

Distributed Energy Resource ICT Reference Architecture

Distributed Control Architecture for Hardware Limited Internet of Things DERs

Bo Petersen¹, Henrik Bindner¹, Bjarne Poulsen² and Shi You¹

¹DTU Electrical Engineering, Technical University of Denmark, Anker Engelundsvej 1, 2800 Lyngby, Denmark

²DTU Compute, Technical University of Denmark, Anker Engelundsvej 1, 2800 Lyngby, Denmark

Keywords: Smart Grid, Internet of Things, Drivers, Native Communication, Historical Data, Real-Time Data, Predicted Data, Communication Standards, IEC 61850, OpenADR, Serialization, Discovery Service, Network Discovery, Service Discovery, Communication Negotiation, Communication Middleware, Capability Discovery, Generic Interface, Access Control, Tracker Service, Administration Interface, Plug 'N' Play, Application Launcher, Automatic Configuration, Self-Healing, Topology Detection.

Abstract: For Distributed Energy Resources to participate in the grid, and help solve the problems of unreliability and inefficiency, caused by weather dependent, and distributed energy resources, they must have a processing unit, data connection, and an ICT architecture. The aim of the paper is to describe the software components of the ICT architecture, thereby improving the design of scalable ICT architectures for automatically controlled DERs. Future plug 'n' play software components that improve the scalability and eases the development of such ICT architectures are also described in the paper. The ICT architecture should be scalable to many different types of DERs with minimal effort and should enable control by automated generic controlling entities. The ICT architecture primarily consists of three layers, the driver layer that uses native communication to talk to the unit hardware, the data layer that supplies historical data, real-time data, and future prediction to the communication layer, which is responsible for talking to the controlling entities. With the plug 'n' play extension components which adds the application launcher, automatic configuration, self-healing and topology detection.

1 INTRODUCTION

With the increasing amount of Renewable Energy, the power grid faces challenges caused by the intermittent production of energy by weather dependent energy resources like solar panels and wind turbines, and by the increasing share of distributed energy resources.

To handle these challenges of power grid reliability and power use efficiency, the Distributed Energy Resources (DERs), both generation and consumption units, must participate in the operation of the power grid.

This participation can be achieved with economic incentives for the owners and must go beyond having the owners control the DERs manually to move production, with aggregators and local controllers that control the DERs automatically, either by having these controlling entities participate in energy and flexibility (Zhang, 2014) markets or by using price signals.

The necessary parts to enable automatic control by controlling entities is a processing unit, data connection and an ICT architecture consisting of software components (figure 1).

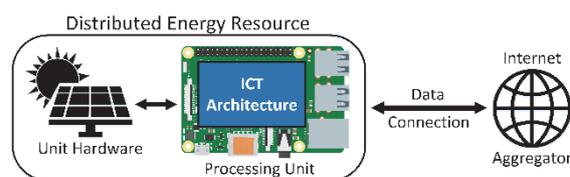


Figure 1: DER parts.

The focus of the paper is not the controlling entities, which could be located on the DERs, but the software components of the ICT architecture necessary for automatic control.

The aim of the paper is to describe the software components, in enough detail to give the reader an overview of what a scalable DER ICT architecture should contain. Not all components are necessary for

every use case, but they are necessary for a generic architecture.

The plug ‘n’ play section describes the application launcher and possible extensions to the ICT architecture.

The state of the art for this area is a collection of scientific articles defining and aggregating the requirements of ICT architectures for the Smart Grid or Smart Homes, whereas this paper is specific to the ICT architecture for DERs, and proposes scalable solutions to fulfill the requirements for a DER ICT architecture (Rohjans, 2012) (Zaballos, 2011) (Kok, 2009).

The hypothesis of the paper is that with the right components a scalable DER ICT architecture can be constructed that works for all DERs, with a minimal amount of work for each different DER in the form of configuration files, and enables automated generic controlling entities.

