INTELEC 2025 Houston

"Powering Critical Infrastructure for a Sustainable Future"

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Themes of INTELEC 2025 – Houston
"Powering Critical Infrastructure for a Sustainable Future"

- Datacenters in focus
    - Solid State Transformers (SST)
    - High efficiency rectifiers
    - Backup systems
    - Infrastructure design optimization
        - Different rectifier and converter topologies
- Microgrids & Energy Storage
- Offshore energy – Relevant in Houston
    - Utilize decommissioned & operational oil rigs for sustainable energy purposes and datacenters

- Technologies in focus
    - Rectifier efficiencies
    - Converters efficiencies
    - SST
    - Cooling of components
    - Size optimizing
- Key Speakers:
    - Prof. Phil Krein,
    - Prof. Johann W. Kolar
    - Dr. Don Tan (IEEE Technical Activities)
    - Prof. Mark Dehong Xu (Power Electronics)

Powering AI
Challenges & Ways to overcome

- **Explosive load growth in power and energy demands**
  - 1,2 MW cabinets / 1 MW power rack
    - Efficiency matters!
  - Liquid cooling as standard
- **Load fluctuations – quick spikes**
  - Higher slew rate
  - "Joint problem for SW- and power electronic engineers" - Prof. Phil Krein
- **Cooling of the datacenters**
  - Include thermal engineers in early stage of designing power solutions. (To avoid solving the problem after a finished design).
  - High water demand: challenging for redundancy, especially in dry areas.
    - Can be helped through SW. Smart shifting of calculation power between datacenters/sites.

- **Collaboration between engineers**
  - Include thermal engineers in early stage of designing power solutions.
  - SW engineers to collaborate with power electronics engineers
- **Shifting from $48V_{DC}$ to $800V_{DC}$ rack distribution**
  - Copper mass reduction with ~200kg
- **Datacenters as responsive loads, through smart SW solutions could integrate well with RES (wind, solar, and other intermittent power sources).**

Resilience planning in Data Centers Power & Cooling

Resilience: Ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions.

Primary resilience stressors

- Extreme dependence on external infrastructures
  - Electric grid
  - Water networks
- High power density
  - 10–100+ MW per site
  - AI workloads → fast, bursty loads
- Tight coupling of systems
  - Power → Cooling → Servers
  - Limited tolerance to downtime. Minutes of outage = millions in losses

Planning strategies to improve resilience

- Buffers
  - Batteries (energy autonomy)
  - Diesel / fuel storage
  - Water tanks
  - Thermal inertia
- Local sourcing
  - Microgrids
  - On-site generation

- Operational flexibility
  - Load shedding
  - Load distribution orchestration.
  - "Virtual energy storage" via ICT control
- Design choices
  - Reduced conversion stages
  - DC distribution
  - Smarter power electronics

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Data Center Resilience Planning
Capacity-Based Metric for ICT Power Resilience

- Extreme dependency on power and water

- Buffers: Batteries, fuel, water tanks, thermal inertia. (Extend autonomy)

- Load control: Load shedding and workload migration as virtual storage

- Power supply options: Grid, Gensets, Microgrids, On site generation (RES) all influence resilience

- New metric based on available power provision capacity vs actual load

  - Resilience as relative capacity margin over time

  - Improves older "uptime-style" metric through

    - Capturing performance degradation

    - Reflecting component condition

    - Showing when capacity approaches failure

- Resilience is multi-dimensional

- Dependencies dominate the resilience problem

- Server workload is a powerful resilience lever

- Local sources improve resilience – each option has limits

- New capacity-based metric enables realistic planning

Resilience: Ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions.

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Digital Twin for Telelecom & Data Center Power System – Ventia & Telstra partnership

- **The Digital Twin**
  - Models 30,000 48VDC systems through actual asset data
  - Processing time reduced from 2.5 hours to seconds (30x faster

- **Why it matters**
  - Legacy metric = Outages -> slow and misleading due to weather impacts
  - Digital twin -> 3 years earlier insight into resilience trends and enables data-driven battery replacement planning
  - Spend-to-resilience prediction: input a budget -> get expected resilience lift
  - Optimizes which sites to replace to maximize resilience per dollar

- **Real world case**
  - Battery budget increased from $17M to $39.6M
  - Outages counts showed worse resilience for 3 years
  - Digital Twin showed immediate improvement
  - Support urban/rural/remote optimization

