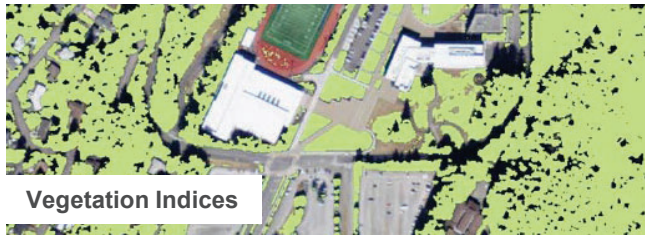


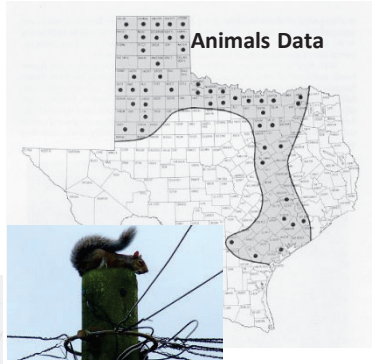
T. Mc. Junkin, C.G. Rieger, "Electricity distribution system resilient control system metrics." 2017 Resilience Week, Workshop Proceedings, Idaho National Laboratory, September 2017

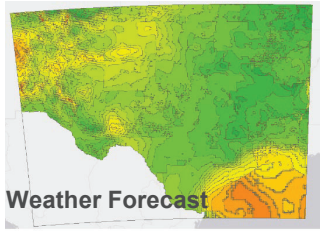
M. Kezunovic, Z. Obradovic, T. Dokic, B. Zhang, J. Stojanovic, P. Dehghanian, and P. -C. Chen, "Predicting Spatiotemporal Impacts of Weather on Power Systems using Big Data Science," Pedrycz, Witold, Chen, Shyi-Ming (Eds.), Springer Verlag, Data Science and Big Data: An Environment of Computational Intelligence, ISBN 978-3-319-53474-9, 2017.

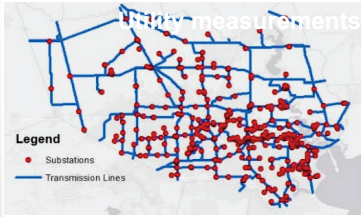
Correlation between the outage causes and related data



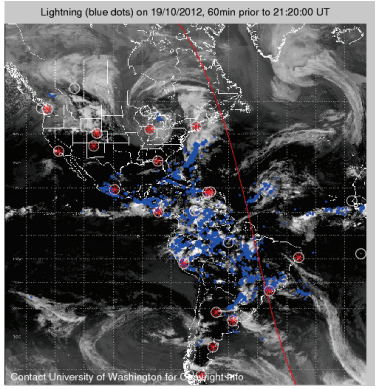








Network Assets



M. Kezunovic, L. Xie, S. Grijalva, "The Role of Big Data in Improving Power System Operation and Protection," Bulk Power System Dynamics and Control Symposium, Rethymnon, Greece, August 2013.

