Outcomes, Insights, and Best Practices from IIC Testbeds: Microgrid Testbed

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This article gathers information from Industrial Internet Consortium's (IIC) Communication and Control Testbed for Microgrid Applications. The information and insights described in the subsequent paragraphs were captured in an interview conducted by Joseph Fontaine, VP of Testbed Programs at IIC, with Brett Burger, Principal Marketing Manager, Monitoring Solutions, at National Instruments.

TESTBED PROFILE

The history of the traditional power grid is large-scale, bulk power generation concentrated at large power plants. Power traditionally flowed downhill, transmitting to neighborhoods through feeders. It was stable, reliable (in developed nations) and, with a few sensor measurements, owners could understand what the network was doing. Microgrids break this traditional paradigm. The general concept of a microgrid is an arbitrary region that contains electrical generation, load, and optional storage. One use case for a microgrid includes adding resiliency and robustness to a traditional power grid.

Other use cases include remote power applications such as military forward operating bases or remote villages in developing nations where large populations are disconnected from the main infrastructure. In both cases, there may be a local grid with poor reliability or a diesel generator that requires trucking in fuel. In these situations, microgrids can reduce the reliance on imported fuel and improve electrical network reliability.

Though microgrids offer many benefits, they come with engineering challenges. Solar and wind generation is, by nature, more dynamic than power from nuclear or fossil fueled plants. Wind and solar generation both rely on power electronics designed to standards that assume the majority of generation is from large scale power plants. Microgrids break that assumption.

The IIC's Communication and Control for Microgrid Applications Testbed, or Microgrid Testbed, examines IoT technologies that can help solve these engineering challenges while focusing on open architectures and interoperability.

New Technology

One new technology examined in the Microgrid Testbed is Time-Sensitive Networking, or TSN. TSN is a set of standards governed by the IEEE 802.1 working group and adds, amongst other features, synchronization and scheduling to standard Ethernet.

Wind, solar, and on-grid battery storage use inverters to convert from DC power to the 50 Hz or 60 Hz AC power used in transmission and distribution systems. Inverter standards were created under with the assumption that they constitute a small percentage of capacity on a grid, effectively requiring an already stable network dominated by synchronous generation (Synchronous generators output AC power at grid frequency without the need for any conversion electronics).

That assumption, small percentage of renewables, is breaking down as some regions build up a higher percentage of renewable energy (think solar in southern California and wind in west Texas or off the coast of the UK). It also breaks down for microgrids.

When designing a microgrid, there may be good reason to run it completely off solar power or all wind, using all local storage. Examples, as mentioned above, include forward operating military bases and remote villages.

When inverters designed to be a small percentage of generation capacity meet topologies looking for high concentrations of renewables, the problematic result is grid instability.

Engineers and researchers used the synchronization aspect of TSN and the lab build out of the Microgrid Testbed to construct a microgrid capable of operating with 100% of generation sourced by inverter-based components.

The Microgrid Testbed has been designed to demonstrate the concept with the standard control scheme, and then flip over into "TSN mode," where the inverters that are running solar, wind and storage profiles can communicate with each other. They have a sense of time. They have a sense of prioritization. And those are two capabilities this new TSN technology is bringing to the table. Currently, there are no deployed grids that are using TSN as the core technology to synchronize inverters. In fact, TSN products like the NI CompactRIO© controllers and Cisco IE switches only became available on the market recently. There are research organizations investigating this technology for the power grid and the Microgrid Testbed team is working with some of them.

In alignment with the [Industrial Internet Reference Architecture](), one of the tenets of the Microgrid Testbed is openness and interoperability. The vision is to have all of these inverters, controllers and protection devices, on the same local microgrid network working together. Because TSN is an IEEE-governed standard, those devices could all be made by different vendors and, in theory, still operate as a single system. This interoperability vision has played a large role in guiding the efforts of the Microgrid Testbed – will a new idea or element to explore translate across multiple vendors? Across different communication standards? How would it work?

STRATEGY

The current Microgrid Testbed deployment footprint is an experimentation unit set up in the National Instruments Industrial IoT Lab in Austin, Texas. The Industrial IoT Lab was created to help companies work together on innovative solutions and drive discussions with domain experts to solve real world challenges. In the interest of openness and interoperability, it is encouraging other vendors to come in, plug in their gear and see if it works.

The demonstrator unit helps the testbed team to engage with potential collaborators and interested utility companies to focus on the communication and control technologies such as DDS, TSN, OPC UA, and OpenFMB that are the primary focus of the testbed.