This is a conceptual paper with ideas and concept for building a DER ICT architecture. A prototype was created including many of the software components of the paper, not including the plug ‘n’ play section components, except for the application launcher. The paper does not follow the IMRaD structure but the “Big Book” paper structure (Best Custom Writing, 2017), as the paper does not present experimental results, and this structure, therefore, more accurately presents the content of the paper.

2 MODEL

The ICT architecture model consists of three layers, the driver, data and communication layers (figure 2). While only one instance of the data layer and communication layer is necessary, multiple drivers are needed to talk through multiple types of native communication to the unit hardware. It could also be the case that one driver talks to the unit hardware of multiple units, e.g. one inverter for multiple solar panels.



Figure 2: ICT architecture layers.

The ICT architecture, therefore, keeps the data separated into multiple virtual devices, that each represents a logical unit.

The driver layer is responsible for native communication with the unit hardware, converting

measurements into a generic format, and supplying it to the data layer, while also receiving control commands from the data layer, and sending them to the unit hardware.

The data layer gets measurements from the driver layer, stores it, provides the past, current and predicted future measurements to the communication layer and relays control commands to the driver layer.

The communication layer supplies measurements from the data layer to controlling entities through external network communication and receives control commands from the controlling entities and relays them to the data layer. It also converts the measurements and control commands to communication standards.

3 DRIVER LAYER

The driver layer is the hardest layer to make generic and will always be partially specific to the unit hardware.

The basic idea is to create drivers that are specific to the types of native communication required to talk to different unit hardware, like Modbus over ethernet, and then implement a common interface that talks to the data layer, pushing new measurements and receiving control commands (figure 3).

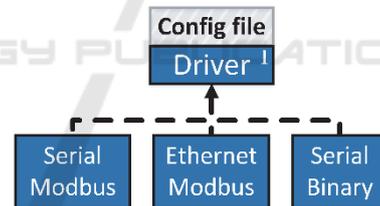


Figure 3: Driver hierarchy.

The native communication specific driver is then combined with a configuration file that has a unit hardware specific map, which maps the native communication addresses to generic value types, names, and paths for communication standards. The paths are not used by the driver layer, but by the communication layer to map the measurements and control commands to communication standards.

The configuration file with the unit hardware specific mappings should be in a format which is human-readable and can be deserialized, like XML, JSON or YAML (Listing 1).

The configuration file should also contain native communication information, like the serial port number and baud rate, unit hardware information like the maximum polling interval and maximum current,

and transformation information like the scaling and offset of measurements.

```
<mappingConfiguration>
<virtualDevice name="BatteryStorage" location="DTU, Risø Campus, Building 117">
<driver name="BMS" type="SerialBinary" pollingInterval="1000">
<measurements>
<argument value="#AA" />
<return name="BatteryDrainCurrent" binaryOffset="16" binaryLength="2"
type="Int16" icc61850="ZBAT.Amp.mag.i" scaling="1.2" offset="0.12" />
</measurements>
<control>
<argument name="DER schedule (Active Power)" binaryOffset="42"
binaryLength="4" type="Int16" icc61850="DSCH.SchdAbsTm.val{SchdVal:1}"
scaling="2.5" offset="0.65" />
</control>
<configuration>
<return name="Rated Power" value="60" icc61850="ZBAT.MaxChaV.setMag.i"/>
</configuration>
<capabilities>
<type name="Battery"/>
<service name="Flexibility"/>
</capabilities>
</driver>
</virtualDevice>
</mappingConfiguration>
```

Listing 1: Example of a configuration file in XML.

Essentially the driver layer exchanges bytes with the unit hardware converts the bytes using the configuration file map, and exchanges measurements and control commands with the data layer (figure 4).

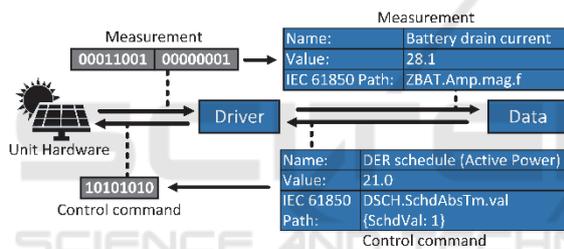


Figure 4: Driver translation example.

