Operations Project Authorization Form

Date Prepared: 01/14/19	**Project Title: Cybersecurity and Power Grid Test Bed**
Company/ies: Eversource Energy	**Project ID Number:**
Organization: EVERSOURCE ENERGY	**Class(es) of Plant: Distribution**
Project Initiator: [redacted]	**Project Category:**
Project Manager [redacted]	**Project Type: Specific**
Project Sponsor: [redacted]	**Project Purpose:**
Estimated in service date: Dec 31st 2019	**If Transmission Project: PTF? N/A**
Eng. /Constr. Resources Budgeted? NO	**Capital Investment Part of Original Operating Plan? YES**
Authorization Type: Full Funding	**O&M Expenses Part of the Original Operating Plan? YES**
Total Request: $1,238,200	

Financial Requirements:

Project Authorization
ERM: _____

FP&A: _____

Executive Summary

NOTE: The total cost of this project will be shared among two Eversource operating companies. Account balancing and reconciliation will be completed by journal entry.

The Eversource Energy Center (EEC) in partnership with the University of Connecticut (UCONN) aims to establish national leadership in Grid-Cybersecurity and respond to the challenges of the Electrical-Grid's emergent new technologies with the intent of providing reliable services for all Eversource's customers as well as making contributions to the modernization of America's aging energy infrastructure.

The rise of distributed energy represents a significant challenge for electrical utilities, the penetration of distributed energy resources (DERs) has changed the way that the distribution system is operated and managed. The steady, one-way of electricity that was the norm for more than a century is now a dynamic, two-way stream of power, shifting back and forth between the customers and Eversource's Distribution and Transmission Systems.
With limited real-time data, visibility, and control, operators can only estimate how much power DERs are feeding back into the grid and they have limited control to identify and avert situations that can affect the safe and reliable delivery of power to customers. Adding to these challenges, Eversource also encounters the effects of extreme weather events and the increase threats of cyber-attacks that can potentially lead to regional blackouts or localized brownouts.

As smarter energy infrastructure is implemented with increasing connectivity and information flow internally and with others externally, this also increases the attack surface for any potential

adversary. Recognizing this, ensure that Eversource will need to enhance and extend cyber defences and evolve into a proactive deterrence rather than the traditional reactive defence.

This project, "Cybersecurity and Power-Grid Test Bed", involves the purchase of software and hardware to support the project's objectives. The installation and configuration of the Test Bed will be completed by UCONN's faculty and vendors. Equipment will be operated by UCONN's faculty and Graduate students. Research topics will be assigned by EEC with approval of Eversource Energy. The equipment purchased under this project will be kept and maintained by the University of Connecticut.

The state-of-the-art Eversource Energy Testbed to be built will empower cutting edge research in the vibrant field of grid modernization and cybersecurity.

The Eversource Energy Testbed will be used for testing and validating grid modernization and cybersecurity techniques. The major functions of this testbed include:

- Test, validate and prototype cybersecurity technologies for detecting, responding to and preventing known and unknown cyber threats.
- Test, validate and prototype grid modernization techniques, e.g. distribution automation, protection and control, DMS, DERMS; deep integration of renewables, etc.
- Support a variety of communication methods.
- Enable resilience studies such as storm events, renewable energy integration, electromagnetic transients and various attacks.
- Be capable of interfacting new technologies such as SDN, IoT, edge computing, GPS-enabled facilities, Inverter-based renewables, data analytics, etc.

The final design is to build the Eversource Energy Testbed based on NovaCor, the new generation of RTDS real-time simulator. The Testbed consists of the following main components:

a. Two RTDS NovaCor Cubicles including 3 NovaCor Chassis with14 enabled cores, 8 GTNETx2 cards, 2 GTSYNC cards, 4 GTAO cards, 2 CTAI cards, 2 GTDI cards and 2 GTDO cards.
b. Real-time simulation package for large power grid including TSAT/PSAT/TRI, TSAT-RTDS Interface (TRI), 1 ePMU module and 1 high performance PC to run DSA Tools software.
c. Eight Pica8 high performance 10G/40G Ethernet switches for building a softwar-defined network for power grids.
d. Six Dell Edge R470 servers for creating a distributed computing environment for power grids.
e. One KMAX Pro Network Emulator for testing and verifying application performance under adverse network conditions.
f. One Keysight InfiniiVision MSOX4154A Oscilloscope including current probe and SW application budle.
g. One E5071C-440 ENA Vector Network Analyzer 4-port Test Set with a calibration kit.
h. One NI CRIO for testing Industrial Internet of Things (IIoT), monitoring, and control.
i. A monitor wall system for visualization.
j. Two Dell PCs and monitors for RTDS model development, test and experiments.

