DIGITAL TWIN MODEL FOR PREDICTING THE THERMAL PROFILE OF POWER CABLES FOR NAVAL SHIPBOARD POWER SYSTEMS

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Integer Technologies

Office of Naval Research Science & Technology

NAVAL RELEVANCE

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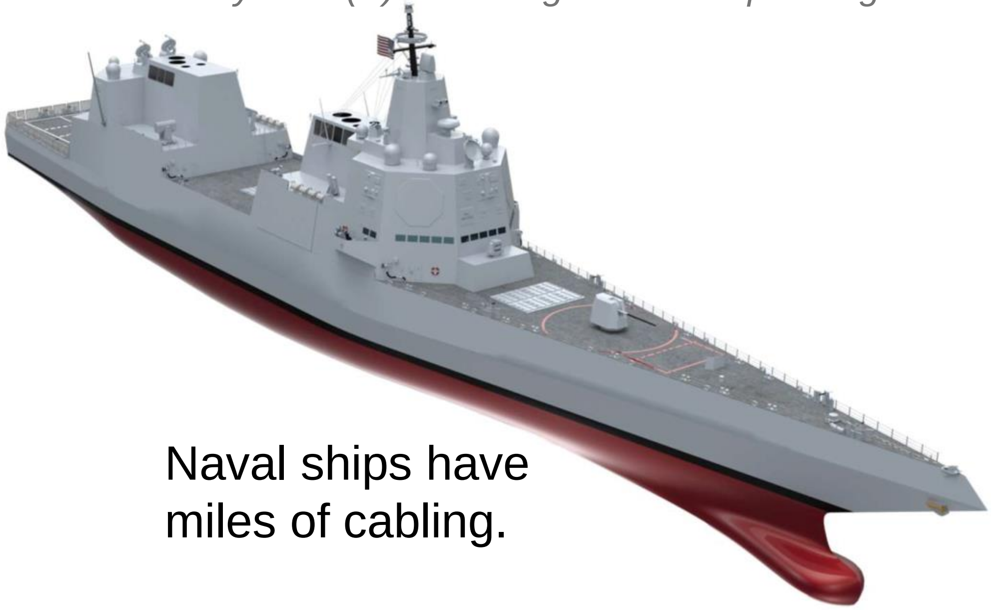
- Naval ships rely on cabling from generators to mission critical loads.
- As power cables heat up, their current-carrying capacity decreases due to increased conductor resistance.
- Cable insulation and terminations are prone to aging and failure due to increased contact resistance caused by oxidation and mechanical stress.

Notional Navy DDG(X) hull design. PEO Ships Image



Naval ships have miles of cabling.