4 DATA LAYER

The data layer has three components for historical data, real-time data and data predictions, which are responsible for the past, current and future measurements respectively (figure 5).

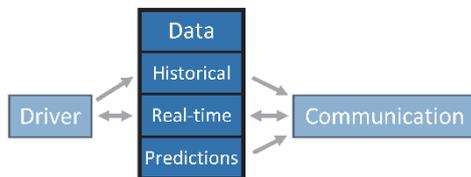


Figure 5: Data layer components.

The historical component has a local data store (e.g. database) that persistently stores the measurements it receives from the driver, and then provides them to the communication layer, on request.

The real-time component keeps current measurements from the driver available for quick access, by storing them in memory, and relays them to the communication layer, so they can be sent to subscribers. It also relays control commands to the driver layer from the communication layer.

The predictions component uses data from the historical component and possibly a meteorological station (which if it is external, requires retrieval of measurements through the communication layer), to provide predictions for future measurements.

The prediction uses machine learning to train on the historical data, to predict the future measurements of the unit hardware, and should take the historical and future metrological measurements into account for weather dependent DERs. It should also take control commands in the form of schedules into account.

For Smart Grid research laboratories and other experimental setups, the prediction could be used to simulate the unit hardware, if historical data is available.

5 COMMUNICATION LAYER

The communication layer consists of a standards translation component that converts the data to communication standards and passes it on to a serialization component that converts the data to a format that can be transmitted over a network, which is what the middleware component does.

Additionally, a discovery service component provides discovery and negotiation mechanisms, and the administration interface component allows the owner and technicians to control and configure the DER (figure 6).

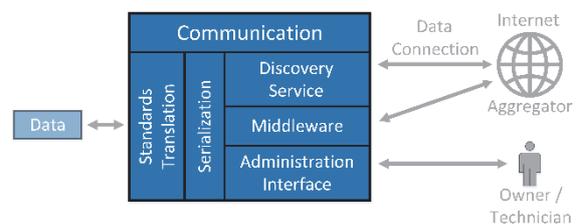


Figure 6: Communication layer components.

5.1 Standards Translation

The standards translation component translates the data from the generic representation to the format of a communication standard, like the IEC 61850

(Machiewicz , 2006), OpenADR (McParland , 2011) or another future standard (figure 7).

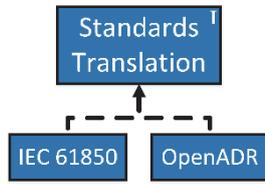


Figure 7: Standards translation hierarchy.

The standards translation component is independent of the data layer to keep the data layer from being tied to a particular communication standard while enabling the DER to communicate with controlling entities using multiple communication standard formats.

The reason multiple communication standards must be used is because no one of them covers all use cases. IEC 61850 describes the unit hardware by physical components which is good for diagnostics, while OpenADR describes it by the services it provides, without providing a specific data model, which is good for ancillary services like voltage control and load shifting but still lacks a specific data model.

This requires future standards to describe the information missing from these standards. This includes capability and requirement descriptions, which are part of the ICT architecture data model.

Figure 8 shows how the generic representation of the battery current is translated to an IEC 61850 ZBAT battery description, and how an IEC 61850 DSCH active power schedule is converted to a generic representation.

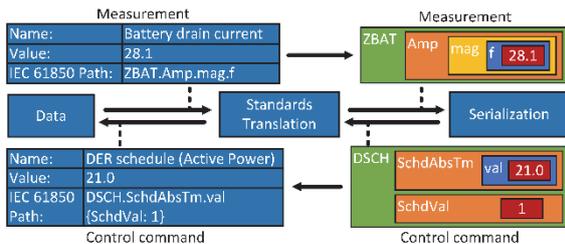


Figure 8: Standards translation example.

5.2 Serialization

The serialization component converts the data from the memory representation of the communication standard format to a string or binary format, that can be transmitted over a network (figure 9).

