Integrating VOLTTRON and GridLAB-D to create a Power Hardware-in-the-Loop Test Bed

Ricardo Rangel

ABSTRACT
Rapidly growing deployment of distributed generation has caused distribution systems to experience power flow that they were not designed to handle. Smart grid controllers can effectively mitigate the impacts of distributed generation with the proper settings. A Power Hardware in the Loop (PHIL) system is able to study the potential of various smart controllers by incorporating simulation and hardware. The integration of GridLAB-D and VOLTTRON, two software tools developed by Pacific Northwest National Laboratory, has created a PHIL system. VOLTTRON is a platform that enables communication and control between smart grid components while GridLAB-D is a distribution system simulation tool. In the PHIL system, GridLAB-D acquires historical power measurement parameters and weather information, via VOLTTRON, of a hardware system. The analysis of the data determines if a controller is feasible or not, and if so, what setting alleviates the system the most effectively. The features of the PHIL system are described and several results are presented.

I. INTRODUCTION

Power system technology has dramatically increased in the past decade. Some of these technologies allow the control of advanced features. Before advanced features of technology are deployed in a system, it needs to be determined if the system will behave effectively. Simulators are great tools to analyze technology on a system; however, models of new technology require time and effort to develop. A way to overcome this obstacle is to incorporate real data into simulators. This process is called Power Hardware-in-the-Loop, and it is a very powerful technique to improve the realistic properties of a simulation. Figure 1 shows the difference between simulation and power hardware in the loop.

The integration of GridLAB-D and VOLTTRON has created a PHIL system. GridLAB-D is a distribution system simulator. It improves research in distribution systems by exploring and configuring virtual distribution systems. VOLTTRON is an agent execution platform that can allow multiple two-way communication between multiple devices. VOLLTRON works by utilizing agents that perform different tasks. Some agents are able to control smart devices such as electric vehicle chargers and smart appliances. Other agents retrieve data such as temperature and power usage and store it in a database. GridLAB-D and VOLTTRON have never communicated before, and a communication link can give GridLAB-D access to all of VOLTTRON's data.

To understand how the PHIL system was created, first, background information is presented; followed by an explanation of the two archiver systems developed and the results.
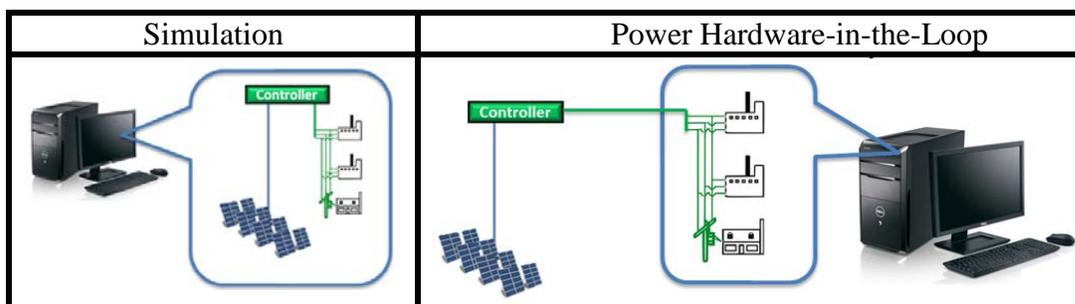
Figure 1: Simulation Types

II. BACKGROUND
A. Communication
The GridLAB-D to VOLTTRON link uses Java Script Object Notation (JSON) as the data-interchange format. Since JSON uses universal data structures, any machine can interpret and send JSON. The JSON format is made of key/value pairs. In most applications, the key is usually a string, in contrast, the value can be any data type such as an object, array, or string. When a simulation is running, GridLAB-D and VOLTTRON exchange data at each timestep of the simulation (typically one second).

Agents within VOLTTRON not only, communicate with smart devices and controllers; they also communicate to other agents by publishing and subscribing to topics. Agents subscribe to topics when they want to receive information associated with the topic. When an agent publishes to a topic, the agent sends a header and a message to agent subscribed to that topic. For example, all the agents communicating with GridLAB-D subscribe to the topic gridlabd/request, and whenever an agent wants to send data to GridLAB-D, the agent publishes to the topic gridlabd/response.

