Electric Power Grid Resilience

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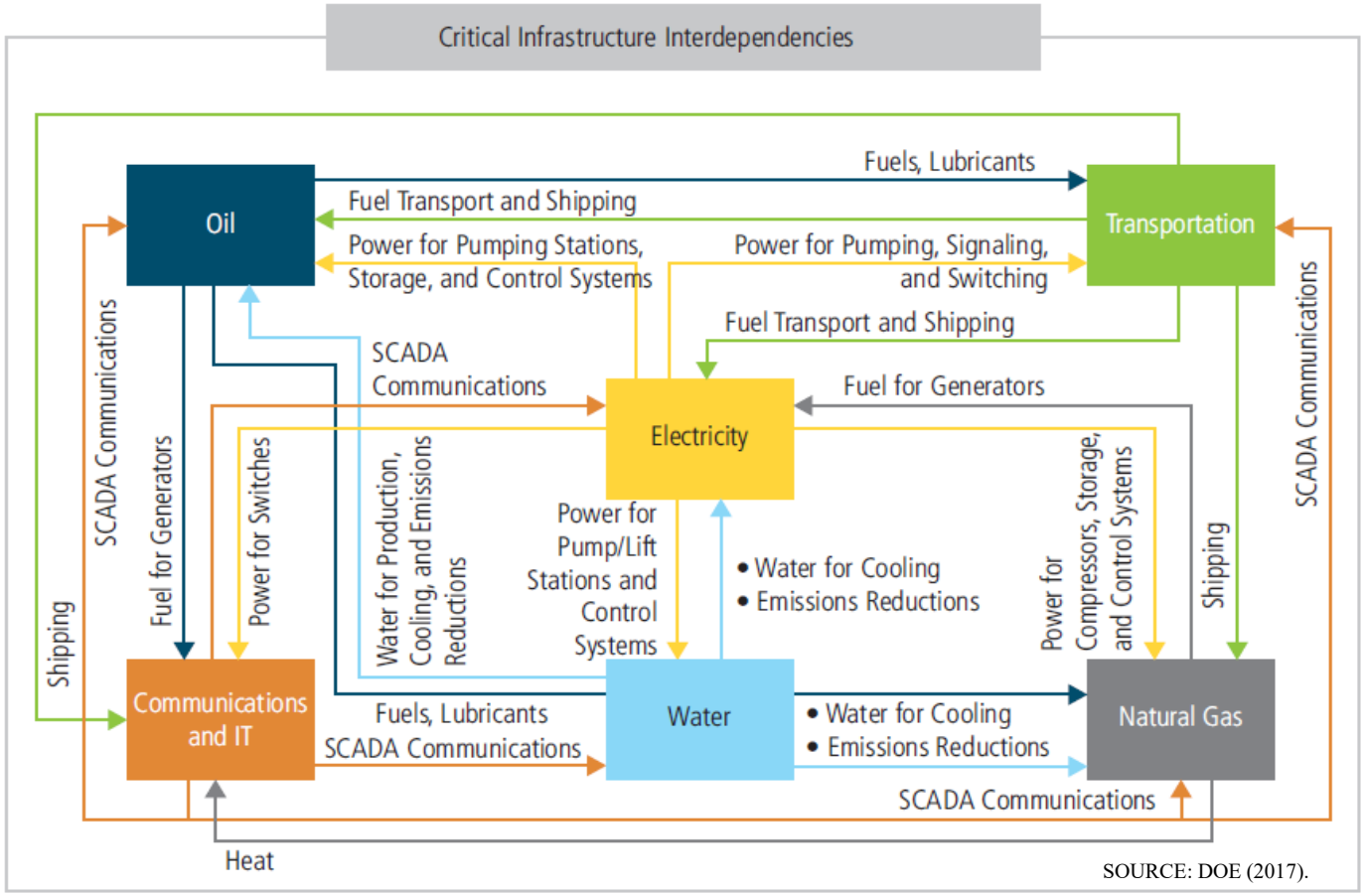
Electricity

Electricity and the underlying infrastructure for its production, transmission, and distribution are essential to the health and prosperity of all citizens. The electricity infrastructure is the critical infrastructure of all critical infrastructures.



SOURCE: DOE (2017).