- **Outcome:**
  - Clear, proactive control of network-wide resilience

REGION	Num 48VDC Systems	Outages per 1,000 Systems prior to Battery Replacement	Battery Budget	Outages per 1,000 Systems after Battery Replacement
ALL	11,275	32.9	$10.0M	9.2
URBAN	4,703	25.9	$6.6M	10.3
RURAL	5,915	27.7	$3.0M	8.4
REMOTE	604	37.9	$0.4M	7.4

Network resiliency prior to battery replacements

Regional spend and resultant network resiliency as optimised by digital twin

Fig. 7. Example results of optimized battery life cycle program where user nominates capital budget and digital twin selects optimized sites for battery replacement.

[3]

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Internal Temperature Distribution Estimation of LIB with Physics-Informed Neural Network

- Background:

  - Temperature on LIB cells are often measured on the surface.

  - Dangerous gradients and degradation happen internally, not seen on surface early enough to stop thermal runaway.

- Physics-informed Neural Network (PINN)

  - Measured: Surface temperature, Current, Voltage, and cooling conditions.

  - Also measured during training: Cell core temperature.

  - Combining heat-transfer PDEs with lightweight NN.

- Idea:

  - Enables real-time temperature estimation with full internal resolution.

  - Can detect dangerous temperature gradients that surface sensors miss/detects too late.

  - Should work with **imperfect** physics knowledge.

- Results:

  - With accurate physics: Core temp Root Mean Square Error (RMSE) ≈ 0.12°C

  - PINN accuracy **beat** the calibrated full-order model.

  - Maintains meaningful predictions when physical parameters are perturbated.

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Full Charge Capacity estimation
Production time improvement, applicable for second life

- Fast non-destructive screening method to evaluate SOH
  - Tested on used EV truck LIB
  - Combining: Previous data with high-rate charge/discharge response and Ah-throughput with the SOC-region Adaptive Correction model.
    - History data: Voltage, Current and SOC
  - FCC estimation within +/-5% across SOC range
  - Reduction in time of 6h/pack
    - 41% speed improvement compared to traditional 0.2C charge- and discharge rate
  - No disassembly required.

Comparison of charging and discharging times at different rates

51,100sec(14.2hour)

41.3%

21,120sec(5.9hour)

0.2C(10A/10A)   0.7C(30A/40A)

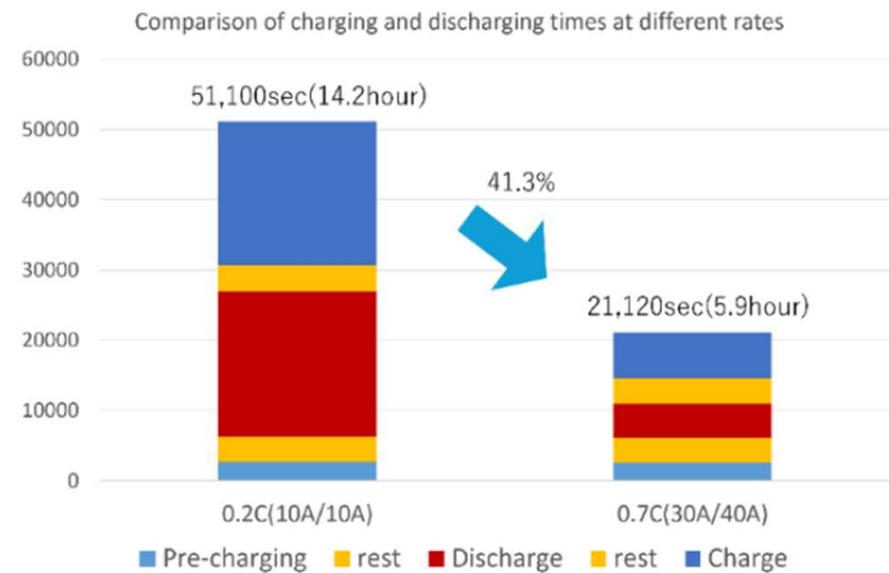■ Pre-charging ■ rest ■ Discharge ■ rest ■ Charge

Fig. 1. Screening time comparison between conventional and proposed methods.

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Efficiency in 2ⁿᵈ Life LIB via Cell Regrouping

- Problem: Reused EV lithium-ion batteries show variations in FCC, SOC, and internal resistance, reducing efficiency in second-life applications.