B. sMAP

VOLTTRON utilizes sMAP (Simple Measurement and Actuation Profile) for storing physical information into a database. sMAP is an interface between hardware and software that was developed at University of California, Berkeley. The goal of the software is to develop a specification for transmitting physical data and describing its contents. The software includes a large set of open source drivers that communicate to devices using their native language. Data is stored in the repository as a list of lists; each list has two elements. The first element is the time stamp in Unix Time (aka POSIX time or Epoch time). The second element is the measurement corresponding to the time stamp [2].

C. VOLTTRON Service Agents

Service agents are pre-installed to provide services to other agents in the platform. If an agent wants a service, it publishes to the service agent's topic with data that configures the service. Two service agents were used to obtain real data: the Weather Agent and the Archiver Agent.

The Archiver agent retrieves data from a database. When an agent wants information from a database, the agent publishes to the topic archiver/request with the desired parameter and time range in Unix time format. Once the Archiver agent receives the data, the Archiver agent publishes the data to the requesting agent.

Weather Underground is a weather service organization that incorporates Personal Weather Stations (PWS) into its network to further the availability of weather data. PWS are privately owned outdoor instruments that measure weather conditions. Basic measurements include temperature, humidity, wind speed, and wind direction. Each PWS is identified with a Station ID, which allows the acquisition of any station's weather measurements.

The Weather agent is a service agent that retrieves climate information from weather underground's database. This agent was modified to allow GridLAB-D the flexibility of specifying the parameters and the zip code or Station ID.

III. AGENTS

To create a PHIL system, requires retrieving real data. To obtain real data, a weather archiver setup and a data archiver setup were created. The weather archiver was designed to obtain weather information from weather underground while the data archiver was designed to retrieve database information. Each application requires the use of three agents which will be described.

A. GridLAB-D Agent

The GridLAB-D Agent (GLDA) is the only agent that communicates directly with GridLAB-D. It utilizes python's socket programming toolbox to send and receive packets via internet protocols (IP) encoded in JSON format. When GLDA starts, it continuously polls the default port 39037 for a request from GridLAB-D. When GridLAB-D sends data, GLDA parses the data and redirects the information to its associated agent. Once all the associated agents builds a response and sends it back to GLDA, GLDA attaches a header to the packet and sends it back to GridLAB-D. This process continues indefinitely until GridLAB-D or GLDA terminate the link. The block diagram for GLDA is shown in Figure 4. This agent was designed by Nate Tenney, a computer scientist from the VOLTTRON development team, and was an integral part of completing the project.
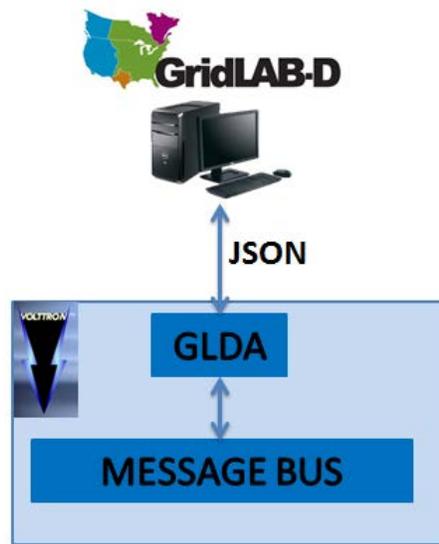
Figure 1: GridLAB-D Agent Block Diagram

B. GridLAB-D Weather Agent

The GridLAB-D Weather Agent (GLDWA) is the intermediary agent between GLDA and the Weather Agent as seen in Figure 2. GLDWA decodes the data from GLDA and determines the weather request from GridLAB-D. If the data packet defines a zip code or Station ID, the GLDWA publishes a request to the Weather Agent to have the URL modified to obtain weather data from the requested location. Once the Weather Agent retrieves the values, it publishes the data back to GLDWA. GLDWA extracts relevant information based on GridLAB-D's request. After GLDWA is finished, it publishes the data to GLDA who sends it to GridLAB-D.