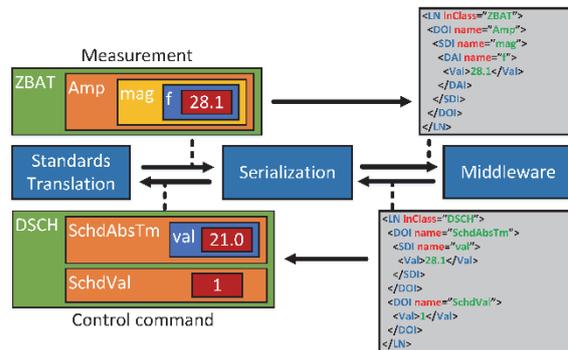


Figure 9: Serialization example.

The serialization format and library used, strongly affects the performance of the external communication to the controlling entities, and depends on the unit hardware and data connection (figure 10).

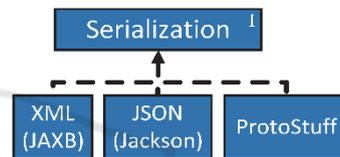


Figure 10: Serialization hierarchy.

The performance and characteristics of a broad range of serialization formats and libraries are covered in an earlier paper titled “Smart Grid Serialization Comparison” (Petersen, 2017), which concludes that JSON has better performance than XML, while being human-readable, binary serializers have better performance than string serializers, and ProtoBuf (ProtoStuff), and ProtoStuff have the best performance.

It is, therefore, important to be able to choose the right serialization for each use case and have the serialization be interchangeable instead of being tied into the middleware.

5.3 Discovery Service

The discovery service uses a separate communication mechanism to communicate with controlling entities prior to the establishment of a middleware communication channel with better performance. This could be an overlay network, that makes internet scale network discovery possible.

The discovery service is responsible for providing passive network discovery, service discovery, and communication negotiation (figure 11).

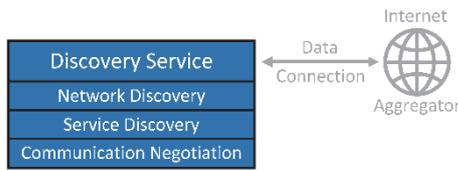


Figure 11: Discovery service subcomponents.

The network discovery subcomponent is responsible for responding to network discovery messages, to allow controlling entities to find the DER.

The service discovery subcomponent acts as a proxy for the middleware by being available on a fixed predefined port, and by providing the middleware ports, allowing middleware to change ports, and for middleware to be added.

The communication negotiation subcomponent lets controlling entities pick which middleware, serialization, and communication standard will be used for the communication.

5.4 Middleware

The middleware component enables multiple types of middleware that all implement the same middleware interface, that enables them to be used interchangeably (figure 12).

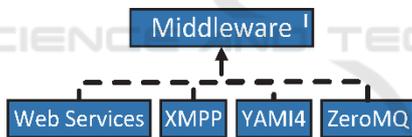


Figure 12: Middleware hierarchy.

Different middleware have different throughput and latency performance, depending on the processing unit and data connection. Therefore, and because different controlling entities might support different middleware, different middleware should be used depending on the use case.

The details of the differences in performance and characteristics for a broad range of middleware is covered in an earlier paper titled “Smart Grid Communication Middleware Comparison” (Petersen, 2017), the performance of serialization combined with middleware is covered in an earlier paper titled “Smart Grid Communication Comparison” (Petersen, 2017), and the performance of combinations of middleware and serialization, with different processing units and data connections, is covered in an earlier paper titled “Smart Grid Communication Infrastructure Comparison” (Petersen, 2017).

These papers conclude that YAMI4 and ZeroMQ have the best combination of performance and characteristics, while ICE and WAMP have satisfactory performance and characteristics. Considerations for the choice of processing units and data connections are also covered, but there is not one perfect choice.

The middleware component has four subcomponents that work through the middleware, the capability discovery, generic interface, access control and tracker service (figure 13).