- Goal: Improve charge—discharge energy efficiency by optimizing both screening and regrouping of reused modules.

- Key Insight: Internal resistance varies strongly with SOC—particularly near high SOC—making efficiency highly dependent on how cells are grouped.

- Method:
  - Screen 24 reused modules based on FCC, OCV, and resistance behavior.
  - Simulate 8 regrouping strategies (random, charge-end aligned, discharge-end aligned, efficiency-optimized).

- Results:
  - Energy-efficiency-optimized screening/regrouping consistently outperformed all traditional methods.
  - Random regrouping sometimes produced high discharge energy, but efficiency-optimized regrouping gave the best overall energy efficiency.

- Conclusion:
  - Advanced screening + regrouping significantly improve efficiency in second-life ESS packs.
  - Supports better renewable-energy utilization due to reduced internal energy losses.

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Why microgrids for critical loads
Case Study in Saudi Arabia

- System: (Achieved 100% renewable supply and carbon neutrality).

TABLE I
COMMERCIALLY PRACTICAL COMPONENT SIZES

Component	Theoretical	Practical	Rationale
PV System	3948.5 kW	4000 kW	Standard modular size
Wind Turbine	2968 kW	3000 kW	3 MW turbine
Electrolyzer	2529.3 kW	3000 kW	3 MW modular system
Fuel Cell	2593.3 kW	3000 kW	3 MW system
H_2 Storage	868.3 kg	1000 kg	Standard tank size
Battery Power	1656.1 kW	2000 kW	2 MW inverter block
Battery Energy	5000 kWh	5000 kWh	2 MW/5 MWh container

- 0 MWh grid import over a year

- GA sizing and MPC dispatch

- 1500 V_{DC}

- Islanded, DC-friendly architecture reduces conversion losses and aligns with server loads.

- Very Optimistic

- Missed battery degradation input.

Annual Energy Share (Full Year 2024)

Grid Out 5.5% · Grid In 0.0% · Batt Discharge 15.5% · PV 24.1% · Batt Charge 17.2% · Fuel Cell 7.4% · Electrolyzer 17.9% · Wind 12.4%
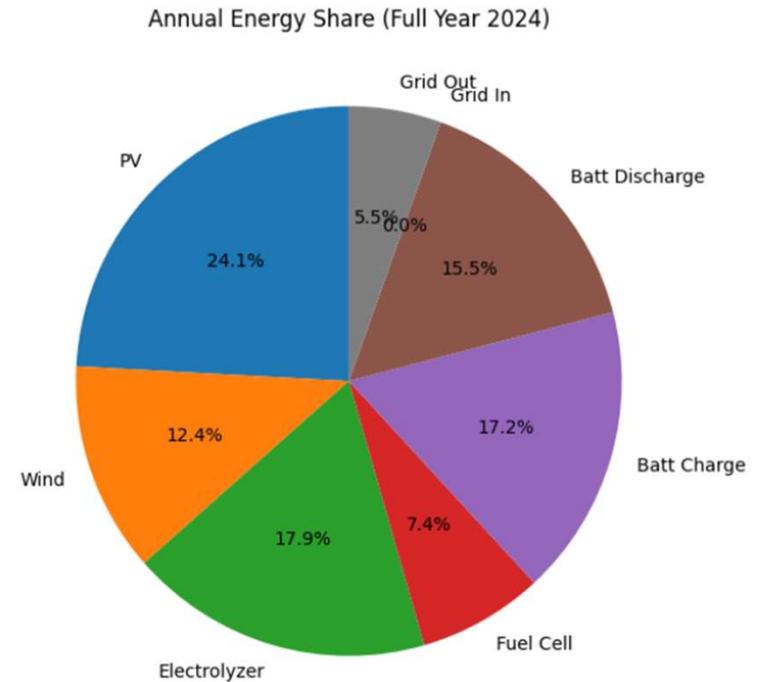
Fig. 8. Annual Energy Flow Distribution in the Optimized DC Microgrid.

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Arbitrage Battery Energy Storage using Deep Q-Networks (DQN)

- DQN method compared to MILP

  – DQN adapts to real-time price spikes & dips better than static optimization.

  – DQN discovers short-lived arbitrage opportunities that traditional methods often miss.

  – Incorporate battery degradation costs directly into the reward function.