The testbed participants recognize that the utility industry is, for good reason, very cautious and deliberate with new technologies. Safety and reliability are paramount.

The testbed eventually needs to be deployed in the field to fully test the solution. Getting there requires a full bevy of system components along with a utility company to house the field test. The testbed team has been in contact with several utilities in the hope of a move to the next stage of field deployment.

Even utility companies who are not necessarily looking to have components put in are contributing to the testbed with best practices and standards testing. For example, one utility company is heavily involved with the Smart Grid Interoperability Panel (SGIP) and some of their work with open communication data standards has assisted in the interoperability between vendor devices. In this case, the Microgrid Testbed team did not want to create a competing quasi-standard, so we have worked to incorporate into the testbed some of the technology advancing through SGIP's efforts.

PLANNING

The IIC continues to prove how important the existence of an ecosystem is to the Industrial Internet of Things (IIoT). National Instruments is a member of the IIC and, for them, it has been a fantastic way to network and collaborate on industry and application-focused innovations.

The core companies that started the Microgrid Testbed are:

- National Instruments, from an edge measurement and control platform standpoint;
- Real-Time Innovations (RTI), from an open-communication protocol standpoint with DDS technology; and
- Cisco, from a physical infrastructure component standpoint.

The Microgrid Testbed was approved on March 3, 2015, just under a year from the founding of the IIC. The IIC provided the catalyst for this testbed to emerge. Certainly, microgrid was not a foreign concept to any of these companies, but the IIC fostered an environment where these companies connected and realized they were each working on adjacent technologies of a microgrid. The three companies focus on their core areas of expertise, but by working together, they enabled the conversation around solutions that deliver value to businesses and industry at large.

Throughout the work of the Microgrid Testbed, their goal is to ensure it is open to all other potential companies who have adjacent technologies, such as companies focused on software analytics, mobile technology, historian databases, etc.

So, an important question is: What does the future of a microgrid controller look like as the playing field moves from controllers that do not talk to other controllers, to – as in the Microgrid Testbed – controllers that *do* talk to other controllers? The future state is where not only the controllers talk to each other, but they make decisions based on available data and historical data.

When working in the new arena of IIoT, there can be a need for specialized resources. National Instruments is a large company and Cisco is an even larger company. Those two companies had the necessary in-house expertise and, in some cases, product focus on this industry. Bringing it all together allowed those experts in individual fields to work toward interoperable components for a complete solution. As a direct example of the ecosystem, friendly environment the IIC creates, if specific expertise is needed, National Instruments and other members know where to go shopping. They can find the IBM®s, the PTC®s, or the SparkCognition®s, etc., for whatever kind of software or hardware tools may be required.

RESULTS

Many companies are putting work into testbeds and they get to learn about adjacent technologies. This in turn makes vendors better suited to deliver technology components that can fit into a complete solution. For the eventual end user, the testbeds are reducing integration risk and speeding time-to-market for many of these technologies – helping to drive business results through innovation.

Lab Environment

In the lab, the testbed team can run a functioning, low-voltage (for safety) grid that can disconnect from the local three-phase power outlet of the grid and run in island mode with no synchronous generation. That scenario is using the TSN technology, but it also requires some control theory. Specific resources, as mentioned earlier, are needed here. Some of the in-house expertise includes people who have worked on control algorithms to run inverter controls, running the insulated-gate bipolar transistors (IGBTs) that are part of an inverter and synchronizing with the adjacent inverters.

The testbed team worked with an integration partner, Viewpoint Systems, to build out what the team refers to as the five "core cabinets." These cabinets are somewhat portable and contain instrumentation for microgrid setup.

The first in the line of daisy-chained cabinets is the "Main Grid" cabinet that connects to the 3-phase 208VAC in the lab and uses transformers to drop the voltage to a safer voltage below 24VAC. This cabinet also has a built in switch/relay that is used to connect or disconnect the microgrid from wall power. On an actual microgrid connected to a controlled network, this would be referred to as the point of common coupling.

The next three cabinets are the testbed's inverter cabinets. They have a 50-kilowatt power stack from a company called SEMIKRON®. These are grid-scale components though they are not pushing 50 kilowatts through them. Real equipment is closer to grid ready and is important for both development and demonstration to utility professionals. Those power stacks are controlled by a CompactRIO edge controller from National Instruments. Because that specific model of CompactRIO has TSN capability, the testbed team can synchronize the control routines across the three cabinets. The controllers have an Intel® multi-core Atom processor and a Xilinx® field-programmable gate array (FPGA) that form the processing base for the control algorithm.

