Evaluation of the Netherlands' International Test Facility for Smart Grids

B. Palmintier and A. Pratt
National Renewable Energy Laboratory

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Technical Report
NREL/TP-5D00-63638
June 2015

Contract No. DE-AC36-08GO28308

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Prepared under Task No. WTJL.1000

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List of Acronyms

AGC	automatic generation control
EnTranCe	Energy Transition Center
ESIF	Energy Systems Integration Facility
FPAI	Flexible Power Application Infrastructure
IGMS	Integrated Grid Modeling System
ITF	International Test Facility for Smart Grids
NREL	National Renewable Energy Laboratory
PV	photovoltaic
RVO	Rijksdienst voor Ondernemend Nederland

Executive Summary

The Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland, or RVO) engaged the U.S. National Renewable Energy Laboratory (NREL) for two primary purposes: to evaluate the International Test Facility for Smart Grids (ITF) sponsored by RVO and to learn best practices for integrated test facilities from NREL's Energy Systems Integration Facility (ESIF). This report covers the ITF evaluation and is largely based on a one-week visit to the Netherlands in November 2014.

Background information on the goals and objectives of the ITF is provided, followed by a description of its current status and capabilities, including (1) unit testing of individual (hardware) components, (2) integration testing of (hardware) device interaction with simulated or small-scale hardware smart grid systems, and (3) scalability/performance testing using software simulations of a single medium-voltage distribution grid with a focus on demand-response approaches. A high-level comparison to other smart grid test beds and simulation platforms is also provided.

Several aspects of the ITF are addressed, including its business model, modularity, compatibility, applicability to non-Netherlands locations, ability to provide testing across multiple energy systems, scalability, performance, multisite connectivity, and project management and schedule. Suggested actions are summarized in the table below.

Table 1. Suggested Actions

Item	Comments and Suggested Actions
ITF business model	In its current implementation, the ITF is less of a facility than a service, framework, and modeling system. Consider changing the name to better reflect this reality.
ITF simulation status	Include a fully integrated, proof-of-concept demonstration for a small example scenario as a near-term deliverable for the ITF project.
Modularity	Consider developing and publishing an application programming interface for the larger simulation framework to enable additional tools to be incorporated more easily.
Compatibility	Consider developing translation utilities to ease the import and export of system data and results among the ITF tools and the data formats commonly used by utilities and other smart grid stakeholders.
Applicability to non-Netherlands locations	Survey current and planned simulation modules for usability for worldwide simulation. Consider alternative tools that can be used for worldwide simulation, and ensure support for three-phase unbalanced power flow.
Simulation time step	Consider adding a module or adopting a different simulation tool that can capture faster time-step services.
Ability to provide testing across multiple energy systems	Consider developing simulation models for integrated system components or developing a modular application programming interface with support for multi-domain tools.

Scalability	Conduct multiple medium-voltage-system proof-of-concept simulations with the entire simulation suite followed by scaled testing with 1, 10, 100, and 1,000 different medium-voltage systems with correspondingly increasing numbers of customers.
Price (and physics) taker	Map, design, and test simulation proofs of concepts to first enable and then confirm closed-loop interactions for price and physical phenomena.
Voltage levels	Expand distribution system power flow to include the low-voltage network. Consider a path forward for integrating high-voltage power flow to capture bulk phenomena.
Performance	As part of the scale testing suggested above, profile system performance. Identify and fix any identified bottlenecks.
Hardware test link	Consider conducting one or more proof-of-concept integrated simulations.
Multisite connectivity	Consider establishing a dedicated data connection (virtual network) among the ITF locations to enable integrated real-time experiments.
Project management	Consider engaging more actively with the full consortium and regularly checking in.
Schedule	Discuss and agree on specific concrete deliverables and a schedule for the remaining project period. Adjust scope, resources, and expectations as appropriate.

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Background and Objectives

International Test Facility

The Netherlands' International Test Facility for Smart Grids (ITF) is a multiyear project funded by the Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland, or RVO) that has the intention of developing the capability to simulate and test emerging smart grid technologies at scale. The consortium is led by DNV-GL (formerly DNV-Kema) with close cooperation from TNO.[1] Other members of the consortium include the Eindhoven University of Technology, ICT Automatisering, VITO,[2] and the Energy Academy Europe's Energy Transition Center (EnTranCe).

ITF has three main capabilities:

1. Unit testing of individual (hardware) components, including protocol compliance and interaction with the grid
2. Integration testing of (hardware) devices using simulated or small-scale hardware smart grid systems
3. Scalability/performance testing using software simulations of a single medium-voltage distribution grid with a focus on demand-response approaches.

The first two capabilities are partially covered by existing test labs among consortium members, so the primary focus has been on the software-based scalability/performance test capability.

Goals of the ITF

The primary stated objective of the ITF by the ITF team is to help manage the risk of "the large-scale implementation of [the] smart grid…by offering realistic simulation environments" [1].