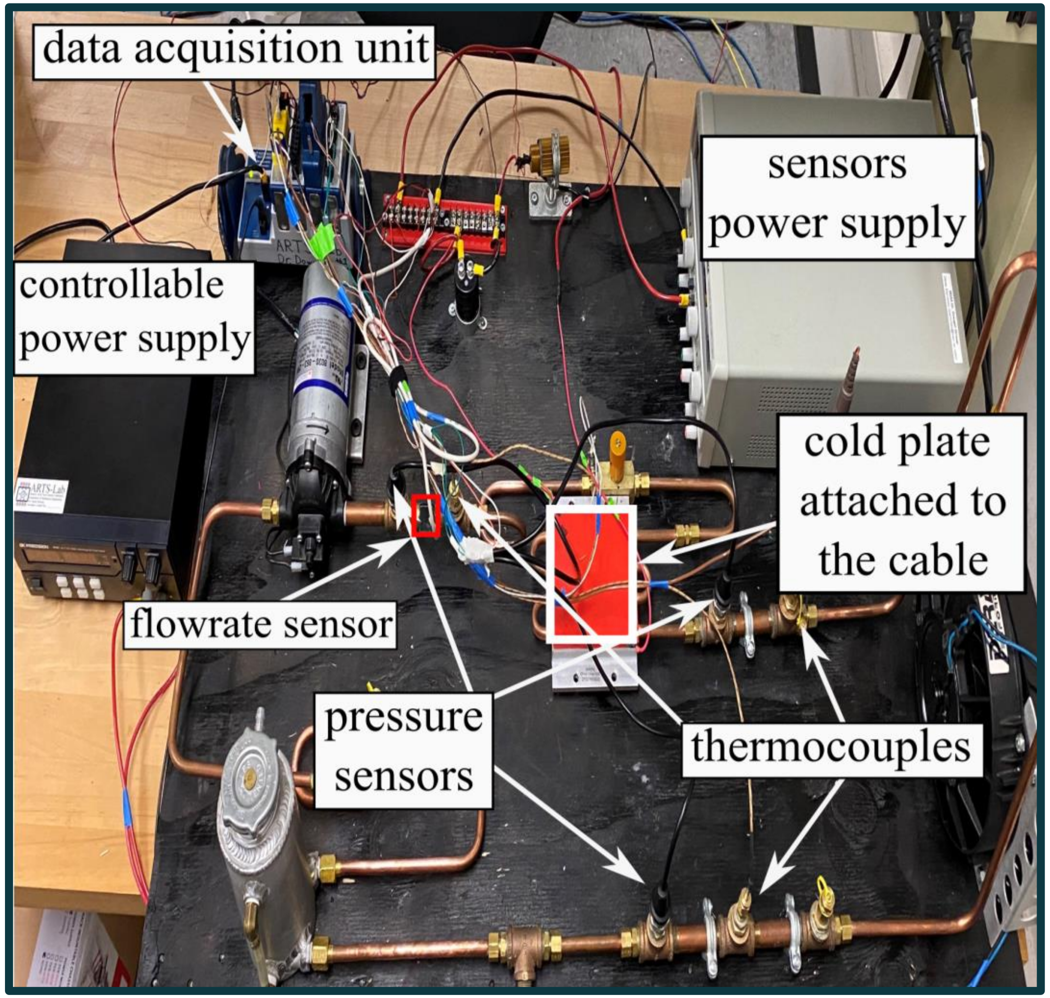
Can we determine cable lifetime and proactively manage power transfer through the ship?

DIGITAL TWINS

- The Digital Twin (DT) approach is gaining popularity in the aerospace and automotive industry, offering a promising framework for system modeling and analysis.
- DT involves digital models that accurately represent the behavior of physical systems.
- The maritime industry is showing interest in adopting DT technology for shipboard power system components.
- Predicting and monitoring the thermal profile of shipboard power cables can improve mission success and enhance power system operation.