The final cabinet in the row of five is the "load cabinet." A microgrid requires load and this cabinet was built to automatically or remotely control the basic types of loads: lights, a motor, resistive heaters, etc. The testbed has all of those in the load cabinet to be switched on or off as needed.

Cisco switches connect all of the CompactRIOs in all of the cabinets together. TSN systems need compatible edge nodes and IT infrastructure to work. It is easy to talk about interoperability and being able to have plug-and-play or interoperability messages, but like the earlier conversation about the network stack, it is not as easy as plugging a cable into Box A and into Box B and then they can talk. There are so many layers of technologies involved that even experts on the testbed are continuing to learn.

Simulations

The team can run simulated generation profiles on each of the three inverter cabinets to simulate solar, wind and storage. The team discussed using real solar, wind and storage – a possible plan for the future but the simulations make it easier to model multiple scenarios. For example, wind is very dynamic. Literally, one second could generate large output from the wind turbine or wind farm, then five seconds later there is next to nothing because that was a wind gust. These are the types of profiles that are very difficult to control because they happen so fast.

Traditionally, the edge sensors send data back to a cloud or to a central distribution management or energy management system. That round trip from sensor back to control action can take longer than the wind gust. So by pushing control down to the edge, connecting it with surrounding sensors and other protection and control devices, the testbed team can coordinate much faster, response times. Again, this would not be a problem if wind/solar were a small percentage of the grid because the inertia of the grid would simply absorb it into unperceivable perturbations.

Speed

Grids around the world operate at 50 Hz or 60 Hz (cycles per second). These are standards – such as VHS/Betamax, HD-DVD/BlueRay – except there was no clear winner even though they exist in the same global industry, albeit typically continents apart.

There are multiple switches (IGBTs), inside this inverter and they must be articulated at the right time to get the proper frequency output. FPGAs are great for IGBT control because of their inherent speed and synchronization ability combined with being programmable (especially helpful in a testbed). Whether using CompactRIO or a custom-built controller, FPGAs are, at the low level, the technology of choice for IGBT control.

From a TSN standpoint, the Microgrid Testbed can synchronize pulses between the controllers on the order of 100-nanoseconds. Both of those technologies (programmable FPGAs and TSN) are very well positioned to help solve the microgrid problems, certainly relative to dynamic control and device-to-device communication. However, the effort is focused on the reality that this is a new standard, a new protocol.

Expanding Into Larger Field Deployment

There are additional concerns around distance as the testbed moves into a larger field deployment and the need arises to ensure synchronous coordination across a larger space. The problem gets more complex with scale because, at some point there is a need to physically run a cable to different locations. The TSN protocol is designed to work at those great distances. So, the problem emerges not from a technology standpoint, but more from an infrastructure standpoint. As all the different parts are networked around the city and country, all the switches and nodes must be TSN-compliant along the path. This rollout may look like the transition from 100Mbit Ethernet to 1Gb Ethernet.

In a microgrid, many times – such as the remote village application or the foreign operating base examples mentioned earlier – all of the control equipment could be in a single substation. A substation could be a building. It could be a big building or it could be the size of an 18-wheeler cargo container. The Microgrid Testbed housed at the Industrial IoT Lab, realistically mirrors future end deployments: Putting all the equipment in a rack, connecting the equipment with a single Ethernet cable, and having all the equipment be TSN-compliant on a small scale.

Lab Status

The Microgrid Testbed lab in Austin is simultaneously in a state of completion and development. When Jamie Smith, Director of Embedded Systems, National Instruments, opened the lab in February 2017, he made the tongue-in-cheek comment, "Nothing in the lab is finished," to denote that it is meant to be a working lab, and all the testbeds housed within are meant to be working testbeds. So, the testbed team goes to IIC meetings and networks with other people to discover whether there could be someone with tablet technology or some other software technology, etc., wanting to contribute to the testbed.

Utility experts are now being invited to the lab to witness all the parts of the solution currently being tested. The testbed team asks the utility experts for validation that the innovations of the testbed help solve the real-world problems. Those conversations have already begun and continue to be evolving discussions, probing and identifying other problems the utilities would like the testbed team to solve and move to deploy those solutions. The team is actively working toward moving to a field deployment with other partners' involvement.

Grid Re-Synchronization

One of the wrinkles of having a microgrid is, because of the way inverters are designed today, even when running from storage, it becomes difficult or impossible to reconnect to the main grid. It *can* happen with today's technology but it is not guaranteed and when it does happen, is not a fully controlled maneuver.