Weather Driven Risk Analysis

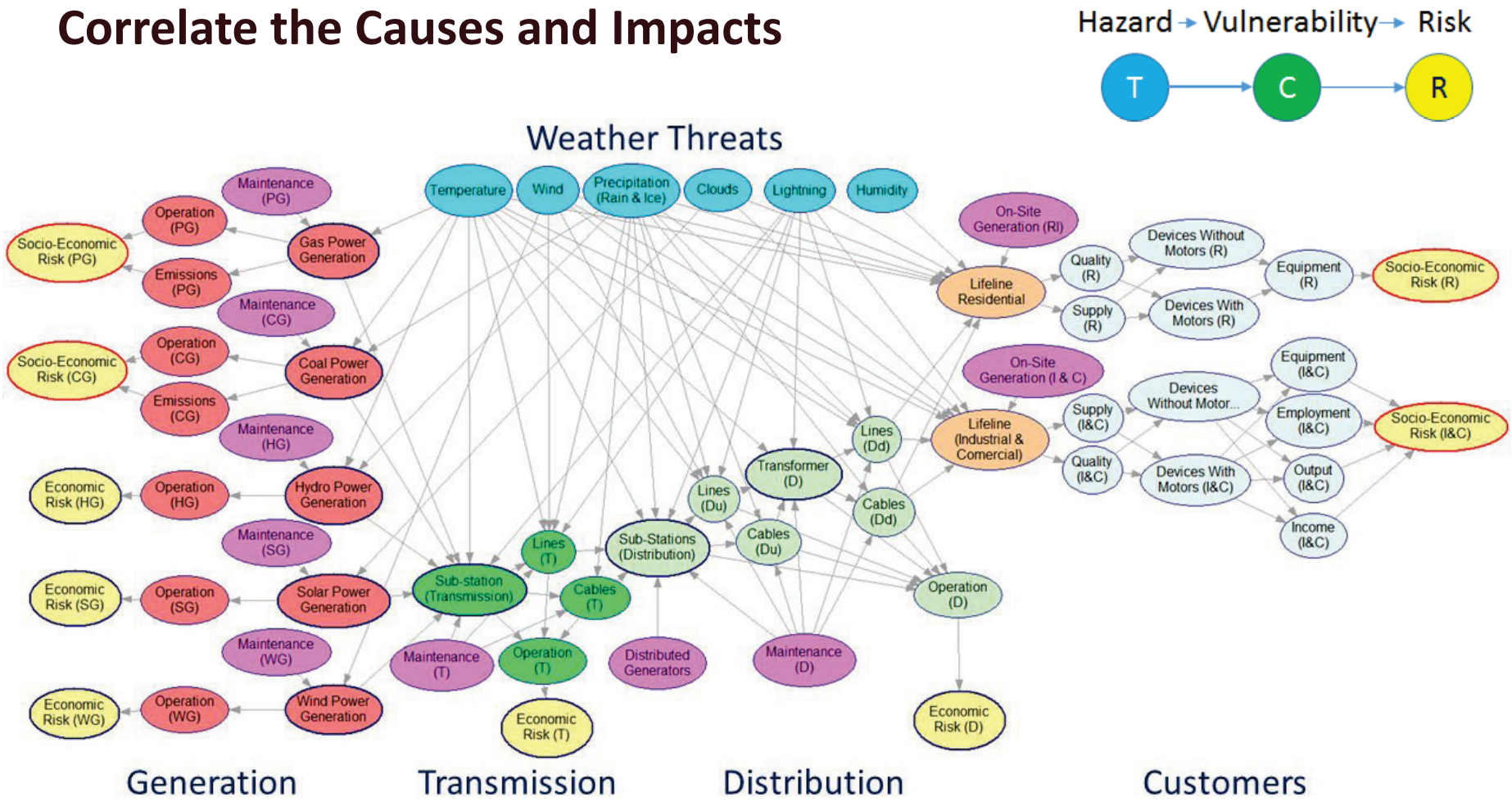
State of Risk = Hazard x Vulnerability x Economic Impact

- Probability of hazardous weather conditions
- Depends on *Weather Forecast*
- Pick a moment in time (or a period of time) and estimate probability of hazardous conditions

- Probability that hazardous conditions will cause an event in the network
- Depends on *Historical Weather and Outage Data*
- Learn from the historical data what may happen if hazardous conditions occur

- Expected economic impact in case of an event
- Depends on the type of economic loss that the user wants to consider
- Identify type of economic loss that is of interest for the study and calculate it

Correlate the Causes and Impacts

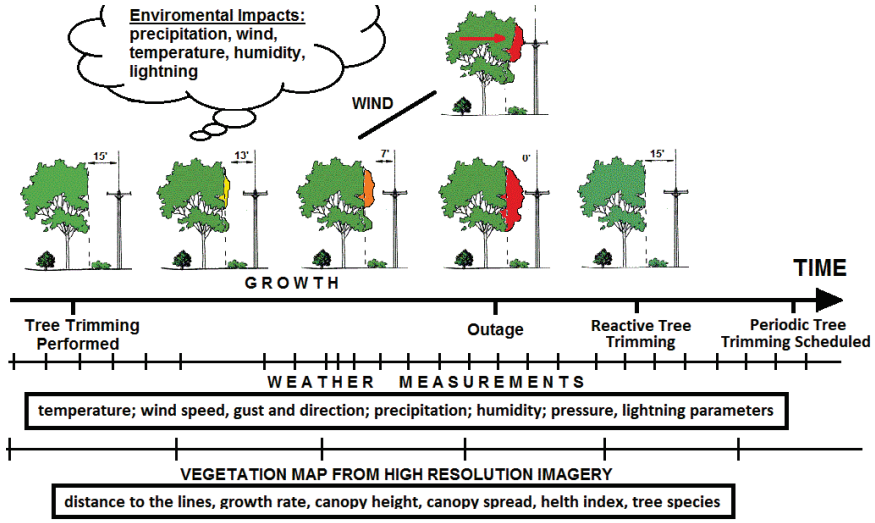


Example #1: SoR Prediction and management of component outages

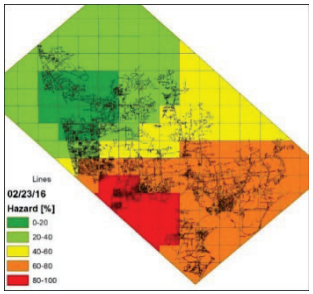
Example #2: SoR prediction and management of system-wide outages

M. Kezunovic, P. Pinson, Z. Obradovic, S. Grijalva, T. Hong, and R. Bessa, "Big Data Analytics for Future Electricity Grids," Electric Power Systems Research, Vol. 189, No., pp. 106788, 2020.