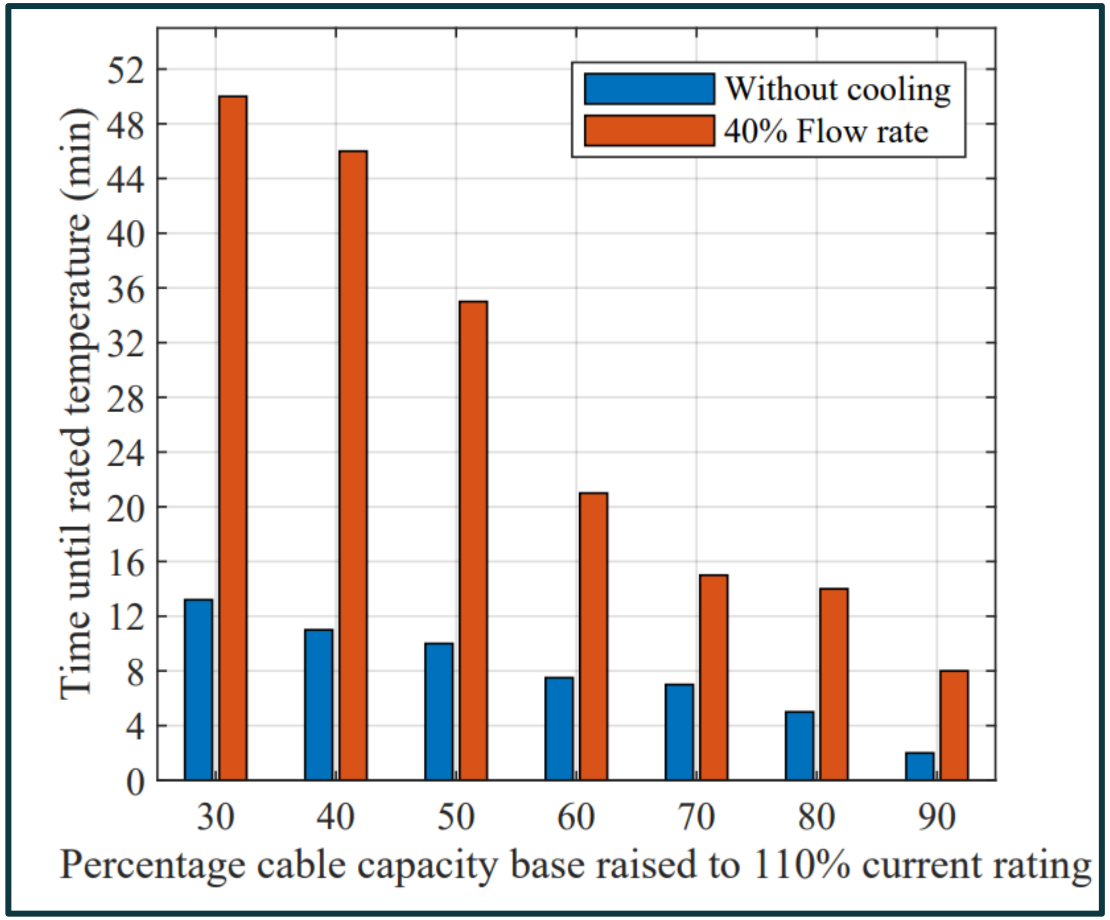
DEVELOPING THE DIGITAL TWIN FOR CABLE

- Observe and predict thermal profiles of power cables in naval ship power systems.
- Considers the impact of cable temperature with power transfer.
- DT model tested under various currant load profile scenarios.
- Results compared with the physical system for verification.



PHYSICAL CABLE TEMPERATURE & COOLING

- Studied natural and forced cooling.
- Started at steady-state current with a sudden rise to 110% rated current.
- Studied time until cable reached thermal rating.
- Forced cooling greatly increases time until rated temp reached.
- Results affected by flow rate and cable-capacity percentage.