When the main grid goes down, the microgrid disconnects and continues to run. There may be a short blackout to those on the microgrid, but because it is self-sufficient, it starts up again rather quickly. However, when it is time to reconnect to the main grid, it becomes complicated. Because there is no active control over the frequency and voltage on a microgrid, the frequencies between the main grid and microgrid need to match by happenstance to reconnect. If that occurs, then there is technology on the market today that will make the connection and both the main and microgrid are in sync. If the two grids are not on the same frequency then protection systems prevent the re-connect and the microgrid will run until storage (batteries) are depleted, blackout again, and then reconnect. The inconvenience of two blackouts is another microgrid problem that new IIoT technology can help solve.

Standards

TSN is the technology enabling the synchronization required in the Microgrid Testbed to run a stable grid on 100% inverter sourced power. National Instruments and Cisco are both heavily involved in the TSN standard development, both from the IEEE side as well as with the Avnu Alliance. Avnu is an organization working on the promotion and usage of TSN.

DDS is an open-communication protocol that is used to implement machine to machine communication at the edge where the two machines may be from different vendors. Presently, RTI is working on porting the DDS communication protocol to work on TSN Ethernet.

Thirdly, OpenFMB, a data framework for IP/IoT messaging protocols, has been adopted by many utility companies that want to freely choose between multiple vendors and ensure it is going to work in their network without having to "rip and replace" everything. Some devices in the earlier demonstrations of the Microgrid Testbed were adapted to OpenFMB.

You can also combine them all to have TSN, DDS, and OpenFMB all on the same network. OpenFMB deals with the data model (what data types devices and applications share with each other) and how to securely send the data between applications and devices. Referring to the IIRA diagram that the team has been following, there is not one protocol, so it could be DDS. It could be AMQP, MQTT, any of the other IP/IoT protocols.

Looking at the state of today, there are two dominant communication protocols for utility companies: DNP3 and 61850. DNP3 is used heavily in North America. 61850 is a growing standard that much of Europe is adopting right now. At the device level, there is Modbus and Serial. Many standards. With these existing standards and the new ones just discussed, microgrid solutions must include bridging and gateways to allow the conversation with the utilities around their existing deployments.

TECHNICAL REFERENCES

The IIC's Industrial Internet Reference Architecture (IIRA) influenced the Microgrid Testbed. The Microgrid Testbed team focused on applying the IIRA to their testbed. Based upon their experiences, they developed an IIRA mapping document which influenced the IIRA itself, a living document, evaluated continually and republished periodically to incorporate the learnings from testbeds and real world deployments.

The IIRA mapping document was published as a white paper covering how the IIRA adapts to the smart grid, building awareness of the IIoT technologies in that market that fit naturally into what is defined as the smart grid or the microgrid utility space. Future deliverables include reference guides of this nature that will steer other vendors into looking at these open, interoperable ways of building product.

In its current state, in the lab, the Microgrid Testbed recognizes security as a concern. As they move to an open field deployment and adopt the requirement of protecting the microgrid from internal or external threats, security will be a primary concern and they will look to the IIC Security Working Group and the Industrial Internet Security Framework (IISF) for guidance.

Communication with the Security Working Group is already underway because it is necessary to plan for the security requirements. The Security Working Group assists in conducting a threat assessment – identifying threats and the types of vulnerabilities that are most important, such as denial of service, physical access, Trojan horse, etc. The testbed team will work with each utility to ask the questions and conduct the initial assessments as they move toward deployment.

SUMMARY

National Instruments, RTI, Cisco and their partners are working together to help take IIoT technologies to the power grid of the future. The Microgrid Testbed scales the traditional technology down to the smallest of power systems, enabling an architecture of small, efficient microgrids connected into a larger, intelligent IIoT system. Their work together is speeding time-to-market for many of these technologies. Through their connections within the IIC ecosystem, the testbed team continues to discover new technologies which may provide valuable contributions to the testbed. The Microgrid Testbed's influence is already recognized in the contributions to the IIRA, enhancing that document for others and benefiting from the collective wisdom of those who authored the IIRA, in a circular loop of knowledge and feedback.

The Microgrid Testbed is fostering the important discussions around the many different standards and the complexities along the technology stack. The testbed participants' connections with IEEE and Avnu Alliance have created a very valuable feedback loop on TSN applications in energy. The end users who have joined the testbed and those who will join in the future will find the true value of the testbed.

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