Grid Reliability

The North American Electric Reliability Corporation (NERC) defines reliability in terms of two core concepts:

1. Adequacy: The ability of the electricity system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.

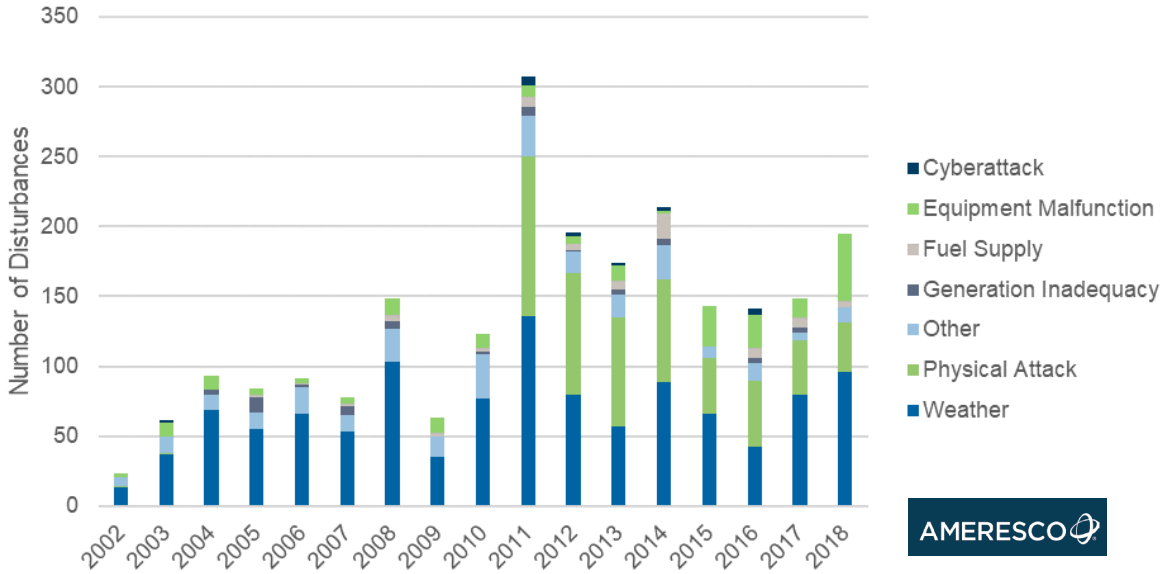
2. Operating reliability: The ability of the bulk power system to withstand sudden disturbances, such as electric short circuits or the unanticipated loss of system elements from credible contingencies, while avoiding uncontrolled cascading blackouts or damage to equipment.

Grid Disturbances

THE WALL STREET JOURNAL
Feb. 18, 2022

America's Power Grid Is Increasingly Unreliable
Behind a rising number of outages are new stresses on the system caused by aging power lines, a changing climate and a power-plant fleet rapidly going green

Electrical Grid Disturbances in the U.S., 2002-2018



Resilient System

Resilience is different from reliability.

While minimizing the likelihood of large-area, long-duration outages is important, a *resilient system* is one that acknowledges that such outages can occur, prepares to deal with them, minimizes their impact when they occur, is able to restore service quickly, and draws lessons from the experience to improve performance in the future.

Four-stages of the concept of resilience [Flynn 2008]:

1. Preparedness
2. Reliance on resources
3. Recovery
4. Alert to insights and lessons learned.

Flynn, S.E. 2008. America the resilient: Defying terrorism and mitigating natural disasters. *Foreign Affairs* 87: 2–8.

Big Data ⟵ Volume, Velocity, Variety, Veracity & Value ⟶ Big Data

Smart Micro-grids

Wind/Solar power data & forecast

Energy storage

Load demand

Energy pricing

Intelligent Sense-making

Situational Intelligence & Visualization

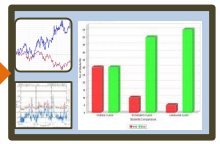
Decision Making & Intelligent Control

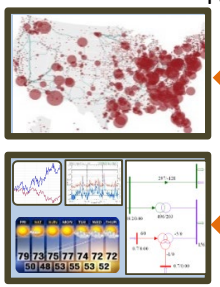
Cyber power flows

Control/Dispatch signals

Secured Wireless

Visualization





Smart Power Systems

Wind/Solar power data & Forecast

PMU data

Energy storage

Intelligent Sense-making

Situational Intelligence & Visualization

Decision Making & Intelligent Control

Cyber power flows

Control/Dispatch signals

Global reference time (GPS Satellite)