Through the design of the weather communication protocol, several versions were developed. Depending on the application, one version may be more useful than another version. Table 1 shows the four versions that were developed, and Table 2 shows the parameters associated with GLDWA version 3.
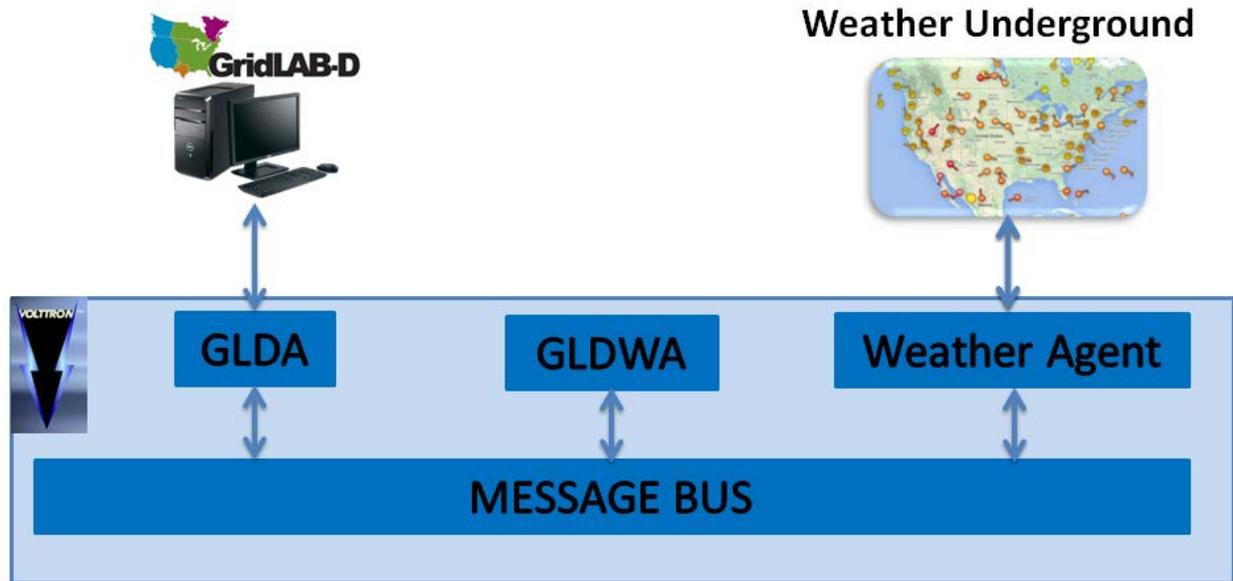
Figure 2: Weather Archiver Block Diagram

Table 1: GLDWA versions

| Version 0 : Temperature and Insolation	This version returns real-time temperature and insolation to GridLAB-D's climate object from the zip code in the weather agent's configuration file.
Version 1: Specify Zip Code	This version is the same as Version 0. However, GridLAB-D can specify the zip code directly in the GridLAB-D model.
Version 2 : Specify Zip Code or Station ID	This version allows GridLAB-D to specify either a zip code or a Station_ID directly in the GridLAB-D model.
Version 3 : Specify Parameters and Zip Code or Station ID	This version allows GridLAB-D to specify which weather parameters to obtain while still enabling it to specify either a zip code or Station_ID.

Table 2: GLDWA version 3 attainable parameters

temp_f	wind_gust_kph	heat_index_c	solarradiation
temp_c	pressure_mb	windchill_string	UV
relative_humidity	pressure_in	windchill_f	precip_1hr_string
wind_string	pressure_trend	windchill_c	precip_1hr_in
wind_dir	dewpoint_string	feelslike_string	precip_1hr_metric
wind_degrees	dewpoint_f	feelslike_f	precip_today_string
wind_mph	dewpoint_c	feelslike_c	precip_today_in
wind_gust_mph	heat_index_string	visibility_mi	precip_today_metric
wind_kph	heat_index_f	visibility_km	

C. GridLAB-D Data Agent

Figure 3 shows the block diagram for the GridLAB-D Data Agent (GLDDA). GLDDA is the intermediary agent between GLDA and the Archiver Agent. It decodes GridLAB-D's request and communicates to the Archiver Agent to extract information from the database. At the start of