The sponsor of the ITF (RVO) is interested in "integral testing of the system, not just the parts" [2, p. 14] that fills a gap by "connect[ing] three complex systems…electricity, gas, and (district) heat" [2, p. 13].

A market survey was conducted early in the project to gauge potential customer interest in the ITF. Although the results were described as "not overwhelming," [1] four areas of interest were found most relevant:

1. **Scaling** of smart grid approaches, particularly for demand response and load shedding
2. The feasibility of smart grid **business models**, particularly for aggregators providing balancing, grid support, and home services
3. Optimization of scenarios for **societal/ecological** benefit

[1] TNO is typically referred to only by its acronym. The full name is the Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organization for Applied Scientific Research).
[2] VITO is typically referred to only by its acronym. The full name is the Vlaamse Instelling voor Technologisch Onderzoek (Flemish Institute for Technological Research).

4. A secondary interest in the **robustness** of smart grid systems, including response from distributed agent-based systems during critical situations and performance impacts of a bad agent or other data manipulation attack.

Background of This Report

As part of Technical Service Agreement 14-651, RVO engaged the U.S. National Renewable Energy Laboratory (NREL) for two primary purposes: to evaluate the ITF and to learn best practices for integrated test facilities from NREL's Energy Systems Integration Facility (ESIF). This report covers the ITF evaluation and is largely based on a one-week visit to the Netherlands in November 2014. A summary of this trip can be found in Appendix A.

ITF Status

Although the ITF scope includes the possibility of hardware testing and the potential for multisite integrated testing, today the ITF's efforts largely focus on a "large-scale" software simulation environment.[3]

Certainly, many consortium partners have considerable preexisting infrastructures for hardware testing in isolation. Highlights include Eindhoven University of Technology's Smart Grid Laboratory,[4] the Energy Academy Europe's EnTranCe facility (under construction),[5] VITO's Energyville (under construction),[6] and DNV-GL's Flex Power Grid Laboratory.[7]

It seems that the primary effort to unify these existing capabilities is through an ITF data warehouse that would provide a central database for collecting simulation data from various experiments to facilitate collaboration. At present, this data hub has been designed but not yet fully implemented.

The main focus of the ITF has been on a larger-scale integrated modeling platform (ITF-Sim) intended to provide scalability analysis. A block diagram of this capability is shown in Figure 1.

[3] The vast majority of discussions during NREL's on-site visit to the ITF surrounded this large-scale simulation framework; however, there was not a specific or dedicated ITF facility. Also, the ITF introduction presentation stated that the "International Test Facility for Smart Grids…assess[es] the system under test by creating a simulated energy market and electricity grid," [1, p. 4] but it provided minimal description of other capabilities.
[4] See https://www.tue.nl/en/university/departments/electrical-engineering/research/research-programs/electrical-energy-systems-ees/organisation/facilities/smart-grids-laboratory/.
[5] See http://www.en-tran-ce.org/.
[6] See http://www.energyville.be/?q=en/building_thor_park.
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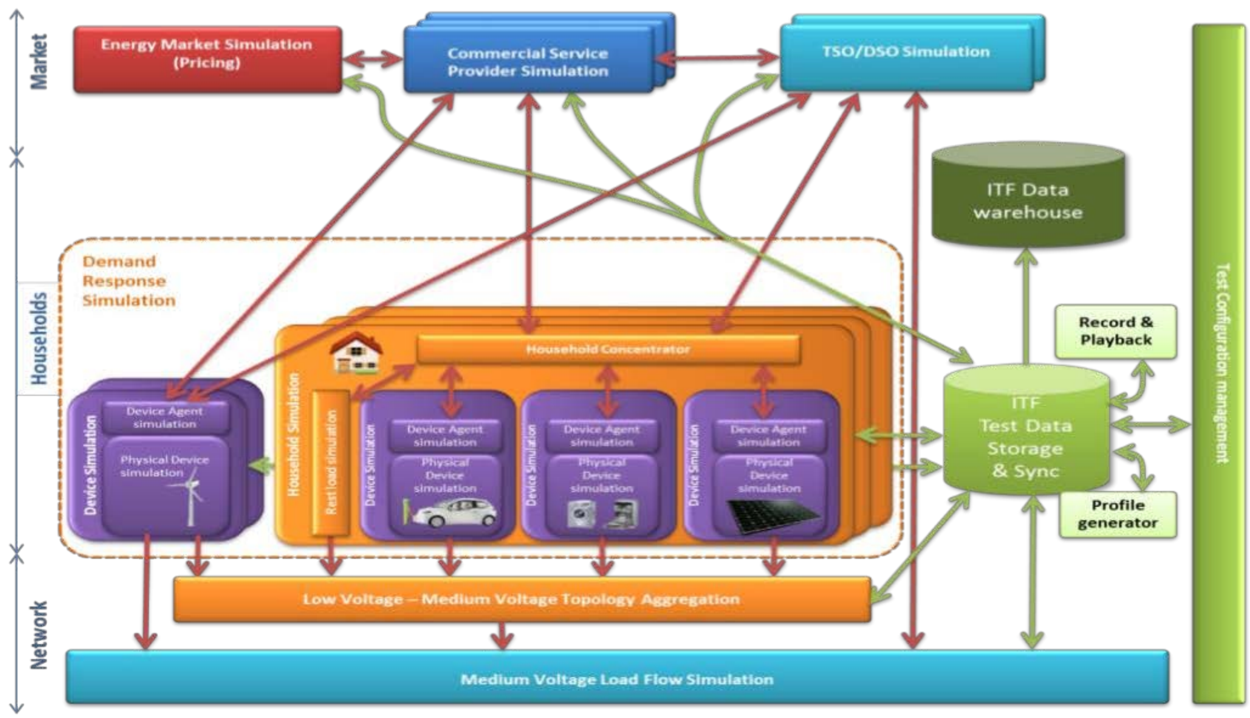