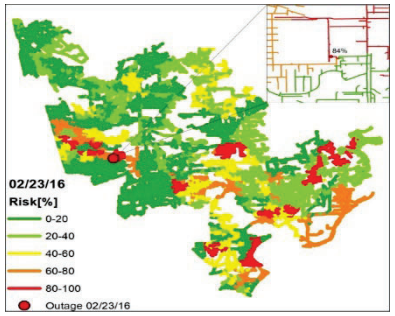
Example #1:Prediction of Outages due to Distribution Vegetation



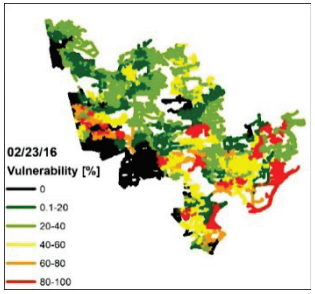
Weather Hazard

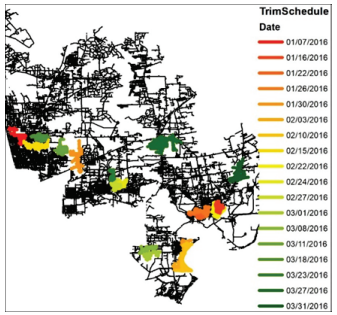


Risk Map



Network Vulnerability





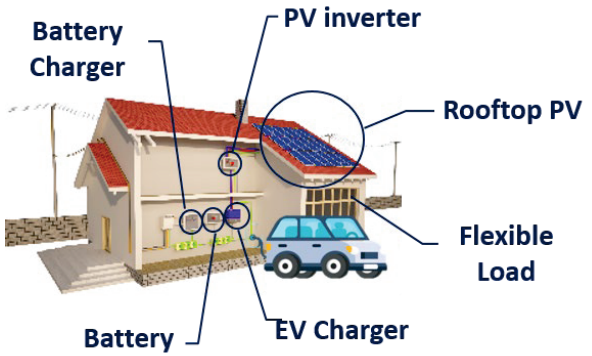
Overall risk reduction 32.85%
Reactive tree trimming cost reduction 27.2%

T. Dokic, M. Kezunovic, "Predictive Risk Management for Dynamic Tree Trimming Scheduling for Distribution Networks," IEEE Transactions on Smart Grid, Vol. 10, No. 5, pp. 4776-4785, September 2018, DOI: 10.1109/TSG.2018.2868457.

Example #2: Using Nano-Grid for outage mitigation

- Traditional Power System:
  a) Generation
  b) Transmission
  c) Distribution → Passive for Residential Loads

nano-Grid (n-Grid)



Transformation at the Grid Edge

- Photovoltaic (PV) Generation
- Stationary Battery Energy Storage
- Mobile Battery Energy Storage (Electric Vehicle)

Outcomes

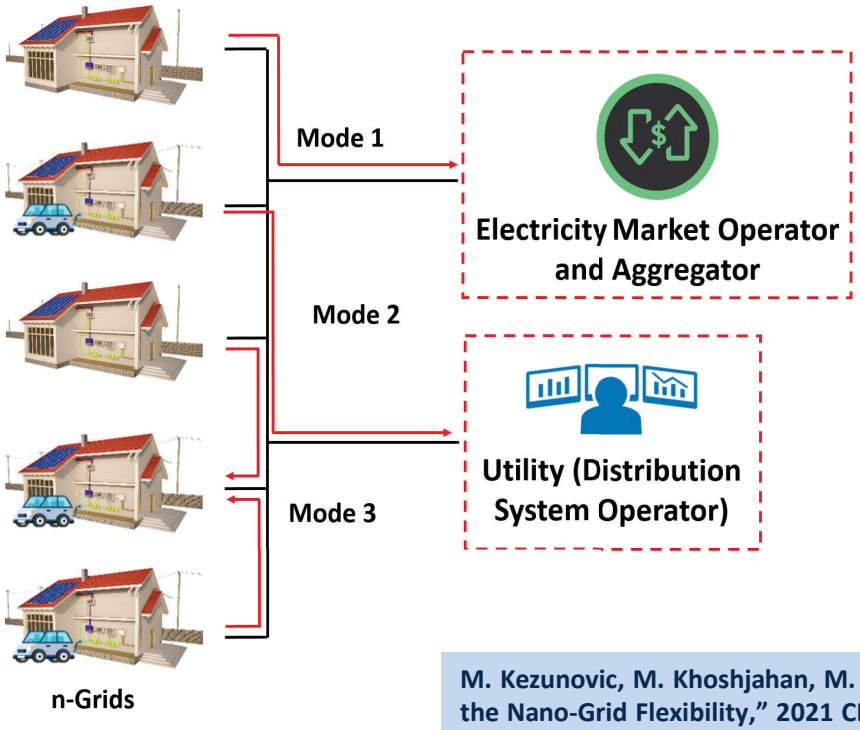
New Challenges:
- New loading peaks and voltage conditions EV charging.
- New complexities in the consumer load profile.