DEVELOPING THE DIGITAL TWIN

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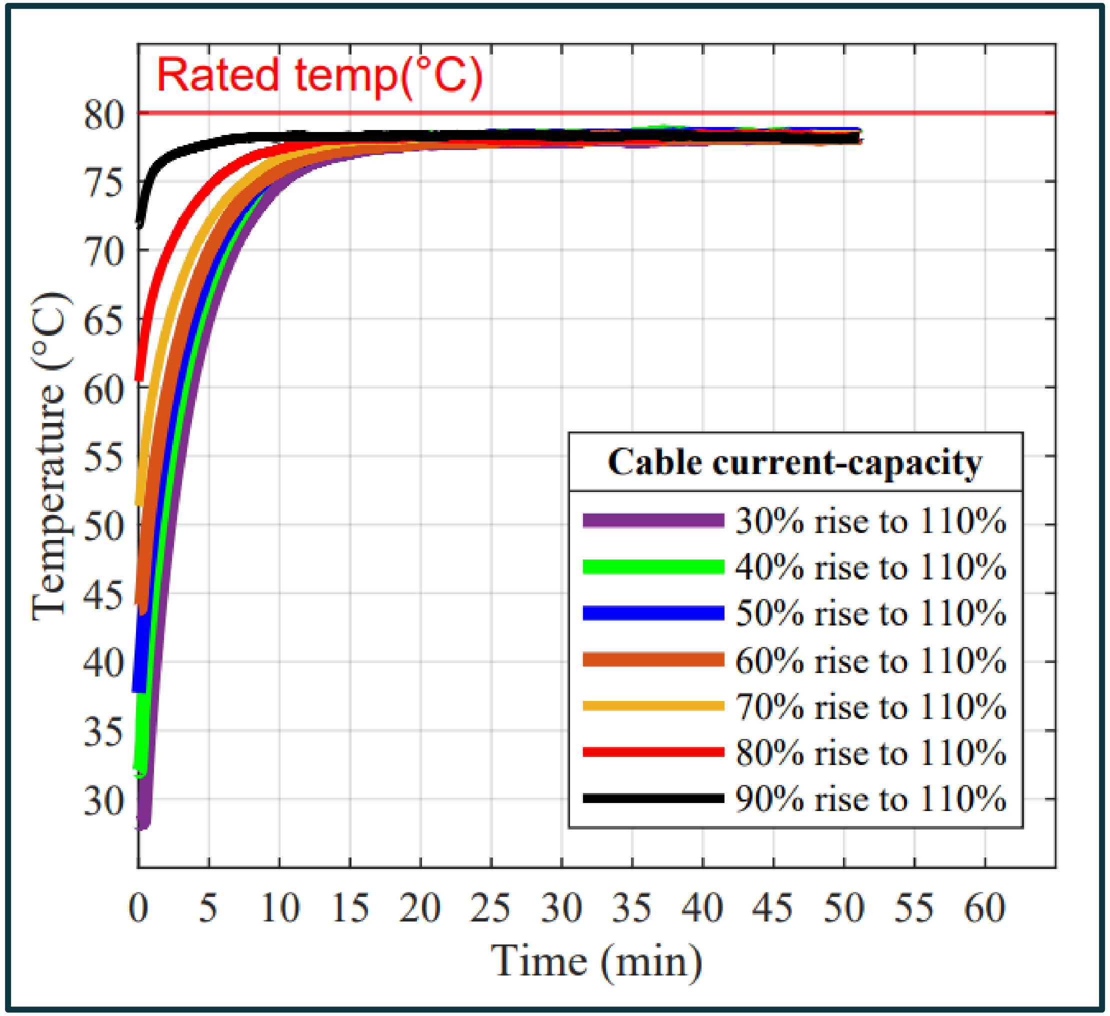
Characterized the exponential thermal changes in the cable.

- Started at steady-state current with a sudden rise to 110% rated current.
- Measured max steady-state temperature and rise time.
- Assumed constant flow rate.