Figure 1. Block diagram of ITF's "large-scale" simulation environment [1], [3]*. Image from RVO*

In this system, the core capability to simulate large populations of distributed energy resources, including agent-based modeling of semiautonomous decision makers, largely leverages the existing Resource Abstraction Layer simulator (RAL-Sim) of the Flexible Power Application Infrastructure (FPAI)[8] framework previously developed by TNO to simulate the PowerMatcher hierarchical transactive control framework. The medium-voltage load flow simulation, energy market simulation, and transmission system operator/distribution system operator simulation modules have already been built for past projects by DNV-GL. The other modules are not yet implemented and will involve custom developments built on past analysis efforts for clients by DNV-GL. These include a commercial service provider simulation, business model analysis (not shown here, but shown in other diagrams as an umbrella over the top), test data storage and synchronization, and (automated) test configuration management. Efforts are underway to link the modules together.

[8] See http://www.flexiblepower.org/.

High-Level Comparisons to Other Smart Grid Test Beds

A team from the Technical University of Denmark recently conducted an international survey of test facilities for the smart grid. Their primary focus was on software tools in use, but the project also included a survey of hardware test facilities presented in [4].[9] Highlights from this report are the integrated testing capabilities from NREL's ESIF,[10] Technical University of Denmark's SysLab, and Austrian Institute of Technology's SmartEST lab. All of these facilities support integration studies of multiple technologies, including communication and grid aspects, and as such could be strong opportunities for both future inspiration and collaboration.

Of these, NREL's ESIF is unique in its large scale and its ability to simultaneously conduct integrated testing across electric, thermal, fuels, and data systems. The ESIF represents a very large-scale investment that is unlikely to be practical within the ITF; however, scattered throughout the ITF consortium are a number of strong testing facilities, although they are somewhat more limited in scale. If desired, it would be possible to integrate these diverse facilities along with the ITF-Sim platform to create a virtual facility that fulfills the ambitious integrated goals laid out for the ITF.

A number of efforts compare with ITF-Sim. Specifically, GridLAB-D [5], in active development since 2008 by the U.S. Pacific Northwest National Laboratory, provides an integrated smart grid simulation platform for a single distribution system. It includes end-use load models, three-phase unbalanced power flow, and simple-price/market-based interactions. As a result, it is somewhat comparable to TNO's RAL-Sim, but GridLAB-D natively includes power flow simulation, whereas RAL-Sim does not. However, RAL-Sim is built around a more generalized, well-designed, and published interface abstraction that allows component reuse beyond RAL-Sim, even by third parties. In contrast, although GridLAB-D is open source, it has a custom simulation-only focused interface for multi-agent interaction. A similar agent-based tool for distribution simulation is also available from the German university Oldenburger Institut für Informatik in the Mosaik co-simulation platform [6]. Also, NREL is actively developing the Integrated Energy Systems Model (IESM), a co-simulation tool for distribution systems that will allow for the exploration of market structure and retail tariff impacts on smart grids. In its present state, the tool combines GridLAB-D with large numbers of model-predictive control-based home energy management systems [7].

Researchers at the University of Leuven have developed a library in Modelica, an open-source modeling language, "for the integrated modeling and simulation of buildings and districts" called the Integrated District Energy Assessment by Simulation (IDEAS) library [8]. IDEAS contains sublibraries for buildings, low-voltage electrical distribution grids, and building and distribution network controls. A number of other open-source (e.g., OpenDSS) and commercial (e.g., PowerFactory, Cyme, Synergi, DEW) distribution modeling tools have also been used for this type of analysis by using external tools providing more sophisticated load or device models.

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[9] Additional related reports are available from this same source.
[10] See http://www.nrel.gov/esif/index.html.

