GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Category 1 (Foundational/Regional) Project Final Report

Report Completion Date:

Section 1: Project Information

Project Information	
Control #: Title:	**GMLC 1.2.1** **Grid Architecture**
Project Title:	**Grid Architecture**
Project PI Name and Lab Affiliation: Project Co-PI (plus-one) and Lab Affiliation:	**Jeffrey Taft, PNNL** **Arjun Shankar, ORNL**
DOE Project Manager(s):	**Chris Irwin, Guohui Yuan**
Period of Performance:	**2/4/2016 – 9/15/2020**
Date Closed:	**9/1/2020**

Section 2: Project Assessment and Checklist

Project Assessment and Checklist	Y/N	Confirmation Date	Comments
Have all quarterly reports been submitted?	**Y**	**9/1/2020**	
Have all milestones have been delivered?	**Y**	**9/1/2020**	
Are all products finalized (e.g. technical reports, journal articles)?	**Y**	**9/1/2020**	
Have all project products been finalized and presented/submitted to DOE Project Manager(s) and/or GMI Leadership?	**Y**	**9/1/2020**	
Have all potential sensitivities been identified and addressed with DOE Project Managers and/or GMI Leadership?	**Y**	**9/1/2020**	
Has the project team received feedback from Project Stakeholders (e.g. advisory group)?	Y	**9/1/2020**	
Are there any open or pending costs?	**N**	**9/1/2020**	

Section 3: Outcomes, Deliverables, Publications

Provide the following:
**In addition to titles, provide links to any websites or other repositories where deliverables and/or other information will be available after the project has been completed*
**Publications available for public release, URLs, etc. listed here should be uploaded to GMLC Open Point*

1. **List of Outcomes: see attachment below**
2. **List of Deliverables: see attachment below**
3. **List of Publications: see attachment below**
4. **List of Awards or Recognition: see attachment below**
5. **List any ROIs – Software, Intellectual Property, Licensing, Patents, Etc.**

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Section 4: Final Costing

Each Lab Financial POC Completes Final Costing of GMLC Projects for their lab. PIs, Lab Leads will need to assist but not required to report financials with this final report.

Section 5: Final Thoughts/Comments

Final Thoughts	Comments
Lessons Learned	Grid Architecture provides the only comprehensive approach to understanding the grid and grid modernization. Its use provides insights not available by other means.
Opportunities for Improvement	Deeper integration of graph theory; expansion of GA tool set; creation of more regional models and addition of more model detail
Future Projects: Ideas for future work? Possible next steps and research direction?	Translation of reference architectures to designs; field implementations; use of GA as means to coordinate DOE grid modernization efforts and develop new approaches to electricity delivery.
Other:	Use to guide sensing/measurement development, cyber security and completely revise the industry approach to resilience.

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Outcomes, deliverables, publications:

Item	Status
Architecture Glossary	complete
Tools:	
Grid Architecture Evaluation Tool	complete
Industry Structure Diagram Viewer	complete
Reference Architectures:	
High Resilience Reference Architecture package (26 documents, main spec 62 pages)	complete
Variable Structure Reference Grid Architecture package (18 documents, main spec 38 pages)	complete
Advanced Bulk Power System Reference Architecture package (27 documents, main spec 68 pages)	complete
High Penetration DER/Distribution Automation/Storage Reference Architecture package (41 documents, main spec 88 pages)	complete
Urban Converged Networks Reference Architecture package (15 documents, main spec 38 pages)	complete
Models:	
ERCOT Industry Structure	complete
ERCOT Market-Control Process	complete
PNW Industry Structure – GTD Separated	complete
PNW Industry Structure – GTD Integrated	complete
Great River Energy Industry Structure	complete
New York Industry Structure	complete
US Electric Sector Regulatory Structure	complete
US Electricity Market Structure	complete
US Electricity Market Component Model	complete
General Market-Control Model	complete
Component Class Model definitions – 18 component classes	complete
Additional Work Products	
Grid Services Master List and Taxonomy (shared with all of GMLC early in the project)	complete
Electric Utility Industry Entity Class List	complete
White paper: The Impact of 5G Telecommunications Technology on US Grid Modernization 2017–2025	complete
White paper: Sensor Network Issues for Advanced Power Grids	complete

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White paper: Connectivity, Centrality, and Bottleneckedness: On Graph Theoretic Methods for Power Systems	complete
White paper: DER Telemetry Communication Architecture for ESOs, DSOs, and System Operators	complete
White paper: Toward a Practical Theory of Grid Resilience A Grid Architectural Approach	complete
White paper: Grid Architecture at the Gas-Electric Interface	complete
User guide: Grid Architecture Evaluation Tool Users Guide	complete
White paper: The Use of Embedded Electric Grid Storage for Resilience, Operational Flexibility, and Cyber-Security	complete
White paper: Grid Architecture for Buildings	complete
ITEM	**STATUS**
White paper: Emerging Trends and Systemic Issues Influencing Today's U.S. Electric Grid	complete
White paper: Problem Domain Reference Model - GMLC 1.2.1	complete
White paper: Grid Characteristics: Using Definitions and Definition Structure for Decision-Making	complete
White paper: Extended Grid State Definition Document (integrated from GMLC Sensing and Measurement Strategy project)	complete
Industry Outreach:	
Grid Architects' Boot Camp (done with SGIP/SEPA, 14-hour online training for selected industry members, content turned into a book)	complete
Five-article series in ELP (now powergrid.com) with SGIP/SEPA	complete
Entire issue of IEEE PES Magazine devoted to Grid Architecture (Sept/Oct 2019)	complete
ARID reviews of reference architecture done with SEPA and GWAC/Grid 3.0 groups	complete
Grid Architecture tutorials and presentations at SEPA Grid Summit (tutorial), Grid 3.0 2017, IEEE PES General Meeting 2018 (tutorial), ISGT 2017 (tutorial), FERC Technical Conference panel 2018 (presentation), Resilience Week 2018 (60 minute keynote address), SE Apparatus School 2017 (long tutorial), direct meetings with Avista, PGE, Commonwealth Edison, Exelon Utilities, HECO, Great River Energy; MACRUC (panel presentation); EPRI-sponsored webinar, MEPPI presentation, NCEP presentation, NCUC presentation, PEAC 2020 (remote presentation), ISGT 2020 (presentation /panel), North American CIM User's Group Meeting 2019 (presentation)	complete
Second Grid Architects' Boot Camp May 11, 2020 – June 30, 2020	complete

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Tutorial at IEEE PES General Meeting 2020 (done online)	complete
Other:	
Licensed Boot Camp materials to Utilicast so that they can teach the methodology to utilities (non-exclusive)	license agreement and materials transfer complete