Project Costs Summary

The cost of this project is shared by the following Eversource operating companies:
A- Transmission [60%] , B- CT-Distribution Engineering [40%]

Account balancing will be accomplished by either journal entry or direct entry.

	UCONN219 - Projects	DISTRIBUTION	TRANSMISSION	TOTAL
Work Orders				
UCONN219-1	Cybersecurity-Power Distribution Test Bed	$495,200 | 40%|	$742,800 | 60%|	$ 1,238,000
		$ 495,200	$ 742,800	$ 1,238,000

Note: Dollar values are in thousands

	Prior Authorized	2019	20__	20__	Totals
Capital Additions - Direct	$ -	$ 1,119.9			$ 1,119.9
Less Customer Contribution		$ -			$ -
Removals net of Salvage ___%		$ -			$ -
Total - Direct Spending		$ 1,119.9			$ 1,119.9
Capital Additions - Indirect		$ 5.6			$ 5.6
Subtotal Request		$ 1,125.5			$ 1,125.5
AFUDC		$ 56.7			$ 56.7
Total Capital Request		$ 1,182.2			$ 1,182.2
O&M					$ -
Total Request		$ 1,182.2			$ 1,182.2

Financial Evaluation

Financial Evaluation

Note: Dollar values are in thousands

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Direct Capital Costs		2019	20__	20__	Totals
Straight Time Labor		$ -			$ -
Overtime Labor		$ -			$ -
Outside Services					$ -
Materials		$ 1,119.9			$ 1,119.9
Other, Including contingency amounts (5%)		$ 56.0			$ 56.0
Total Direct Costs		**$ 1,175.9**			$ 1,175.9
Indirect Capital Costs					
Indirects/Overheads (including benefits)		$ 5.6			$ 5.6
Capitalized interest or AFUDC, if any		$ 56.7			$ 56.7
Total Indirect Costs		**$ 62.3**			$ 62.3
Total Capital Costs					
Less Total Customer Contribution		$ -			$ -
Total Capital Project Costs		**$ 1,238.2**			$ 1,238.2
Total O&M Project Costs					$ -

Note: Explain unique payment provisions. Purchase of the equipment by Eversource will be the only cost associated with this project.

Future Financial Impacts:

Provide below the estimated future costs that will result from the project:
Note: Dollar values are in thousands:

Future Costs	Year 20__	Year 20__	Year20__	Year 20__+	Total Future Project Costs
Capital	$ -	$ -	$ -	$ -	$ -
O&M	-	-	-	-	-
Other	-	-	-	-	-
TOTAL	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**

Describe the estimated future Capital, O&M and/or Other costs noted above:

No future cost will be associated with this project.

What functional area(s) will these future costs be funded in?_____N/A_ _____
A representative from the respective functional area is required to be included as a project approver.

If this is other than a Reliability Project, please complete the section below;

Provide below the estimated financial benefits that will result from the project:
Note: Dollar values are in thousands:

Future Benefits	Year 2019	Year 20__	Year20__	Year 20__+	Total Future Project Benefits
Capital	$ -	$ -	$ -	$ -	$ -
O&M	-	-	-	-	-
Other	-	-	-	-	-
TOTAL	$ -	$ -	$ -	$ -	$ -

Describe the estimated future Capital, O&M and/or Other benefits noted above:

What functional area(s) will these benefits be reflected in?_____ _____
A representative from the respective functional area is required to be included as a project approver.