All of these environments are best suited for use with a single distribution system, and typically they do not capture critical interactions with the larger bulk/wholesale power system. The Integrated Grid Modeling System (IGMS) simulation platform under development at NREL uses co-simulation to link large numbers of instances of GridLAB-D to bulk power flow and wholesale market simulations. This scope is similar to the larger ITF-Sim effort, although IGMS explicitly captures the interactions among larger numbers of distribution systems, whereas ITF-Sims currently focuses on a single distribution system. IGMS also simulates down to the automatic generation control (AGC) timescale (4 to 6 seconds), compared to ITF-Sim's planned 5-minute time step. The AGC timescale enables exploring impacts on reserve deployments and the impacts on distributed energy resources or aggregators when providing the associated frequency regulating (primary) reserve. Other tools in this integrated T&D space include the GridSpice project [9], which combines bulk power and distribution analysis, and [10], which proposes a platform for co-simulation of the market domain, using the AMES Wholesale Power Market Test Bed, and the distribution physical power system domain, using the GridLAB-D distribution platform.

There has also been some past effort to develop more generic co-simulation frameworks. For example, the U.S. Pacific Northwest National Laboratory is developing the Framework for Network Co-Simulation (FNCS) [11] aimed at linking GridLAB-D to other simulation tools, including the NS-3 communication simulator and a custom transmission simulator. Similar integration would be possible using the Functional Markup Language (FML) [12] or SimPy [13]. Such an integrated system would provide a scope similar to the ITF-Sim environment.

Observations and Suggestions

Business Model

The ITF business model seems to be a service-oriented approach in which analysis and testing capabilities are developed as needed to support specific customer needs.

Supporting information includes:

- "The International Test Facility for Smart Grids is a testing and verification *service*" (emphasis added) [1, p. 4].
- "Unlike conventional testing services, our offering is able to create a realistic simulation environment by incorporating proven simulation modules" [1, p. 4].
- "The International Test Facility (ITF) for Smart Grids provides *services*…that can be tailored to the customer's needs" (emphasis added) [1, p. 3].

This consulting-style approach differentiates the ITF from the other test beds described above. This type of service dedicated to the smart grid could certainly provide tremendous value for the changing power grid landscape; however, the use of "facility" in the name implies something closer to many of the other prebuilt test beds described above, in which something tangible—often a building or part of a building—exists or is constructed with the goal of supporting a specific purpose. A different name for this effort would help clarify its actual scope.

Suggested action: Change the name of the ITF to better reflect its actual approach.

ITF-Sim Integrated Testing

The entire ITF-Sim suite has never been tested together.

Suggested action: Include a fully integrated, proof-of-concept demonstration for a small "toy" example scenario as a near-term deliverable for the ITF project. The insights gained will be invaluable in successfully integrating the tool for future, richer analysis. Such a demonstration would also greatly increase the tool's credibility with potential customers.

Modularity

As shown in Figure 1, ITF-Sim is built from a combination of existing and developing modules and uses a semi-customized co-simulation framework to pass data among them. This current design is fairly modular: It will be reasonably easy to separate out components for stand-alone use. TNO's FPAI simulation framework also exposes a well-established application programming interface that would make it reasonably easy to incorporate new models or tools into the lower-level demand-response simulation. At the larger-scale market, the transmission system operator/distribution system operator and aggregator agents are connected using an MQ Telemetry Transport publish-and-subscribe message bus that should make it practical to add additional tools at this higher level. Such an integration would require developers to agree on the set of messages and related application-specific protocols.

Suggested action: Consider developing and publishing an application programming interface for the larger ITF-Sim to more easily enable the incorporation of additional tools into the framework. This development effort would also help coordinate the multiparty project team.

Compatibility

The larger-scale integrated modeling platform of ITF-Sim heavily leverages the resource abstraction layer simulation of RAL-Sim developed by TNO. This system defines its own interfaces; however, it is available as an open source, which could allow third-party developers to interact with the system from other software packages. The components developed by DNV-GL are closed source and largely rely on a deep set of proprietary tools developed by DNV-GL during past projects. One exception is that the market agent is built around the commercially available PLEXOS modeling tool from Energy Exemplar. This tool has become the de facto standard for large-scale production-cost modeling that captures market and generator dynamics. As a result, ITF-Sim will offer compatibility with tools already used by the project team, but it will require data conversion from customers before being able to simulate specific systems.

Suggested actions: Consider developing translation utilities to ease the import and export of system data and results among the ITF tools and the data formats commonly used by utilities and other smart grid stakeholders. Support Common Information Model-style ontologies, specific simulation tools such as PowerFactory, and potentially raw geographic information system data. These tools would help both the ingestion of system data for simulation with the ITF and greatly increase the usability of output data from testing and simulation stored in the data warehouse. Alternatively, portions of the ITF system could be designed to be swapped out to directly use non-proprietary commercial tools for various simulation elements.

Applicability to Non-Netherlands Locations

ITF-Sim seems to have been designed to primarily serve the Netherlands and closely related power systems, because the core modules are not easily adapted to non-European feeder configurations, such as less reliable network architectures that might be found in developing markets in India and China or the United States' extensive use of single-phase medium-voltage distribution "laterals" and low-voltage networks limited to only a few customers.

