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SIRFN Power System Testing
A Cyber-Physical Power System Testing Framework for Power System Transformation

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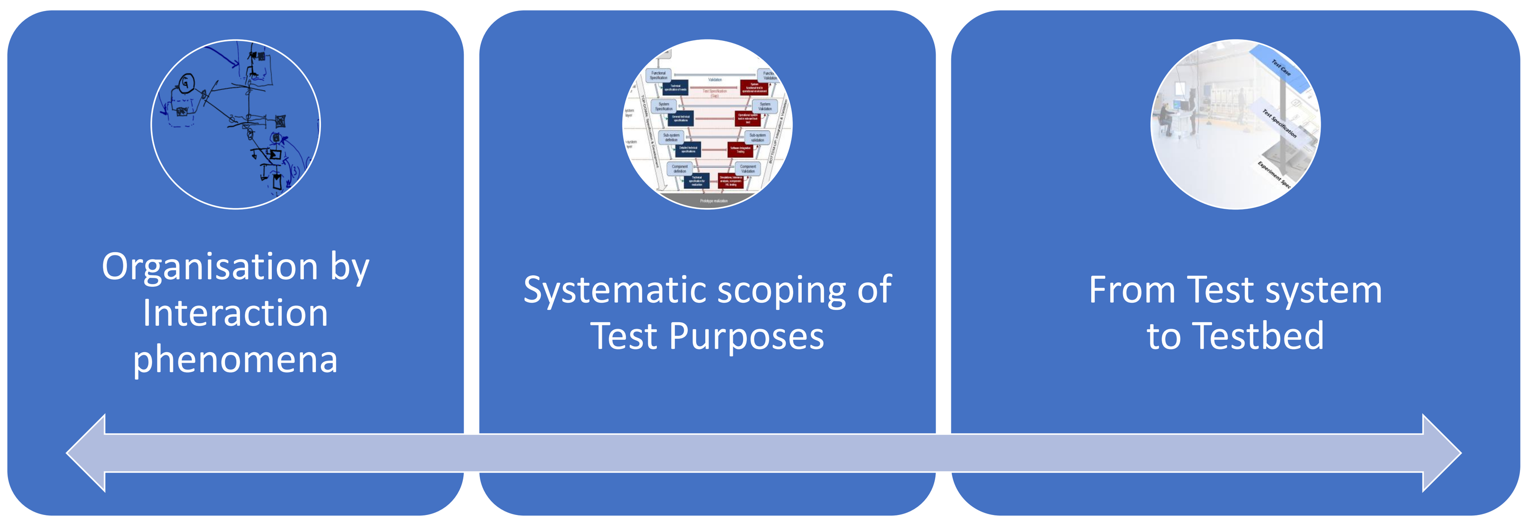
Motivation

The dependability of the power infrastructure is ensured by established testing practices. However, these practices do not address new stability phenomena [1,2] or issues arising from cyber-physical interactions through increasingly digitalized control technologies.

With the above-described challenges and developments, the complexity of test planning and scoping is vastly increased [3]. The proposed framework focuses on facilitating complex cyber-physical system tests.



Three Pillars

I. Organisation and scoping of analytical and testbed requirements by interaction phenomena.
II. Systematic specification of test purposes
III. Incremental and iterative refinement of simulated test system and (real-time) hardware testbed

Interaction Phenomena & System Testing

System testing aims to represent the realistic interactions and system behaviours in a safe testbed environment. For example, a new class of control strategies for rare stability events needs to be thoroughly scrutinized – however the testing conditions are challenging to define.

Scope by Interaction Phenomena

Simulations and testbeds require a focus on specific phenomena. Alignment between simulators and testbeds can be achieved with respect to the relevant phenomena, both in the power system and cyber (control, communications) domains. The classification for power system stability is based on [4], and for communication/cyber phenomena inspired by [5].

Power System Phenomena

- Rotor Angle Stability
  - Transient • Small Disturbance
- Voltage Stability
  - Short-term • Long-term
- Frequency Stability
  - Short-term • Long-term
- Resonance Stability
  - Electrical • Torsional
- Converter-driven Stability
  - Fast interaction
  - Slow interaction
- Congestion effects
- Voltage Quality

Cyber Phenomena

- Channel events
  - Delays • Bandwidth
  - Package loss
- Signaling events
  - Congestion
  - Data corruption
- Interoperability Issues
  - Functional • Semantic
- Operational conflicts
  - Goal-driven • Constraint-driven
- Cyber-security Events
  - MITRE ATT&CK taxonomy [https://attack.mitre.org/]