the simulation, GridLAB-D sends the start time associated with the simulation. Since GLDDA does not know the duration of the simulation, it makes a request to the Archiver agent for a day's worth of historical data from the model's starttime. Once GLDDA receives the data, GLDDA stores the data in a buffer for future use. Throughout the simulation, GridLAB-D continues sending the timestamp associated with each simulation cycle. For each cycle, GLDDA uses the simulation timestamp to extract the value from the buffer associated with that timestamp. If the simulation exceeds the values in the buffer, GLDDA requests more data using the Archiver agent. This setup gives the GridLAB-D model flexibility since any time duration can be used as long as the database has those values.
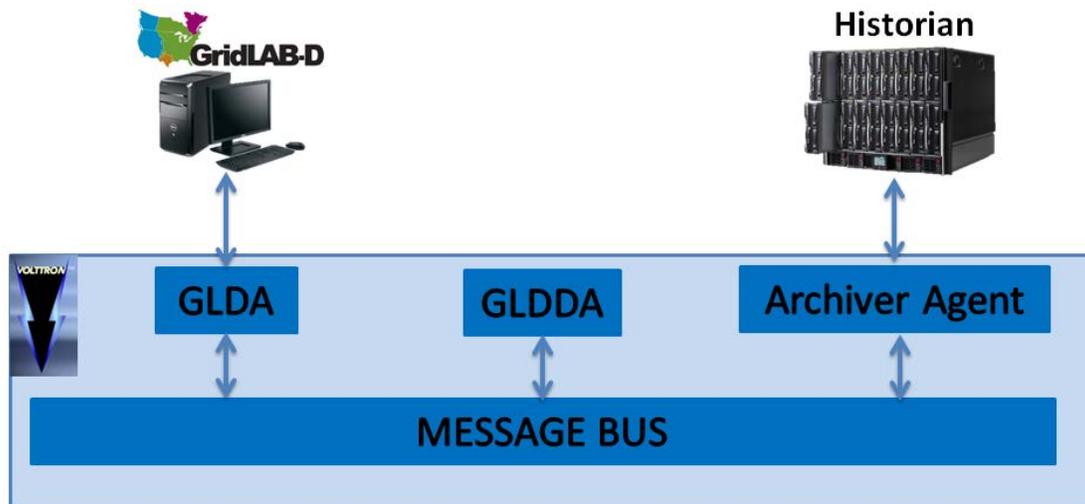
Figure 3: Data Archiver Block Diagram

IV. APPLICATIONS

A. Weather Archiver

GLDDA and GLDWA create real data archivers for the PHIL system. Ambient weather conditions are one of the key factors in determining how power systems are utilized. For example, in photovoltaic analysis, knowledge of the temperature and insolation (measurement of watts per area) of the region helps engineers with designing and troubleshooting solar farms. Temperature and insolation are influential parameters since it affects the power produced. The efficiency of solar panels is dependent on temperature. Therefore, incorporating temperature and insolation also adds reliability to the Power Hardware-in-the-Loop simulation.
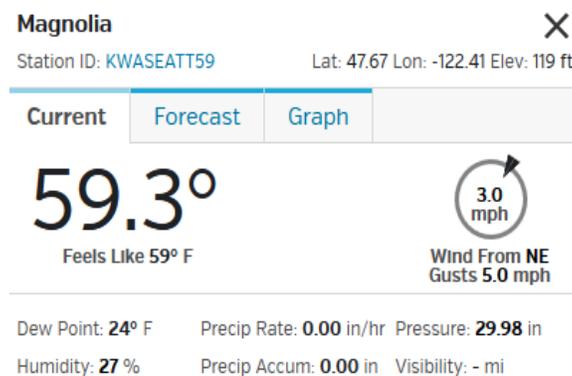
B. Data Archiver

The Data Archiver is fundamental in the Power Hardware-in-the-Loop. In addition, it also has impact in other areas. For example, over 100 parameters affect thermal comfort of a building such as elements of thermodynamics, fluid mechanics, and heat transfer. These factors are related through complex differential equations. By incorporating historical measurements of a building, such as outside air temperature and HVAC power measurements, into a simulation, GridLAB-D can calibrate the other parameters to find the best match of the building. The result is a model that more realistically describes the physical infrastructure of the building. Analyzing

the model with different parameters can determine the Return on Investment of improvements such as insulated windows and new HVAC systems.

V. **RESULTS**

A. **Weather Archiver Results**

One way to validate the weather archiver application is to request arbitrary weather information and compare it with the live information from weather underground's web page. Using GLDWA version 3, a GridLAB-D model was created to obtain temperature (°F), humidity (%), and wind speed (mph) from Station KWASEATT59 in Seattle, WA. After starting GLDA, GLDWA, and the Weather Agent, the GridLAB-D model was executed, and it immediately a brought back a temperature of 59.3 °F, relative humidity of 27 % and wind speed of 3.0 mph. These values matched exactly with the values of the webpage. A screen shot of the webpage is shown in 7.