Suggested actions: Survey the current and planned ITF-Sim module suite for usability for worldwide simulation. Adjust designs for un-built modules to be more general. Consider alternative tools that can be used for worldwide simulation, and ensure that the current system supports three-phase unbalanced power flow.

Simulation Time Step

Although ITF-Sim's nominal time step of 5 minutes will allow exploring a range of quasi-steady-state time series phenomena and market dynamics, it may be too slow to interact with some grid support services, particularly AGC-signaled services such as frequency responsive reserve (primary reserve) that acts on the 4- to 6-second timescale. This reserve class typically has the highest value in ancillary service markets, so it can represent an important revenue stream for aggregators and individual owners of distributed energy resources, such as storage, electric vehicle smart chargers, and demand response. Capturing these faster time steps would require developing an AGC and reserve deployment model that is not part of PLEXOS-based market models. NREL has developed the Flexible Energy Scheduling Tool for Integrating Variable Generation (FESTIV) [14], one of the only tools that captures AGC and reserve dynamics at the bulk power scale, which could be incorporated into ITF for this purpose.

Suggested action: Consider adding a module or adopting a different simulation tool that can capture faster time-step services.

Ability to Provide Testing Across Multiple Energy Systems

As currently designed, ITF-Sim focuses on the electric power system. Considerable reworking would be required to integrate additional systems, such as natural gas, (district) heating, or communication systems.

Suggested action: Consider developing simulation models for integrated system components. Even highly simplified representations would enable beginning to look at multi-domain interactions. Alternatively, the development of a modular application programming interface with support for multi-domain tools would enable third-party solutions providers from other domains to more readily integrate additional tools and provide multi-domain simulations.

Scalability

There is some question as to the actual scalability of the system. The stated objective is to scale to 100,000 to 1 million customers; however, the ITF-Sim framework is built around a single medium-voltage (approximately 15-kV) distribution system, which in Europe typically corresponds to approximately 10,000 customers. TNO's underlying RAL-Sim framework is highly scalable and has been tested with more than a million devices, so there is a question about the scalability of the larger ITF-Sim.

Suggested action: Conduct multiple medium-voltage system proof-of-concept simulations with the entire ITF-Sim suite to ensure that the current design scales. As a follow-on, conduct scale testing to estimate ITF-Sim performance with 1, 10, 100, and 1,000 different medium-voltage systems with correspondingly increasing numbers of customers.

Price (and Physics) Taker

As currently implemented, the distribution system does not impact the bulk system either physically or economically. This is because of the simulation of only a single medium-voltage system, which has a small impact on the wholesale prices or bulk grid voltage and power flow. As a result, the wholesale prices (and bulk system voltages) are effectively treated as exogenous and not changed by what happens at the distribution level. The modeled system is hence a price (and physics) taker. In a smart grid future, the collective impacts of large numbers of smart distribution networks could challenge this assumption and actually influence the price and power flow physics.

Suggested action: Map, design, and test full ITF-Sim proofs of concepts to first enable and then confirm closed-loop interactions for price and physical phenomena.

Voltage Levels

Power flow simulation in ITF-Sim is limited to only the medium-voltage level; the low-voltage (240-V) and high-voltage (> 50 kV) power flows are not captured. The lack of low-voltage power flow means that the approximately 200 customer loads connected to each medium- to low-voltage substation are lumped together.[11] As a result, any voltage violations or overcurrent conditions on the low-voltage network are not captured. The lack of low voltage also makes it difficult to study the potential for distributed energy resources to provide voltage and reactive power support, because the low-voltage impedance is not captured.

The simplifying assumption of not modeling the high-voltage power flow prevents the system from exploring the interactions among neighboring medium-voltage distribution systems or the interactions with bulk power grid phenomena such as voltage and reactive power variations. The system does support distribution and wholesale market interactions, and it could be used with both the zonal prices (for example, one price per country) used in Europe and the nodal or locational marginal prices used in United States and other markets.

Suggested action: Expand the distribution system power flow to include the low-voltage network. Consider a path forward for integrating high-voltage power flow to capture bulk phenomena both to accurate capturing voltage and other inputs to the medium-voltage power flow and to capture interactions among multiple distribution systems.

Performance

Because the system was not yet up and running, it was not possible to directly observe its performance. However, the use of co-simulation and the already highly parallelizable RAL-Sim should provide good ITF-Sim performance for the use cases within its current scope. Increasing the model scope and scale to explore interactions among multiple medium-voltage distribution systems and incorporating low-voltage and high-voltage power flows might require additional architecting to ensure high performance, particularly at the layers of the MQ Telemetry Transport and power flow integration.

Suggested action: As part of the scale testing suggested in the Scalability section above, profile system performance. Identify and fix any identified bottlenecks.