- System description:

  – DC microgrid (Figure 1)

  – Electricity price varies real time every 15min

  – Sliding window of price prediction of 24h

TABLE I: Battery sizing considered for the BESS arbitrage problem formulation [7].

Hyperparameter	Specifications
Battery Capacity (C^{bat})	1000 kWh
Charge Rate ($P^{bat}_{ch,max}$)	160 kWh
Discharge Rate ($P^{bat}_{dch,max}$)	250 kWh
Battery Roundtrip Efficiency $\eta_{ch/dch}$	90%
Inverter/Converter Roundtrip Efficiency (η_{conv}, η_{inv})	95%
Degradation Cost (C^{degr})	\$0.01/kWh
Battery self-discharge ($P^{bat}_{self-dch}$)	0.05%/hr

- DQN profits compared to the traditional MILP method

  – Summer period: ~53% higher profit

  – Winter period: ~11% higher profit

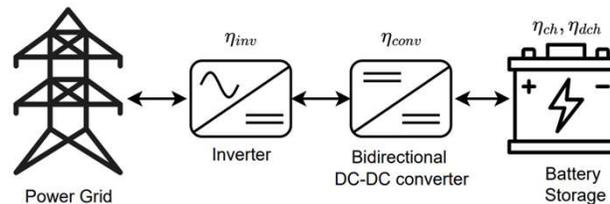 – Full year: ~31% higher profit 42000USD compared to 32000USD

Fig. 1: Schematic of the proposed battery-grid arbitrage framework highlighting the interaction loop between the battery storage and grid system interconnected via several power electronic converters.

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Seamless control & reconfiguration

- Uniform droop-based control for AC/DC converters = no controller switching during mode changes

- Sync voltages/phase first; regulate tie-line current to ≈0 before open/close → disturbance-free connect/disconnect

- Validated in Typhoon-HIL for:
  - AC↔AC,
  - DC↔DC,
  - AC↔DC transitions
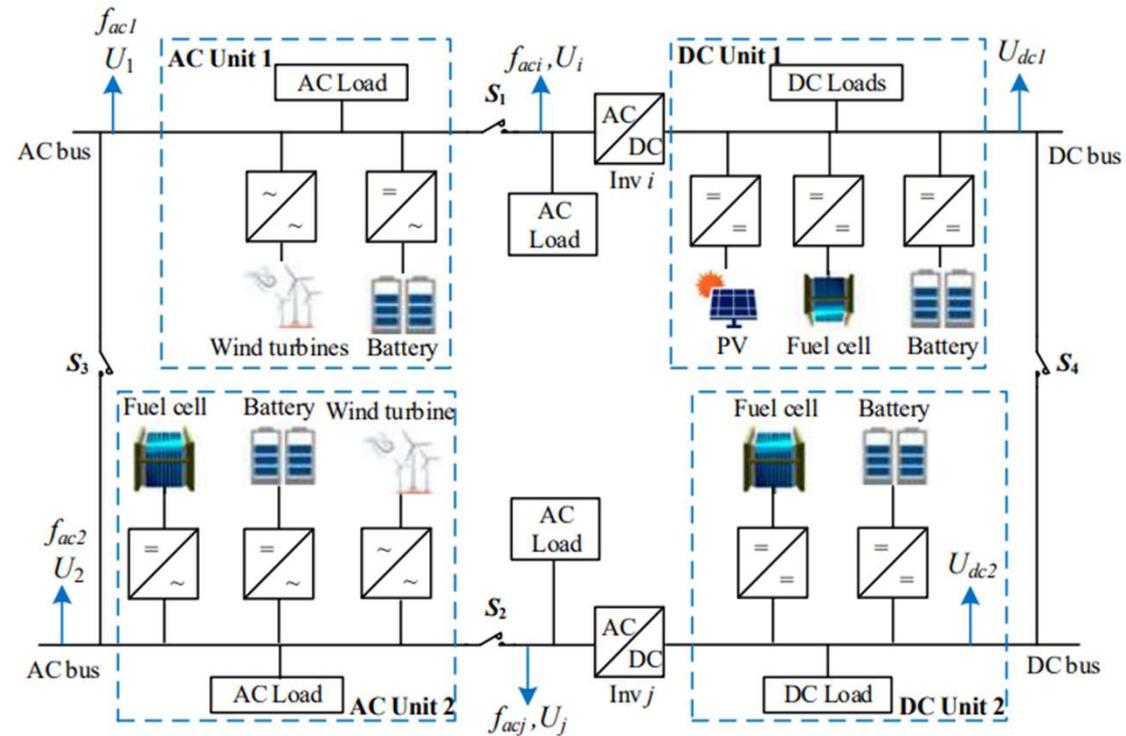
Fig. 1. Structure of converter-based system with distributed units.