Asset Retirement Obligation (ARO) and/ or Environmental Cleanup Costs (Environmental Liabilities):

Is there an ARO associated with this project? If yes, please provide details: N/A

Are there other environmental cleanup costs associated with this project? If yes, please provide details: N/A

Technical Justification:

Project Need Statement

The sustainable growth of our economy largely depends on the reliable operation of the nation's electric distribution grid. With frequent weather events and an increasing number of cyber-attacks, reliable safeguards and technologies are needed to protect the powergrid system. The power distribution grids in the U.S. were impacted by major hurricanes and storms, resulting in thousands of major blackouts in the past three decades and causing over $ 1 trillion damages and enormous social upheavals. Furthermore, the deep penetration of distributed energy resources (DERs) such as photovoltaics (PVs) has caused dramatic changes in the way that utilities look, operate and managed the electrica grid. In addition, cyber threats escalate when unsecured IoT technologies are incorporated into homes, buildings, DER, battery storages and microgrids as smarter energy infrastructures are implemented with increasing connectivity and information flow internally and with others externally, this also increases the attack surface for any potential adversary.

To meet these needs, Eversource Energy aims to develop an innovative Testbed, a stable shared-use instrument to prototype, test and compare design alternatives and planning and operation solutions for electric distribution networks. Once developed, the Eversource Energy Testbed will be a leading R&D testbed for developing and verifying solutions to manage high penetration of renewable energy, and offer new opportunities for utilities, research communities

and national laboratories to further develop advanced design, planning and operation analytics to improve resilience, reliability and cybersecurity of the nation's power distribution infrastructures.

Project Objectives

The project objectives include:
(1) Build a reconfigurable and high fidelity hardware-in-the-loop (HIL) real-time simulator for large scale distribution grid assessment at multiple time-scales;
(2) Design a communication and computing infrastructure and interconnect the communication and computing infrastructures with HIL simulator;
(3) Enable the interface of open-source network emulators, cybersecurity tools, protection, control and IoT facilities to allow the demonstration, testing and validation of cyber-physical security techniques.

Project Scope

The Eversource Energy Testbed will be built in the following steps.

(1) Interface RTDS NovaCor with TSAT through TRI. RTDS is able to perform real-time electromagnetic transient scale simulation for power grids. In particular, RTDS has a 'distribution mode' specifically designed for real-time simulation with distribution systems. RTDS has rich model libraries for microgrids, protection relays, cyber security, HVDS and FACTS, DERs. TSAT produced by Power Tech Labs can perform real-time phasor domain simulation (electromechanical dynamic simulation) for large scale (e.g. 30,000 buses) on a single PC. Federating RTDS with TSAT allows a hybrid real-time simulation of a large distribution network with over a hundred substaitons.
(2) Build a scalable and hierarchical communication infrastructure through 8 powerful Pica8 whitbox SDN switches to connect grid models to the distributed computing infrastructure and physical devices.
(3) Create a distributed computing platform by using 6 Dell PowerEdge R740 servers. The computing infrastructure will be interconnected with the communication network and RTDS to virtualize advanced protection, automation and control functions in the distributed computing platform and test varioius distribution management functions.
(4) Integrate RTDS a professional network emulator hardware KMAX Pro to enable the testing of distribution networks under real-world adverse network conditions like network congestion, slow links, time outs, and other networked failures. RTDS has commited to support UConn's effort to interfacing RTDS with cyber libraries such as DETERLab, NS-3, Mininet free of charge. With the integration of those cyber libraries, the Eversoure Energy Testbed will be able to include behavior analysis and defensive technologies including DDoS attacks, worm and botnet attacks, encryption, pattern detection, and intrusion-tolerant storage protocols.
(5) Connect the Eversource Energy Testbed with high precision measurement and visulazition functions, IoT device, protection and microgrid controllers. A Keysight InfiniiVision MSOX4154A Oscilloscope, a E5071C-440 ENA Vector Network Analyzer, and a NI CRIO testing platform. A monitor wall will be built for visualizing experimental results, and two Dell PCs will be used to run tests and experiments on the Testbed. Distribution system protective relays and microgrid controllers donated by Schweitzer Engineering Laboratories will then be interconnected into the testbed.