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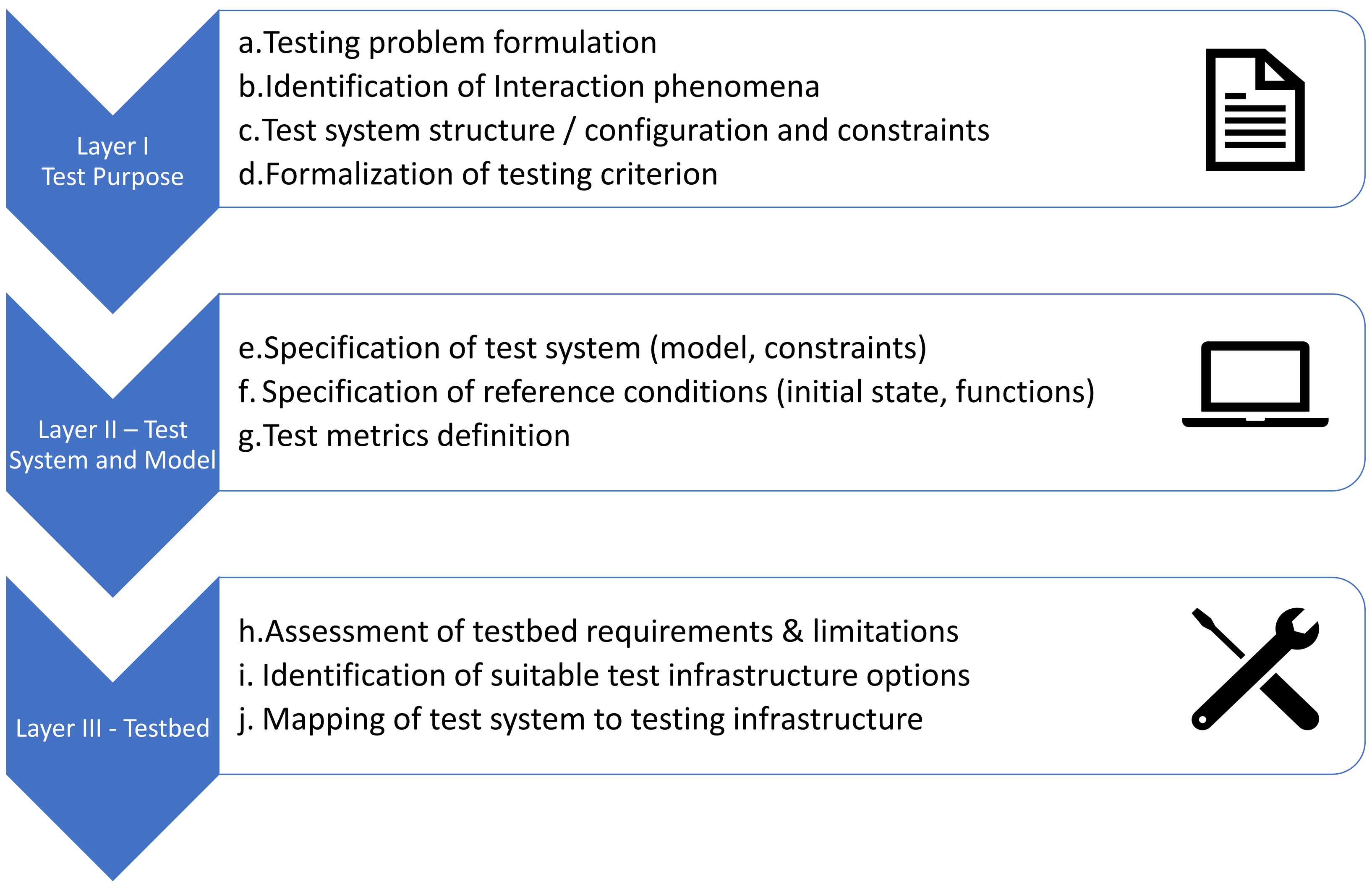
Cyber-Physical Power System Testing

Power system testing focusses on interactions and aims to warrant system properties under presence of (potentially large numbers of) interacting active components.

> **Definition [Power System Testing]**
> The testing of the interactions of several sub-systems with and within a representative power system.

Outline of the Framework

The framework is organized in three layers. The associated steps prioritise test purpose clarification and support test system correspondence.



A System Testing Example (Layer I)

Distribution network operator: How to achieve reliable cyber-physical solutions for distribution networks? Dependency on IT aspects, control, and interactions with numerous less reliable devices raises uncertainty.

a. *Specific testing problem*: Avoid voltage quality issues with decentralised voltage control from EVSE (EV charging posts).

b. *Interaction issues and domains*: two local voltage controllers may cause voltage oscillations due to limit-cycle development between controllers.

c. *System structure:* (DSO consultation) range of typical grid structure and impedance ranges; control standards and EVSE providers.

d. *Criterion formalization:* i) reproduce frequency of phenomena occurrence ii) Quantify success ratio of mitigation strategies

System Testing Methodology Challenges

Two examples of *transferrable* research challenges identified in the group:

- Computational identification of worst-case test conditions for a given (set of) phenomena type(s) (*here*: oscillation appearance)
- Refinement for test system (sim model) based on hardware measurements

Conclusion

The outlined framework builds on existing requirements assessment approaches [3] and facilitates both established and advanced testbed types. By defining the framework, a taxonomy of power system testing problems is becoming practical, specific methodology issues can be isolated, and associated research questions can be identified. In further work, the framework is applied to additional system testing problems and specific methods for acceleration are developed.

This review has been performed by a group of researchers, members of the IEA TCP ISGAN - SIRFN, as part of their efforts to enhance the close collaboration among international test facilities and identifies potential activities for future application and standardization of Smart Grid. In this context, the contributions from the members are acknowledged.
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