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Long duration storage: Hybrid wins

- Offshore case with deck area & weight limits: compare BESS, H_2, hybrid (MILP)

- Hybrid BESS+H_2 exploits battery fast response + hydrogen duration, meeting subsea loads with physical feasibility.

- Data-center case uses battery (ride-through) + H_2 loop (multi-hour/seasonal) for zero-import operation

- Own reflections
  - Will BESS be sufficient to handle the quick spikes?
  - Super cap needed?

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Cybersecurity & privacy SCADA

- Study revelead several critical vulnerabilities of smart grid systems to cyberattacks

- Significant security vulnereability in traditional protocols such as Telnet and Modbus TCP

  - comm loss, abnormal currents/surges, power drops.

  - Mitigations: deep-packet inspection, SCADA logs, LAN isolation. Continous monitoring and fast responses

- Vulnerabilities cannot be detected through theoretical simulations alone.

- Study

  - Very practical setup

  - Quite simple idea to prove how vulnerably standard protocols are.

  - Good improvements suggestions to minimize the risks

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Quick mentions

- CAN FD – Protocol
  - New protocol including a standard released
  - Much improved Security
  - Payloads increase to 64bytes compared to 8bytes in traditional CAN
  - Backwards compatible

- Super Conductor in "High temperature"
  - Prototype in lab in Houston University
  - Thinn material, with high current capacity, and low losses

Conclusion 1/2

- To solve a lot of the challenges:
  - SW + Power System + Cooling to collaborate in earlier stage to be able to meet requirements from data center on energy demand.
  - Components could be skipped with smart algorithms through the help of AI
  - New technology must be investigated, from integrated concepts down to transistor level.
    - Out of the box thinking required.
    - Example: Monolithic transistor
    - 800 V_{DC} rack distribution with high efficiency components

- Energy storage moves more towards intelligent, hybrid and operational flexible systems
  - Intelligent assets through DQN, PINN and better SOH estimations.
  - Smarter 2nd life workflows.
  - Hybrid storage solutions, such as BESS + Hydrogen.
  - Energy storage as a part of resilience planning.
    - Energy buffer and Grid-interaction tool

- Microgrids potential solution for resilient and low carbon digital infrastructure
  - Case studies of 100% renewable microgrids without grid import
  - DC-coupled microgrids can match data center loads better than AC-centric designs
  - EMS studies on real-world validation, including realistic network delays
  - Network as a part of the power system, prioritize critical QoS signals

Conclusion 2/2

- Resilience through reducing dependencies and adding autonomy
  - Require more independence from electric grids and water networks.
  - Mitigation strategies
    - Buffers
    - Local sourcing: microgrids, onsite generation and hybrid storage.
    - Operational flexibility: load shedding, workload mitigations, "virtual storage"
    - Smarter design choices: Fewer conversion stages, DC distribution, integrated cooling-power control

- General about AI
  - Today: 1 AI search require the same energy as 10 traditional google searches.
  - Now that almost each google search also gives an AI answer, the demand on data centers will automatically increase from normal google searches as well!
  - Collaboration and inclusion of AI in every step.

Summary & Reflections about the conference

- Positive take aways
  - Good spread in topics still relevant to the theme.
  - Interesting to bridge the knowledge gap across sectors.
  - Dense conference -> opportunity to get to know the people there. Felt like a community.
- Some improvements for next conference
  - Many presentations within similar areas in parallel, instead of subject based presentations
  - Optimistic schedule, little time for questions and discussions.

- How can we collaborate?
  - SW and HW of course
  - Industry, university, government, etc.
- Low focus on batteries, good and bad.
- SST and high efficiency rectifiers hot topic.
- AI is a fact
  - Opportunity not an issue
  - How to implement?
- Some AI WoW mentioned at the conference
  - Notebook AI good tool to learn content through audio
  - Local AI should be used at every company to secure sensitive data while utilizing the power of AI
  - API to fetch exact data that can be used for example to order components.

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Thank you for listening!

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