Dedicated secured links

PMU

Wind Farm

Solar Farm

Real power flows

Smart Transmission Grid

Smart Micro-grids

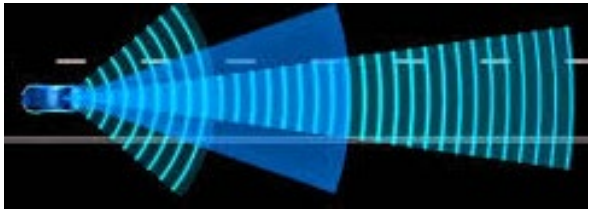
Smart Micro-grid

Cyber Resilience

- Deployment of Smart Grid Technologies - computers, communication networks, other control system electronics, smart meters, and other distribution-side cyber assets, in order to achieve its purpose of delivering electricity to the consumer
- Any consideration of improved power grid resilience requires a consideration of improving the resilience of the grid's cyber infrastructure.
- Cyber resilience aims to protect, using established cybersecurity techniques, acknowledging that that protection can never be perfect and requires monitoring, detection, and response to provide continuous delivery of electrical service.
- Architectures that are resilient to cyber attacks are needed to support cyber resilience.
  - strategies for tolerating cyber attacks and other impairments by monitoring the system and dynamically responding to perceived impairments to achieve resilience goals (to minimize the amount of time a system is compromised and maximize the services provided by the system).

Situational Intelligence

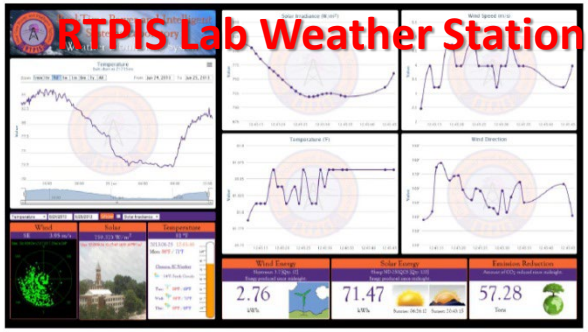
- Situational intelligence (SI) is looking ahead how the situations will unfold over time – *immersion into future*
- In other words, situation awareness (SA) systems present situations based on some measurements of current states at time *t*. Whereas, SI uses SA at time *t* and predictions of future states to predict SA at a time $t+\Delta t$.
- Control centers need to handle big data, variable generation and a lot of uncertainties, and will need SI, that is to derive SA (information, knowledge and understanding) at time *t* and project it into time $t+\Delta t$.

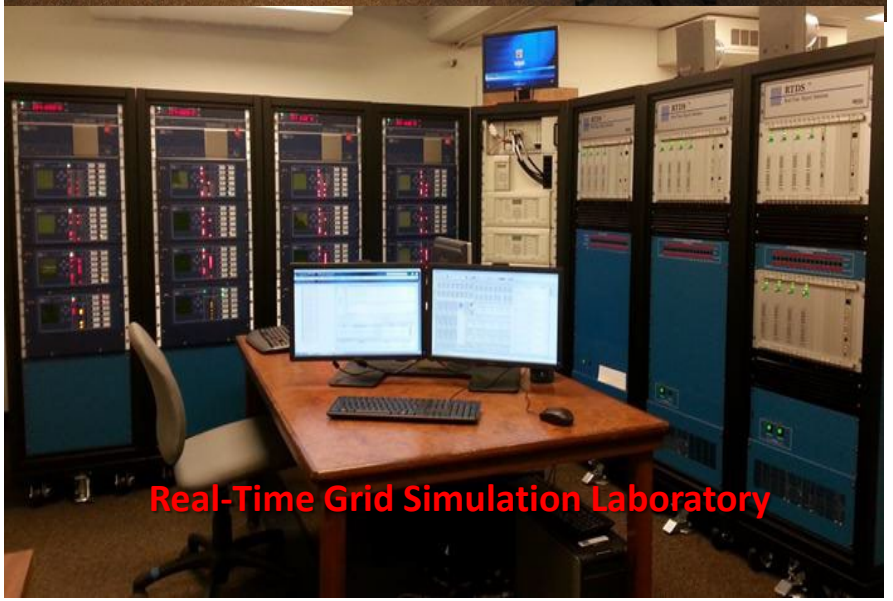


Jayawardene I, Venayagamoorthy GK, Zhong X, "Resilient and Sustainable Tie-line Bias Control for a Power System in Uncertain Environments", *IEEE Transactions on Emerging Topics in Computational Intelligence,* Vol. 6, No. 1, February 2022, pp. 205-219, DOI: 10.1109/TETCI.2020.3042812.