Figure 4: Station's weather information live

B. **Data Archiver Results**

At Lawrence Berkeley National Laboratory, there is an instance of sMAP storing various measurements of a building and storing them in a historian located at the following domain http://smap.lbl.gov . Using GLDDA, a GridLAB-D model was created to collect the outside air temperature of an arbitrary day. In the GridLAB-D model the start time was set to July10, 2014 at 00:00:00 and the stop time was set to July 11, 2014 at 00:00:00. After starting GLDA, GLDDA, and the Archiver Agent, the GridLAB-D model was executed and it brought back 1440 values. Using excel the data was plotted as shown in Figure 8.

Including a slash and "plot" (/plot) to the end of an sMAP's domain gives access to smaps plotting engine. For example, using a web browser, http://smap.lbl.gov/plot allows a person to plot any parameter for any data range. To verify the results of GLDDA, the plot from GLDDA was compared with the plot received from sMAP's plotting engine. SMAP's plotting engine was set to plot the same time range the GridLAB-D model obtained. The plot from sMAP's plotting engine is shown in Figure 6. By comparing these graphs, they look identical which means the data the GridLAB-D model received accurately match the data stored in the repository.
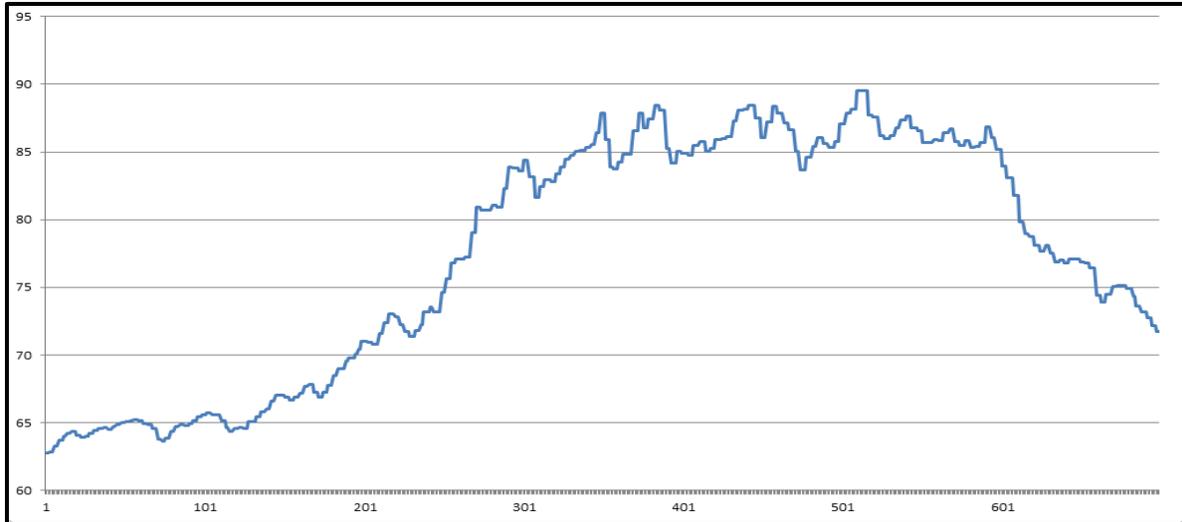
Figure 5: Plot of outside air temperature using GridLAB-D's Data Archiver
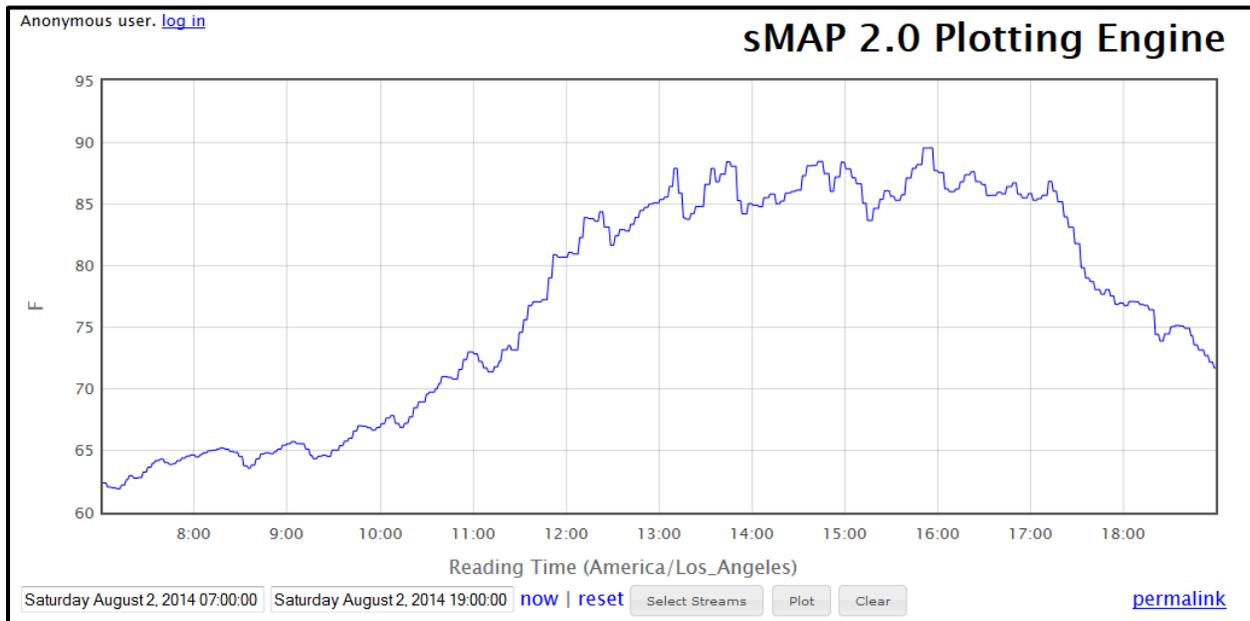
Figure 6: Plot of outside air temperature using sMAP's 2.0 Plotting Engine