Hardware Test Link

Currently, ITF's capabilities for hardware testing and larger-scale simulation are largely distinct. Looking forward, it is likely that there will be increasing interest in the ability to link these

[11] Note that European distribution systems are considerably different from those in the United States. In Europe, there are extensive low-voltage (240-V) networks running off of small medium- to low-voltage substations serving hundreds of customers, and even at low voltage the vast majority of connections are three phase. In contrast, the U.S. distribution system makes extensive use of single-phase "laterals" at the medium-voltage (~4-KV to 40-kV) level and much smaller medium-voltage/low-voltage transformers serve only a handful of customers (often < 10) through short, direct connections. These U.S. single-phase transformers have a center tap on the low-voltage side to provide two 120-V phases that are 180-degrees apart, which allows high-power loads (electric ranges; heating, ventilating, and air-conditioning; clothes driers) to access 240-V, whereas most loads use 120 V.

capabilities to drive hardware testing from larger-scale simulations in real time and to have real-time hardware (or field) measurements impact the larger-scale simulations.

The FPAI simulation framework does have some capability to incorporate actual controllers and devices into its simulations. This capability could be used to link the control signal and responses between this core demand-response simulation and hardware. However, it is likely that additional development would be required to ensure that the entire system—including bulk power, aggregator agents, and power flow—remain synchronized with real time. In addition, capturing the physical network phenomena, such as voltage impacts, would require creating an additional link from the power flow simulation to hardware via a grid simulator (AC power amplifier). Similarly, environmental and weather phenomena, such as solar irradiance for PV and temperature for building energy demand, would also need to be coordinated to ensure simulation consistency. NREL has done some work in this area of co-simulation among larger system models and hardware-in-the-loop testing [15] among other projects.

Suggested action: Consider conducting one or more proof-of-concept integrated simulations. The experience and insights gained from such an exercise would both rapidly accelerate the team's understanding of what is required for integrated experiments and greatly increase the project's credibility for being able to conduct integrated experiments.

Multisite Connectivity

The lack of a single distinct location for the ITF makes it difficult to link the extensive but scattered capabilities of the consortium into a truly integrated offering. Currently, there are no communication links suitable for integrated software or hardware simulations. The current extent of multisite offerings is limited to data sharing through the forthcoming ITF data warehouse. This data warehouse will enable some advanced collaboration, and possibly include a proposed visualization table interactive demonstration for flight simulator interactions; however, as long as the data link is primarily through the data warehouse, any such coordination among sites would inherently be offline and would not enable the unique capabilities to interact directly.

Suggested action: Consider establishing a dedicated data connection (virtual network) among the ITF locations to enable integrated real-time experiments. Again, proof-of-concept demonstrations would greatly increase team capability and credibility.

Project Management

The ITF project has a strong and diverse membership; however, it is unclear how many full-team interactions are happening. It seems that DNV-GL is taking on the role of project coordination, whereas TNO is providing the majority of development. The majority of the consortium members seem to be only partially included in active portions of the project.

Suggested action: Consider engaging more actively with the full consortium. Some of the integrated proofs of concepts suggested in other observations will inherently encourage such collaboration. In addition, regular (quarterly? monthly?) full consortium check-ins would provide improved visibility among all team members and could enable a leap in capability by leveraging expertise and experiences among the entire team.

Schedule

Given the current project status, the ITF has an ambitious schedule to achieve the stated goals of the project in the remaining short time frame.

Suggested action: Discuss and agree on specific concrete deliverables and a schedule for the remaining project period. Adjust scope, resources, and expectations as appropriate.

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Appendix A: NREL's Trip to the Netherlands—Summary and Photos

Table 2. Recap and Highlights

Date (2014)	Location	Contacts	Highlights
Nov. 9	Fly DEN-MSP-AMS	—	Fly to the Netherlands. Land at 6:30 a.m.
Nov. 10	RVO in Utrecht	Otto Bernsen—Host for week Nichole Kerkhof-Damen Wito van Heemstra Marco Kolkman Maus Dieleman Maarten Dasselaar Marion Bakker Frank Witte	All-day meeting with RVO—economic development agency that has a role similar to the U.S. Department of Energy in the smart grid area All: Discuss energy program at RVO Key: IPIN (Innovation Program for Intelligent Networks; equivalent to "Smart Grid") Palmintier: Presentation on ESI, ESIF, and projects Possible foreign cooperation funds Marion interested in microgrid for New York post-Hurricane Sandy. She will be at San Francisco consulate for approximately two months.
Nov. 11	DNV-GL (Kema) in Arnem	Jurgen Timpert, DNV-GL Hans de Heer, DNV-GL Koen Kok, TNO	All-day visit to DNV-GL (formerly Kema)—lead for ITF Tour Flex Power Grid Lab—low-voltage and medium-voltage hardware tests Palmintier: Presentation on ESIF, RHIL, IGMS de Heer: Presentation on ITF—currently only a software design Kok: Presentation on Power Matcher—an open algorithm with software implementation and field trials
Nov. 12	Oosterbeek	John Fonstain, DNV-GL Schi _______, TNO Wilco _______, TNO Johan _______, TNO Koen Kok, TNO[12]	Bernsen's request for second day at DNV-GL not realized. Bernsen and Palmintier had two phone meetings. Call with DNV-GL and TNO to discuss ESIF-TNO link Follow-on call with Fonstain from DNV-GL on data hub Strategy and expectations with Bernsen
Nov. 13	CoGas in Almelo Energy Transition Center	Richard Lohuis, CoGas M. Gehrels, CoGas Anne Beaulieu, EnTranCe Harold Veldkamp,	Spent day throughout the northern part of the country: CoGas building a demonstration microgrid at their company headquarters—primarily a gas utility with electric in 1 of 3 areas. Strong ties to Alliander