Real-Time Power and Intelligent Systems Laboratory

Emphasis: Research, Education and Innovation-Ecosystem Laboratory for Smart Grid Technologies





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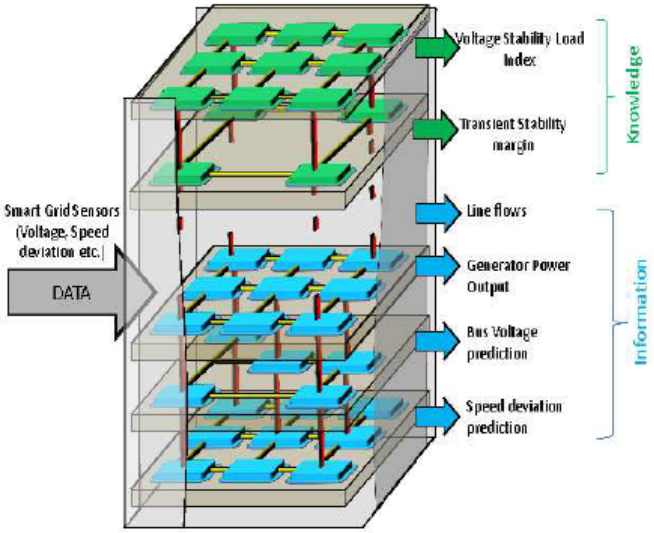
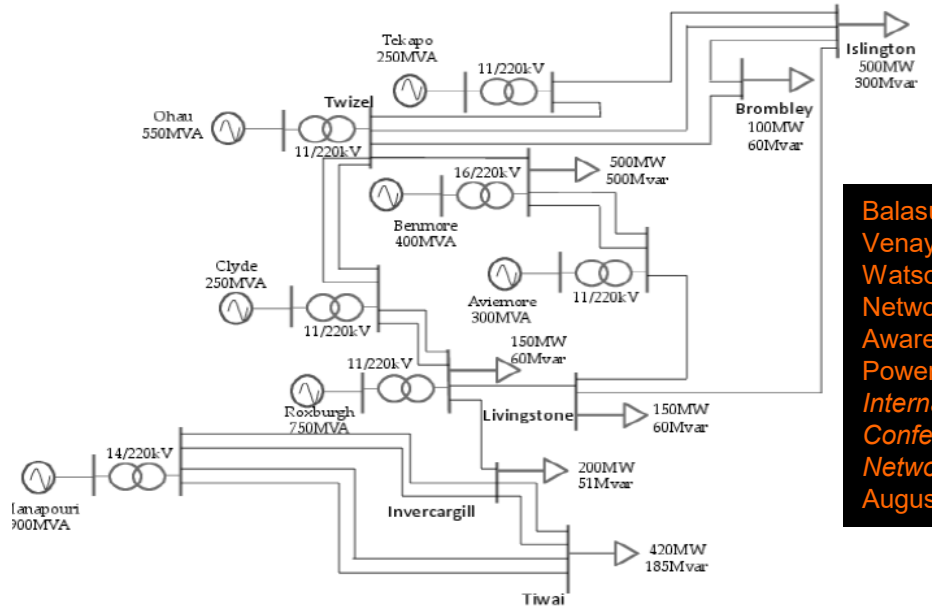
Clemson University's AI based Grid Situational Intelligence





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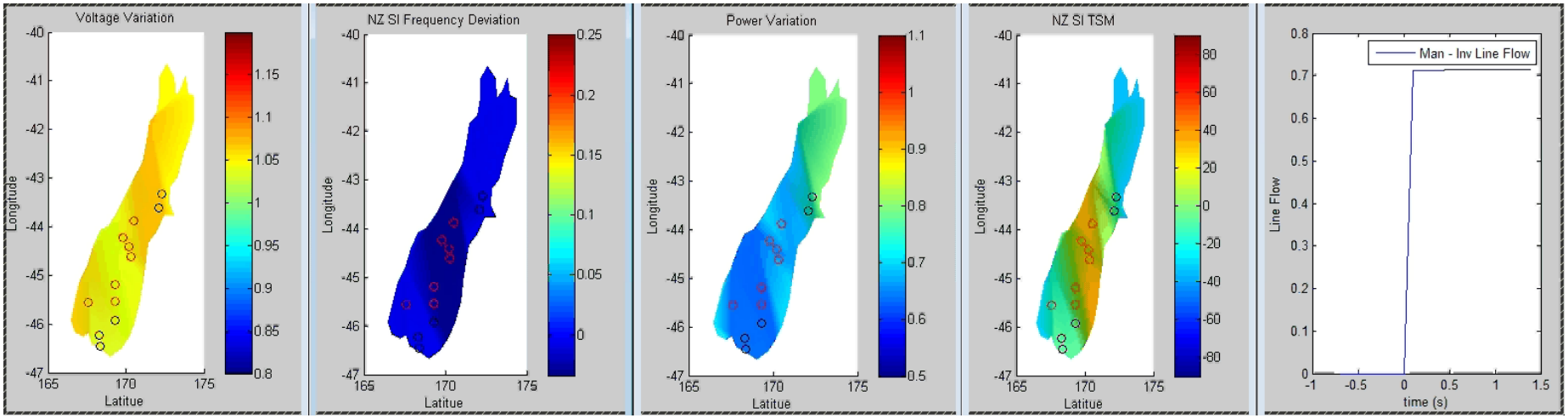