Background / Justification

The distinguishing aspect of the Eversource Energy Testbed lies in integrating a high fidelity power system simulator with cyber tools, IoT, software defined networking, and distributed computing to establish a programmable testbed to help design and verify distribution network technologies. It will substantially improve Eversource and UConn's capacities of research and education on next-generation smart grid, microgrid, cyber security, smart cities and critical infrastructure resilience. It will enable interdisciplinary research activities across UConn departments to accelerate fundamental as well as applied research, and will provide a powerful experimental platform and generate big data sets to stimulate innovations towards resilient, reliable, secure and sustainable power infrastructures.

This testbed will become one of the most powerful cyber-physical power distribution testbeds in New England. It will significantly accelerate technological innvoations in grid resilience, storm preparedness and emergency response by emulating grid responses under various disturbances. It will help validate and prototype technolgoies that address CT's goals of renewable energy penetration (e.g. 40% by 2030), provide accurate mapping of DERs, evaluate energy storage options and meet future energy needs (e.g. EVs). The Eversource Energy Testbed is particularly flexible and useful in cyber and physical security testing as it includes close-loop interface with cyber network simulator to enable cyber attack, defense, and mitigation studies.

Business Process and / or Technical Improvements:

The Eversource Energy Testbed can be used for testing and validating grid modernization and cybersecurity techniques for utilities. It could test cybersecurity technologies for detecting, responding to and preventing known and unknown cyber threats. It fully supports the testing of grid modernization techniques including relays (including traveling wave relays), DERMS, power electronic devices, microgrid controllers, distribution automation, substation automation devices, GPS-enabled devices, and new data analytics etc. The validated new technologies would shape the energy landscape in CT and the New England region by mitigating power outages, saving millions in unnecessary expenditures in infrastructure hardening and increasing the hosting capacity of DERs.

The Testbed has the potential to speed up the employment of cybersecurity techniques for modeling, analyzing and detecting cyberattacks on grid edges, DMS, distribution substations, AMI, as well as security problems in hardware and IT networks. It will help Eversource Energy increase renewable energy penetration by maximizing hosting capacities at special locations and develop online hosting capacity mapping and forecasting. The testbed will allow studies to optimally allocate energy storage systems to enhance electricity reliability and resilience for customers, increase the hosting capacity of DERs, achieve long-term economic benefits through energy arbitrage and market participation, and much more. In the long run, the Testbed project will help Eversource Energy build a flexible service platform to enable increasingly integrated customer side systems, provide flexible and resilient energy for customers while maintaining a reliable grid and improved social welfare.

Alternatives Considered with Cost Estimates

Another Hardware in the Loop (HIL) simulator Opal-RT (together with Scalable Network) is quoted for $990,538.85, which is $113, 013.85 more expensive than the RTDS set. Overall, the Opal-RT-based testbed would cost about $1.22 million if the servers, switches and ancillary equipment are included. A detailed comparision shows that the RTDS based testbed is more cost-effective, and RTDS is known for its stable performance and is more credible and widely accepted in power industry. Furthermore, RTDS offers unlimited and free software maintenance and technical support for UConn, whereas Opal-RT can only

provide a 5 year maintenance at a cost. Customers from top power engineering programs in the U.S., national laboratories, major power utilities and Navy sponsored research programs have unanimously provided positive recommendations for RTDS, especially their newly released NovaCor. After a careful survey and analysis, the Eversource Energy Center (EEC) has decided to build the Eversource Energy Testbed based on NovaCor, the new generation of RTDS real-time simulator.

Project Schedule

Milestone/Phase Name	Estimated Completion Date
Equipment purchase	February – March 2019
Training and setup	May 2019

Regulatory Approvals

N/A

Risks and Risk Mitigation Plans

For quality assurance, the project will be actively monitored and evaluated on a regular basis. Risks and project changes will be effectively addressed through discussions in our bi-weekly meetings between execution team and advisory committee members. Potential risks associated with the development of the testbed and risk mitigation strategies are listed below.