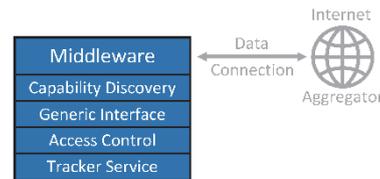


Figure 13: Middleware components.

5.4.1 Capability Discovery

The capability discovery subcomponent provides a DER component description (IEC 61850), a type description, service descriptions (OpenADR), and capabilities descriptions (which could, for instance, be the flexibility of the DER or how much it can change the power frequency).

5.4.2 Generic Interface

The generic interface subcomponent provides a set of generic interfaces for data acquisition and control, which are independent of DER unit hardware.

5.4.3 Access Control

Allowing the aggregator to control the DER, requires that the owner uses a password printed on the DER to log into the UI, and enters an aggregator key, received when signing a contract with the aggregator.

Or by having a centralized system where the DER and aggregator register themselves, with a DER key being given to the aggregator when the owner signs a contract with the aggregator. The key is then retrieved by the aggregator from the centralized system and given to the DER to authenticate the aggregator.

The problem gets a lot harder when DERs need to cooperate to solve power system issues, such as providing voltage control. This requires a distributed trust system that helps a DER to decide whether it should trust requests from local controllers.

The problem of who to trust in a distributed system is important to solve because of cyber security concerns about how a few computers could trick

many DERs into believing that they should perform actions to help the power grid, while actually resulting in the DERs crashing the power grid.

This is just one of the cyber security concerns that must be solved with the rise of the Smart Grid and the Internet of Things.

5.4.4 Tracker Service

The tracker service broadcasts DER alarm and events to subscribing entities, such as aggregators, local controllers, visualizations, and auditing entities. This could be a solar panel that sends an event, that it has now started production because the amount of sun irradiation has gotten large enough or a wind turbine that sends an alarm message because the rotation speed has gotten too fast, because of the wind speed.

It also keeps a log of previous communication requests, in the form of control commands and requests for measurements, which it provides to external entities.

5.5 Administration Interface

The administration interface should provide a graphical interface through a browser to the owner, which provides statistical measurement information, allows the owner to manually control the DER, provides access control administration, and allows a technician to change the configuration of the DER.

6 PLUG 'N' PLAY

The aim of a plug 'n' play extension to the ICT architecture is to have little or no configuration, and as little maintenance as possible.

6.1 Application Launcher

When the ICT architecture is started, the application launcher launches all the fixed components but leaves the interchangeable components, the drivers, serialization, standards translation, and middleware.

It then uses the hardware configuration file to determine which driver components should be launched and does so.

It then provides the available interchangeable components to the discovery service and waits for it to relay the requested standards translation, serialization, and middleware, and launches them on demand, which is a result of the communication negotiation performed by the discovery service.

The application launcher has fixed references to the fixed components and uses reflection to get references to the interchangeable components. It then uses dependency injection to glue the components together to the ICT architecture, by sharing the references with the components.

This allows the application launcher to shut down components that are not being used, and launch components on demand when they are requested.

6.2 Automatic Configuration

The simple, but time-consuming way to create configuration files is to create them from documentation which for the manufacturer might be a small expense compared to creating the unit hardware, but for a company creating a device to connect to any type of DER might make the difference between the project being viable or not.

To avoid spending the time to create a configuration file, a piece of software could be constructed that uses machine learning and measurements from external measurement hardware to reverse engineer the unit hardware specific map. The external measurement hardware could be a smart meter if the power system changes caused by the unit can be isolated.

This would of course not be capable of mapping measurements that cannot be measured externally like the temperature of the unit but could create a partial map that might be enough for certain power system ancillary services.

This could be taken one step further by having an algorithm that cycles through the processing unit ports (e.g. serial or ethernet), to determine which are connected and then attempt to launch drivers with different configuration information, to attempt to establish a connection, but this would be a brute force approach.