VI. DISSEMINATION

A. Installation

For non-VOLTTRON users, the installation of the VOLTTRON platform can be a difficult process. As a result, a VOLTTRON platform with all the functionalities that were described was created and stored in a share drive. Batch files were created to execute GLDDA and all version of the GLDWA with one command. This eases the process of establishing a GridLAB-D to VOLTTRON link for non-VOLTTRON users which allows more people to use the features.

B. Technical Documents

Also, detailed technical documents were created to describe how the GridLAB-D agents developed work. The major parts of the program were described, and the documents also showed how and where the program can be modified. Both GridLAB-D and VOLTTRON maintain wikis which contain technical documentation for users. The technical documentation that describes the GridLAB-D to VOLTTRON communication link will be posted to one or both wikis so that it will be available to all users.

VII. CONCLUSION

It has been demonstrated that the GridLAB-D to VOLTTRON link can effectively transmit data. This data creates a Power Hardware-in-the-Loop that improves analysis by incorporating real data from real hardware devices. The analysis of more accurate simulations will help investigate the best way to control smart devices and operate controls. In the future, improvements in this communication link will allow more advanced simulation capabilities. This research shows the GridLAB-D to VOLTTRON communication link by designing a few test models. The GridLAB-D Weather agent successfully acquired data from weather underground, and GridLAB-D Data Agent successfully retrieved database measurements and incorporated them into GridLAB-D's simulation model. A few applications were stated, and more applications will arise as this technology is developed further.

REFERENCES

[1] Lutes RG, S Katipamula, BA Akyol, ND Tenney, JN Haack, KE Monson, and BJ Carpenter. 2014. VOLTTRON: User Guide. PNNL-23182, Pacific Northwest National Laboratory, Richland, WA.

[2] Stephen Dawson-Haggerty, Xiaofan Jiang, Gilman Tolle, Jorge Ortiz, and David Culler, "sMAP: a Simple Measurement and Actuation Profile for Physical Information," in Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems. 2010. ACM.

[3] Tess Williams, Jason Fuller, Kevin Schneider, Bryan Palmintier, Blake Lundstrom, Sudipta Chakraborty, "Examining System-Wide Impacts of Solar PV Control Systems with a Power Hardware-in-the-Loop Platform,"

[4] Join our PWS Network! (Personal Weather Stations) http://www.wunderground.com/weatherstation/about.asp

[5] VOLTTRON/volttron (GitHub) https://github.com/VOLTTRON/volttron/tree/1.x/Agents/GridlabDAgent