Risks and Risk Mitigation Plans

Risk	Severity	Mitigation Strategy
Latency in Pica8 network larger than required by power system layer functions	L	Use fast recovery techniques that pre-compute alternative paths; reconfigure paths without contacting SDN controller
Unavailability of sufficient dynamic data for DERs and controllers	L	Use typical models and control parameters
Numerical errors in hybrid simulation	L	Outlier/bad data cleansing; careful selection of simulatior steps
Interface issues among HIL simulator and cyber tools	L	Ensure the use of true DNP3, IEC61850, OpenFlow and other standards and CIM technique; fix potential problems through RTDS technical support team

References

Attachments (Quotes, One-Line Diagrams, Images, etc.)

	Equipment/Component*	Cost**
A	RTDS hardware: three chassis based NovaCor system	$ 843,975.00 (include two year extended hardware warranty)

B	Power Tech Labs: DSATools system	$ 46,550.00
C	8x Pica8 P-3922 48-Port 10GbE Switch	$ 47,520.00
D	6x PowerEdge R740	$ 56,157.96
E	KMAX the Network Emulator with 10G interfaces	$ 10,050.00
F	Keysight InfiniiVision MSOX4154A oscilloscope and 1147B current probe and application budle	$ 22,328.00
G	Vector Network Analyser and calibration kit	$ 70,562.05
H	NI CRIO	$ 6,709.08
I	LED Video Wall Display System	~$ 10,000.00
J	2 Dell 3630 PCs and 2 34 Curved USB-C Monitors	~$ 6,000
Total:		$ 1,119,852.09

*Costs may vary when equipment is ordered by Eversource's Procurement Department

a. **RTDS HARDWARE: Three Chassis Based NovaCor System**
   Quotation: refer to '1_P3896.6-Eversource-Jan14-2019-RTDS-NovaCor-Quote.pdf'
   Total Hardware cost (including shipping): $ 817,475.00
   2 Year extended Hardware Warranty: $ 26,500.00

b. **Power Tech Labs: DSATools System**
   Quotation: refer to '1_P3896.6-Eversource-Jan14-2019-RTDS-NovaCor-Quote.pdf'
   Cost: $ 46,550.00

c. **Pica8 P-392 10GbE/40GbE Switches**
   Quotation: refer to '2_CX-96960 Pica8 switches x 8 discounted JAN 2019.pdf'
   Cost: $ 47,520.00

d. **PowerEdge R740 Servers**
   Quotation: refer to '3_Quote_US_PC_SC_3000031809272.1_2018-12-12.pdf'
   Cost: $ 56,157.96

e. **KMAX the Network Emulator with 10G Interfaces**
   Quotation: refer to '4_Univ of Conn (Eversource)_Special Discount.pdf'
   Cost: $ 10,050.00

f. **MSOX4154A Mixed Signal Oscilloscope with Application Budle and Current Probe**
   Quotation: refer to '5_AAAQ30962 - University of Connecticut.pdf'
   Cost: $ 22,328.00

g. **E5071C-440 ENA Vector Network Analyzer and Calibration Kit**
Quotation: refer to '6_Quote #1465940-1.pdf' and 6_Quote #1465949-1.pdf'
Cost: $ 70,561.05

h. **National Instruments CompactRIO**
Quotation: refer to '7_NIQuote_1411936-1.pdf'
Cost: ~$ 6,709.08

i. **2x2 Video Wall Bundle**
Example system:
https://www.displays2go.com/P-38949/4-Screen-LED-Video-Wall-Display-System-includes-Mounting-Brackets-Cables?st=Category&sid=29857
Estimated Cost: $ 10,000.00

j. **2 Dell PCs and 2 Dell Curved Monitors**
Quotation for reference: '8_Quote_US_PC_SC_3000027404024.1_2018-08-01.pdf'
https://www.dell.com/en-us/shop/dell-ultrasharp-34-curved-usb-c-monitor-u3419w/apd/210-arcl/monitors-monitor-accessories?ref=p13n_ena_pdp_vv&c=us&cs=19&l=en&s=dhs
Estimated Cost: ~$ 5,000.00

Project Checklist – Transmission and Substation