[12] All via teleconference

	(EnTranCe), Energy Academy Europe (EAE), and University of Groningen (UoG) in Groningen Informal TNO conversation in Groningen	Alliander Martin Visser, Gasunie Claudio de Persis, UoG Jacquelien Scherpen, UoG André Faaij, EAE Paul Voskuilen, Alliander Richard Beekhuis, TNO	EnTranCe building an integration facility with 20-pluse containers to simulate smart homes—electric, gas, thermal, and data integration. Located next to huge internet data node—could ease trans-Atlantic tests Energy Academy of Europe (runs EnTranCe) could be a strong collaboration for NREL's iiESI Late evening conversation with Beekhuis (TNO). Clarified that resource abstraction layer (FlexiblePower.org) provides core simulation platform—PowerMatcher and ITF built on it
Nov. 14	Delft University of Technology (TU Delft) Alliander at Schiphol Airport Fly AMS-ATL	Miro Zeman, TU Delft Jose Rueda, TU Delft Laura Ramirez Elizondo, TU Delft Bram Ferriera, TU Delft Bram Reinders, Alliander Paul Voskullen, Alliander Paul Burghardt, Smart Grid Evolution Program	Busy day in central-west part of country: TU Delft—strong Electrical Sustainable Energy research group (Peter Palanski is new lead). Many possible partnerships, particularly with Intelligent Electric Power Group. Well-equipped high-voltage, power electronics, and real-time digital simulator facilities. Alliander—possible US-Netherlands outline: (1) ESIF link, (2) ESIF-CoGas microgrid, (3) Austin (Pecan St) and Goor. Blend Energy Switch (PS) and Power Matcher Fly to Atlanta
Nov. 15	Fly ATL-DEN	—	Fly ATL-DEN

Figure 2. Otto Bernsen, Jurgen Timpert, and Hans de Heer in DNV-GL's Flex Power Grid Laboratory in Arnhem, Netherlands, which offers configurable low- and medium-voltage component testing, including testing components to failure. ***Photo by Bryan Palmintier***

Figure 3. Jurgen Timpert shows the inner workings of one bank of the insulated-gate bipolar-transistor-based Siemens 1-MVA grid simulator at DNV-GL's Flex Power Grid Laboratory in Arnhem, Netherlands. ***Photo by Bryan Palmintier***

Figure 4. (Left) Central switching substation and (right) modular container "smart homes" at EnTranCe under construction at the Energy Academy Europe, colocated with the University of Groningen in Groningen, Netherlands. ***Photo by Bryan Palmintier***

Figure 5. One of the > 1-MV static generators at the TU Delft high-voltage test laboratory. ***Photo by Bryan Palmintier***

Figure 6. Laura Ramirez Elizondo at the TU Delft low-voltage microgrid simulator. ***Photo by Bryan Palmintier***

Figure 7. TU Delft Power Electronics Laboratory. ***Photo by Bryan Palmintier***

Figure 8. Bryan Palmintier and Miro Zeman at the TU Delft Solar Photovoltaics Laboratory. ***Photo by Bryan Palmintier***

Appendix B: Energy Systems Integration Facility

Energy Systems Integration Facility
National Renewable Energy Laboratory
15257 Denver West Parkway, Golden, CO 80401

Capabilities

The National Renewable Energy Laboratory's Energy Systems Integration Facility (ESIF), shown in Figure 9, contains a unique collection of laboratories specifically focused on overcoming challenges related to the interconnection of distributed energy systems and the integration of renewable energy technologies into the electric power grid. More than a dozen laboratories are divided into four research areas—electricity, thermal, fuel, and data analysis and visualization—which are interconnected through multiple electrical, thermal, and fuel busses that enable easy testing of systems. The Research Electrical Distribution Bus is monitored, controlled, and visualized via a supervisory control and data acquisition system that gathers real-time, high-resolution data. A suite of alternating-current grid simulators, load banks, connections to the local electric utility, direct-current power supplies, photovoltaic (PV) simulators, diesel generators, fixed energy storage devices, mobile electric vehicles, and PV inverters are available for interfacing with microgrid systems. These capabilities make the ESIF a unique environment to test microgrid controller technology, including system functionality and operability testing as well as system compliance with current interconnection standards such as those specified in the Institute of Electrical and Electronics Engineers 1547.