6.3 Self-Healing

By having a separation of components, the controlling entities should be able to restart the software components and could be able to attempt to reset the unit hardware, in the event of a problem, by initiating a self-healing service. However, this would require, that the service mapping is defined in the hardware configuration file.

Self-healing would also allow the controlling entities to permanently change the power scaling and offset of the system and configuration file.

Determining how to change the scaling and offset would require the controlling entities to have a second

source of measurements for the DER, which could be a Smart Meter if the effects of the unit can be isolated.

6.4 Topology Detection

The idea is to provide information about the power system topology to controlling entities, enabling them to better solve local power system issues like voltage or frequency control.

The topology detection could be part of the controlling entities by comparing measurements of multiple DERs to determine their power system distance.

Alternatively, a more active approach could be used by having a DER perform slight changes to the power system, like changing the frequency a little bit and having other DERs attempt to detect the signal, showing which DERs are closely connected, like echolocation. This approach would use the same technology as Power Line Communication and would have to be part of the DERs.

7 CONCLUSIONS

An ICT architecture with the components described in the paper, along with the plug ‘n’ play extensions, would enable controlling entities to automatically control DERs, with little to no work done to scale to a potentially unlimited number DER with different unit hardware, also requiring little to no maintenance because software problems and hardware calibration problems.

Future work should be done on network discovery that works over the internet and is tailored for Smart Grid applications, by taking unit location and characteristics into account.

Current communication standards should be extended to describe unit capabilities, and predefined data models for service descriptions, as oppose to the current version of OpenADR.

In addition to the many cyber security challenges that need to be solved for the Internet of Things, a mechanism for managing trust between computers in a distributed system is essential for the future Smart Grid.

ACKNOWLEDGEMENTS

Sponsored by the project, PROActive INtegration of sustainable energy resources enabling active distribution networks (PROAIN).

REFERENCES

- Zhang, C., Yi, D., Nordentoft, N. C., Pinson, P., Østergaard, J., 2014. FLECH – A Danish market solution for DSO congestion management through DER flexibility services, *Journal of Modern Power Systems and Clean Energy*, 2nd ed., vol. 2, pp. 126-133, 2014.
- Rohjans, S., Dänekas, C., Usilar, M., 2012. Requirements for smart grid ICT-architectures, ISGT Europe, 2012.
- Zaballos, A. Vallejo, A., Selga, J. M., 2011. Heterogeneous communication architecture for the smart grid, *IEEE Network*, 5th ed. vol. 25, pp. 30-37, 2011.
- Kok, K., Karnouskos, S., Nestle, D., Dimeas, A., Weidlich, A., Warmer, C., Strauss, P., Buchholz, B., Drenkard, S., Hatzigiorgiou, N., Lioliou, V., 2009. Smart houses for a smart grid, CIRED, 2009.
- Best Custom Writing, 2017. Is the IMRAD model right for you, [Online], Available: <http://www.bestcustomwriting.com/blog/writing-in-general/is-the-imrad-model-right-for-you/>. [Accessed 21 04 2017].
- Machiewicz, R. E., 2006. Overview of IEC 61850 and Benefits, *IEEE PES Power Systems Conference and Exposition*, Atlanta, GA, pp.623-630, 2006.
- McParland, C., 2011. OpenADR open source toolkit: Developing open source software for the Smart Grid, *IEEE Power and Energy Society General Meeting*, San Diego, CA, pp. 1-7, 2011.
- Petersen, B., Bindner, H., Poulsen, B., You, S., 2017. Smart Grid Serialization Comparison, *SAI Computing Conference*, London, 2017.
- Petersen, B., Bindner, H., Poulsen, B., You, S., 2017. Smart Grid Communication Middleware Comparison, *SmartGreens*, Porto, 2017.
- Petersen, B., Bindner, H., Poulsen, B., You, S., 2017. Smart Grid Communication Comparison, *ISGT Europe*, Torino, 2017.
- Petersen, B., Bindner, H., Poulsen, B., You, S., 2017. Smart Grid Communication Infrastructure Comparison, *ICPES*, Toronto, 2017, in press.