New Opportunities:
- n-Grid flexibility in providing services to the grid and load.
- Utility grid opportunity to utilize the n-Grid flexibility

M. Kezunovic, M. Soleimani, H. Abu-Rub, S. Bayhan, M. Trabelsi, "Hardware in the Loop Simulation of a Nano-Grid Transactive Energy Exchange", 2nd International Conference on Smart Grid and Renewable Energy (SGRE) 2019 , Doha, Qatar, November, 2019, DOI: 10.1109/SGRE46976.2019.9020686.

Harvesting n-Grid Flexibility

Mode 1	n-Grids to market operator via aggregator
Mode 2	n-Grids to distribution system operator (DSO) with or without aggregator
Mode 3	n-Grids in peer-to-peer exchange with DSO coordination, and with or without aggregator

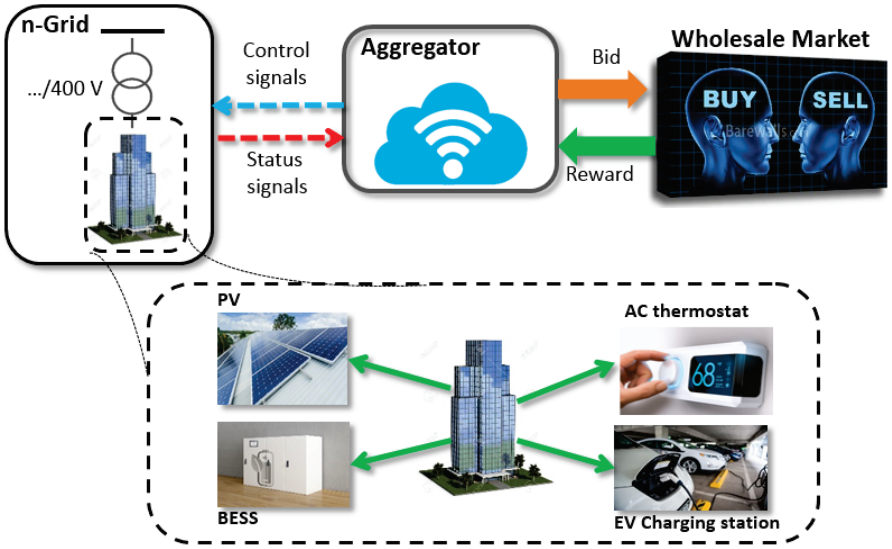


n-Grid operating modes

M. Kezunovic, M. Khoshjahan, M. Soleimani, "Harvesting the Nano-Grid Flexibility," 2021 CIGRE Grid of the Future Symposium, Providence, RI, October 2021.

N-Grid Resource Management for WSM

- The aggregator is envisioned as a mediator between the n-Grids and the WSM.
- It can manage the n-Grids resources directly through internet of things (IoT).
- The aggregator must capture different uncertainties (risks) to ensure its profitability:
  - market prices,
  - EVs arrival, departure and initial energy,
  - ambient temperature,
  - PV generation and
  - n-Grids' electric load.



The n-Grid aggregator framework for participation in WSM.

M. Khoshjahan, M. Kezunovic, "Robust Bidding Strategy for Aggregation of Distributed Prosumers in Flexiramp Market," Electric Power Research Journal, 2022 (In print)

Conclusions

- State of Risk (SoR) prediction using Big Data gives TRANSFORMATIONAL opportunities for risk assessment, management and mitigation
- If we are able to PREDICT forced outages, this offers pro-active opportunities for control, planning and protection management and mitigation actions
- The outage PREDICTION can be at different spatiotemporal scales, minutes to hours, days and quarters, and spatial as granular as component or system
- The time spent on DATA PREPARATION is the most consuming part of the overall development, and may take up to 80% of the development efforts
- The TEST RESULTS are easy to confirm since the testing can be done using the data from the past when the outcomes of the events are already known

Thank you!

Questions?

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