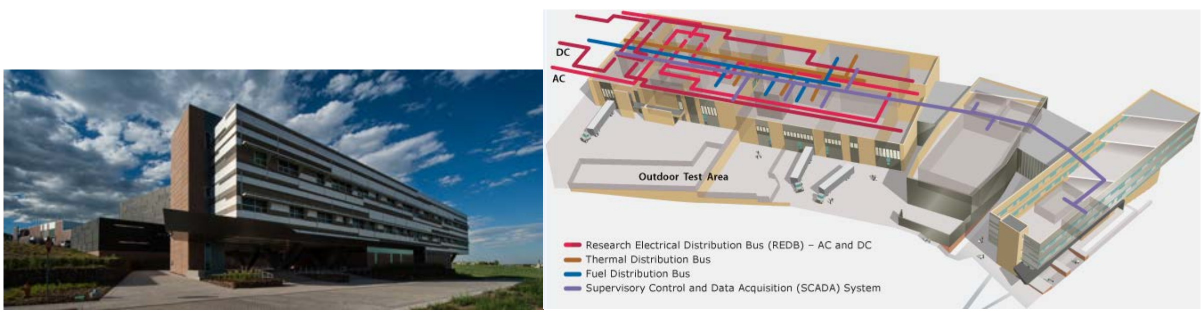

Figure 9. (Left) Photograph of the ESIF and (right) diagram of multi-energy busses connecting various energy laboratories. ***(Left) Photo by Dennis Schroeder, NREL 26382, and (right) graphic from NREL***

ESIF's megawatt-scale power hardware-in-the-loop capability allows researchers and manufacturers to conduct integration tests of hardware devices in the context of real-time, dynamic grid models. The ESIF's 1-MW, bidirectional, three-phase alternating-current grid simulator has independent phase control that enables the simulation of a wide variety of grid scenarios. A 1-MW RLC load bank with 50-VA resolution allows for the development of control and optimal dispatch algorithms for distributed energy resources and loads. The real-time simulation platforms presently in use are Opal-RT/RT-Lab, which is fully integrated with MATLAB/Simulink, and RTDS/RSCAD. Additionally, co-simulation of the real-time simulator with a large number of commercially available power system analysis software tools is also possible.

Equipment

Various types and sizes of grid simulators (AC power amplifiers) are available in the ESIF, ranging from a 15.75-kW unidirectional, small, alternating-current grid simulator to a 1-MW, bi-directional, three-phase, alternating-current grid simulator. The grid simulators have independent phase control that enables the simulation of a wide variety of grid scenarios and multiple points-of-common-coupling. A variety of load banks are available, configurable from 5 kW to 250 kW, including resistance-only and controllable R-L-C load banks. Various types of PV simulators are also available, from the largest at 1.5 MW to the smallest at 100 kW. The smallest consists of 10 10-kW modules and is suitable for testing very fast maximum power point tracking algorithms. Various advanced commercial PV inverters are also present at the ESIF, including several large three-phase PV and storage inverters (≥ 500 kVA) and many small, three-phase (less than 15 kW) PV inverters and a single-phase PV inverter (less than 5 kW) from various manufacturers. All of these are equipped with advanced functionalities, such as voltage and frequency ride-through, frequency/watt control, volt/volt-ampere reactive (VAR) control, constant power factor control, anti-islanding control, VAR injection, and voltage regulation. In addition, some NREL-developed prototype inverters are available that can provide flexibility for exploratory testing and research purposes. Other distributed resources available at the ESIF include diesel generators of various sizes, a natural gas generator, and small energy storage systems.

The real-time simulation platforms at the ESIF include multiple Opal-RT and RTDS systems available for research. Physical test equipment such as grid simulators and PV simulators can be controlled using real-time simulations to provide power hardware-in-the-loop capabilities to characterize a single or multiple distributed energy resources in terms of their individual and system-level responses with system performance optimization.

At the ESIF, a sophisticated data acquisition system based on a commercial supervisory control and data acquisition system platform and National Instruments' CompactRIO can collect data at a sample rate of 51 kHz per channel and has the capability to capture multiple channels concurrently. The data is synchronized with the Global Positioning System to a nanosecond resolution and includes the ability to time stamp and align multiple captures. In addition, high-speed digital oscilloscopes and power analyzers are available to collect waveform data, including two Yokogawa DL850s (16 channels), two Yokogawa DL750s (16 channels), one Yokogawa WT1860 power analyzer (6 elements: 6 voltage and 6 current), multiple Tektronics scopes, and two Yokogawa PZ4000 power analyzers. Several voltage and current probes are also available, including differential voltage probes and fast current probes.