ESTS

DIGITAL TWIN GOVERNING EQUATION

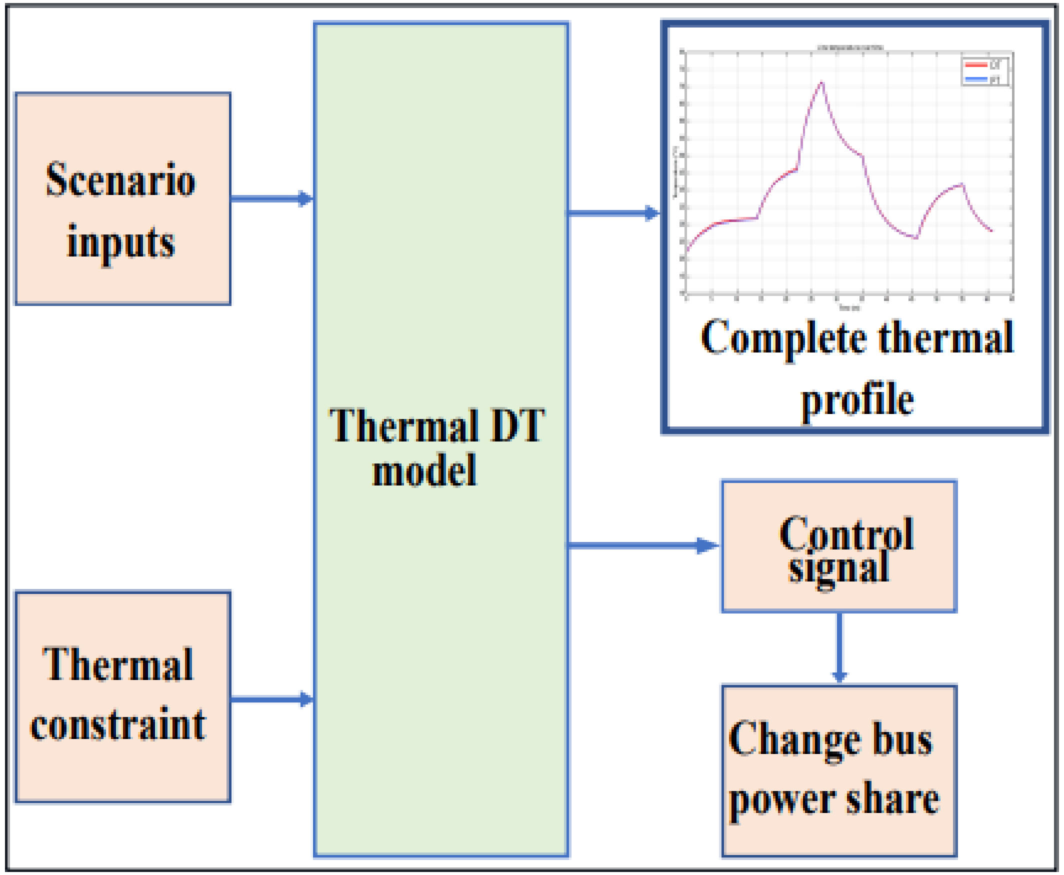
- Must begin with initial (expected) condition.
- Thermal equivalent circuit represents thermal behavior:

$$T_n(t) = T_{n-1} + [\mathrm{T(I)} + \mathrm{T_{n-1}}]\left(1 - e^{-t_n/c}\right)$$

- t_n: Current time step
- c: Time constant
- $\mathrm{T_{n-1}}$: Temperature at time, t_{n-1}
- $\mathrm{T(I)}$: Steady-state temperature dependent on current: $T(\mathrm{I}) = 0.2434I^2 + 0.01839I$
- $T_n(t)$: Estimated temperature at time, t_n