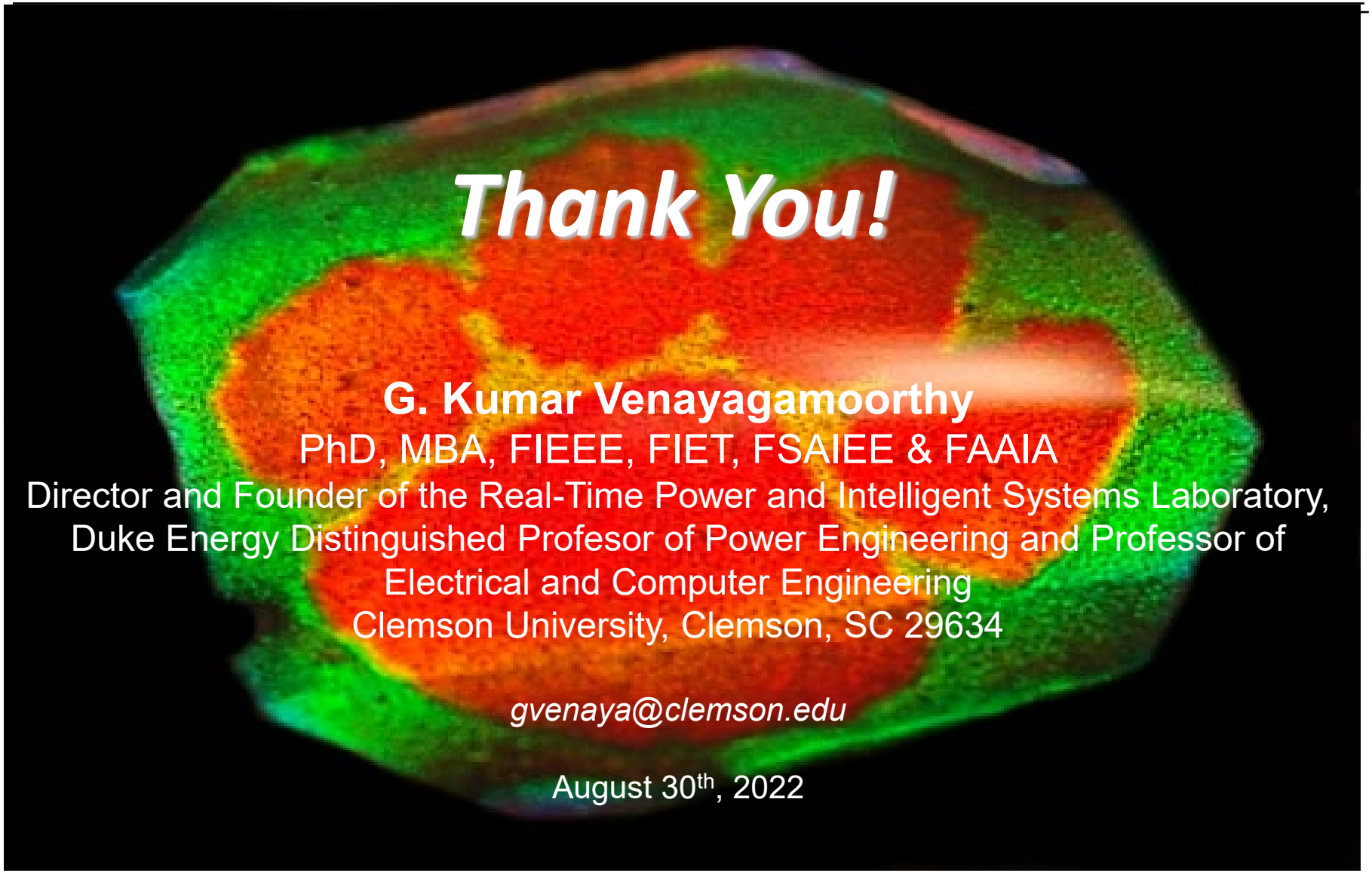

Thank You!

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