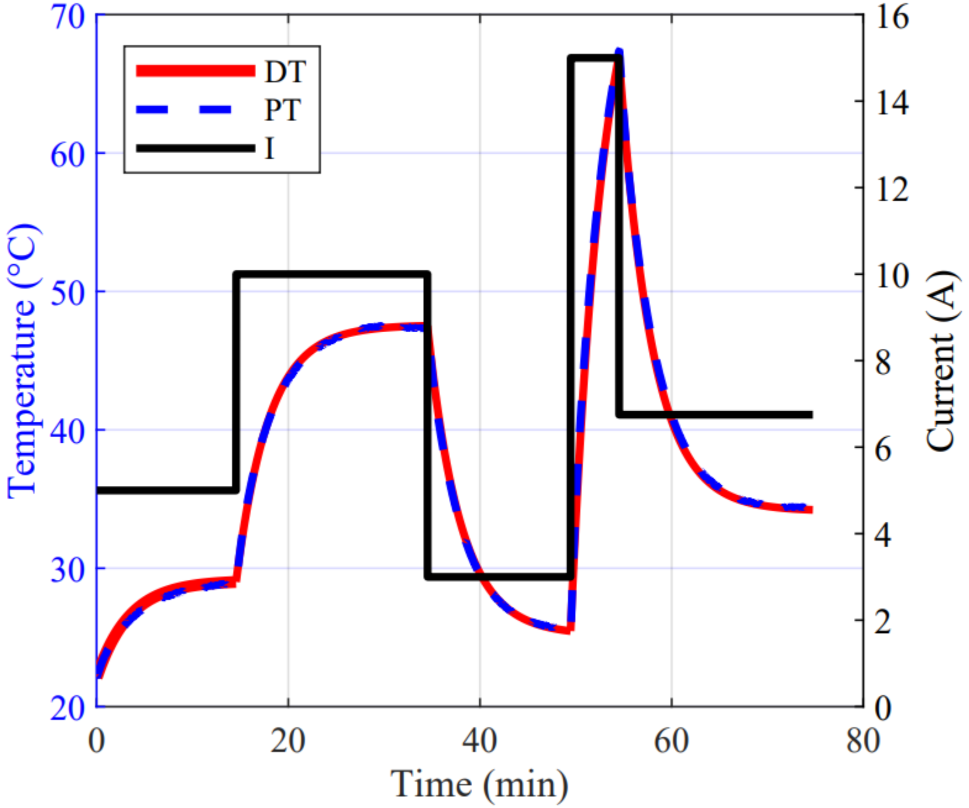
APPLYING THE DEVELOPED DIGITAL TWIN

- Potential mission segments are provided to the DT.
- A thermal profile is calculated.
- The DT compares outcomes to defined requirements.
- A flag alerts the decision maker if constraints are exceeded.
- The power can be rerouted to maintain system requirements and demands.

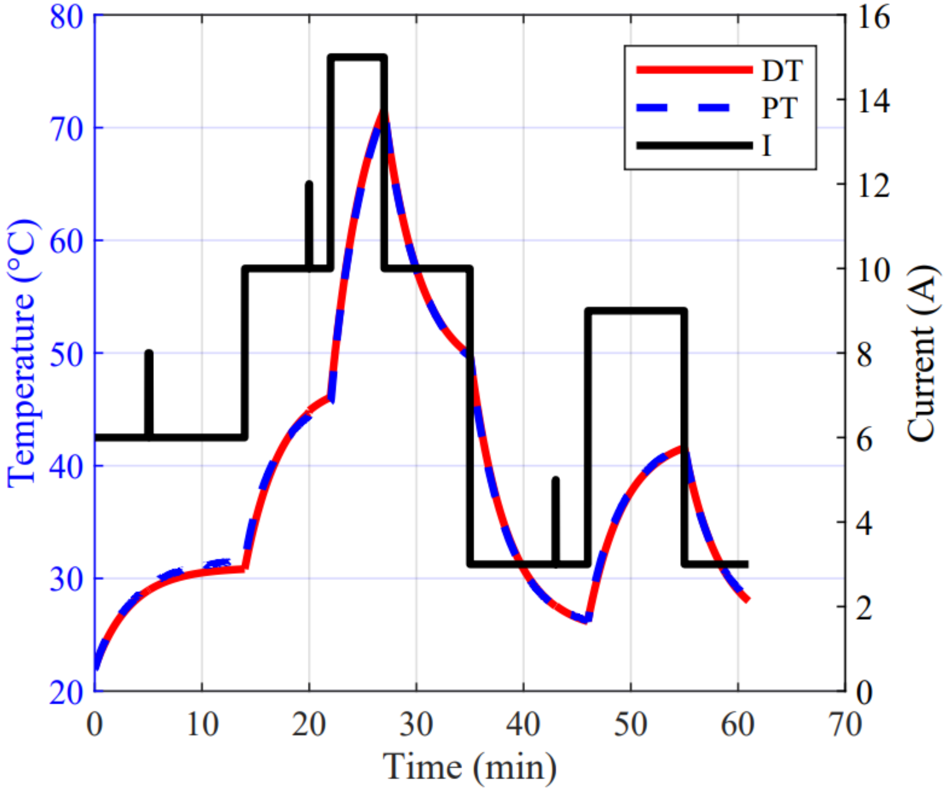


TWO POTENTIAL MISSION SCENARIOS

Simple Power Demand



Integrated Pulsed Power Demand



CONCLUSIONS & FUTURE WORK

- Electro-thermal cable DT can predict thermal profiles.
  - Under varying and/or pulsed load conditions.
- DT is an accurate representation of the hardware.
  - Max temperature deviation is ±0.7 °C

Future work:

- Using the electro-thermal DT for studying current overload capability of thermally-limited cables in multi-bus systems.
- Control signal from DT can optimize power management, improve power flow decisions, and adapt to ship posture, system damage, and mission requirements.

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Thank You

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