FREEDM SYSTEMS CENTER

FREEDM 2024 Research Symposium

NC STATE UNIVERSITY

Utilizing Smart Inverter Virtual-Sensor Nodes for Enhanced Behind-the-Meter Visibility in High PV Penetration Distribution Feeders

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Outline

Motivation

Reducing costs by leveraging pre-deployed hardware

Experimentation

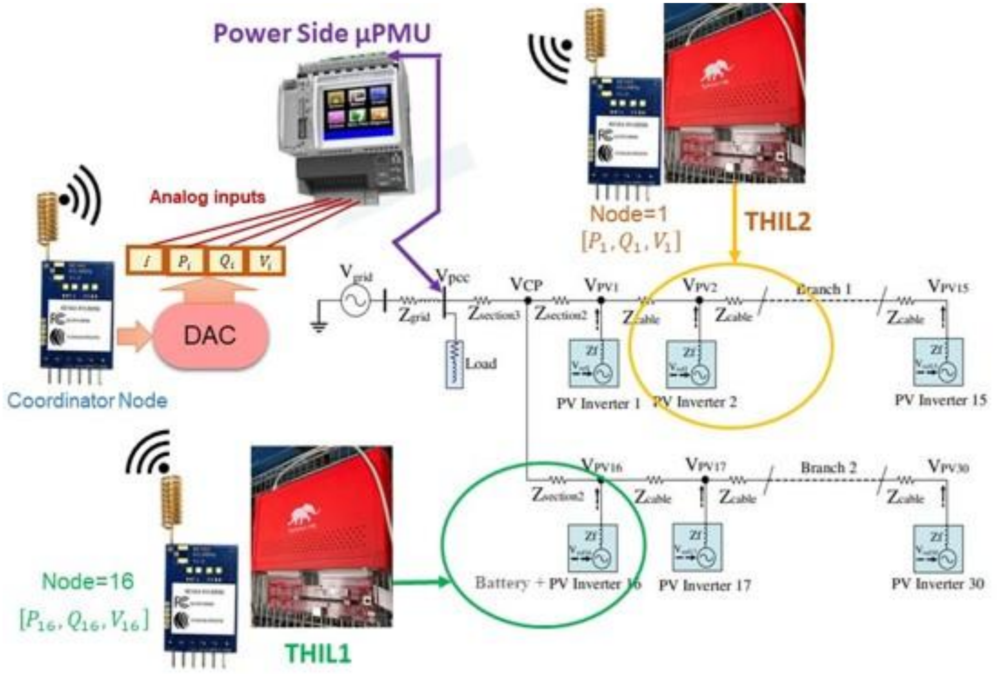
Validating concepts in RTDS and typhoon HIL

Conclusion

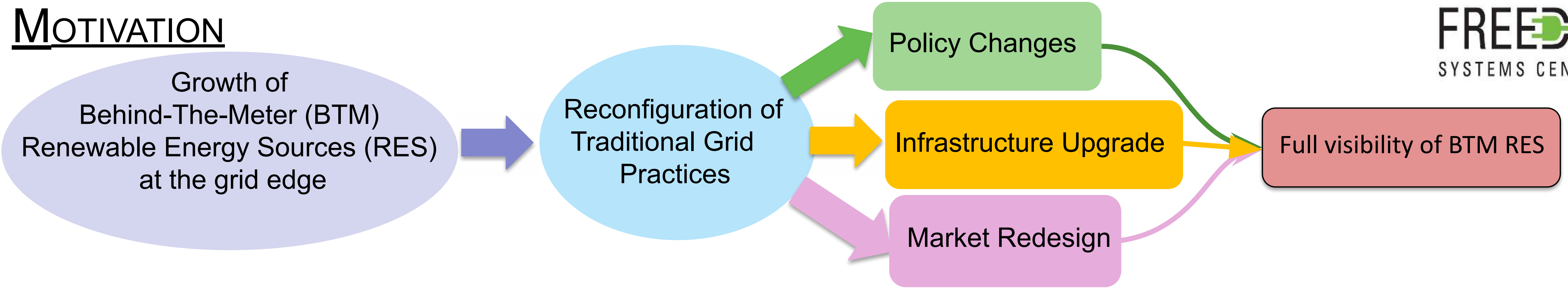
Demonstrated viable communications on platforms

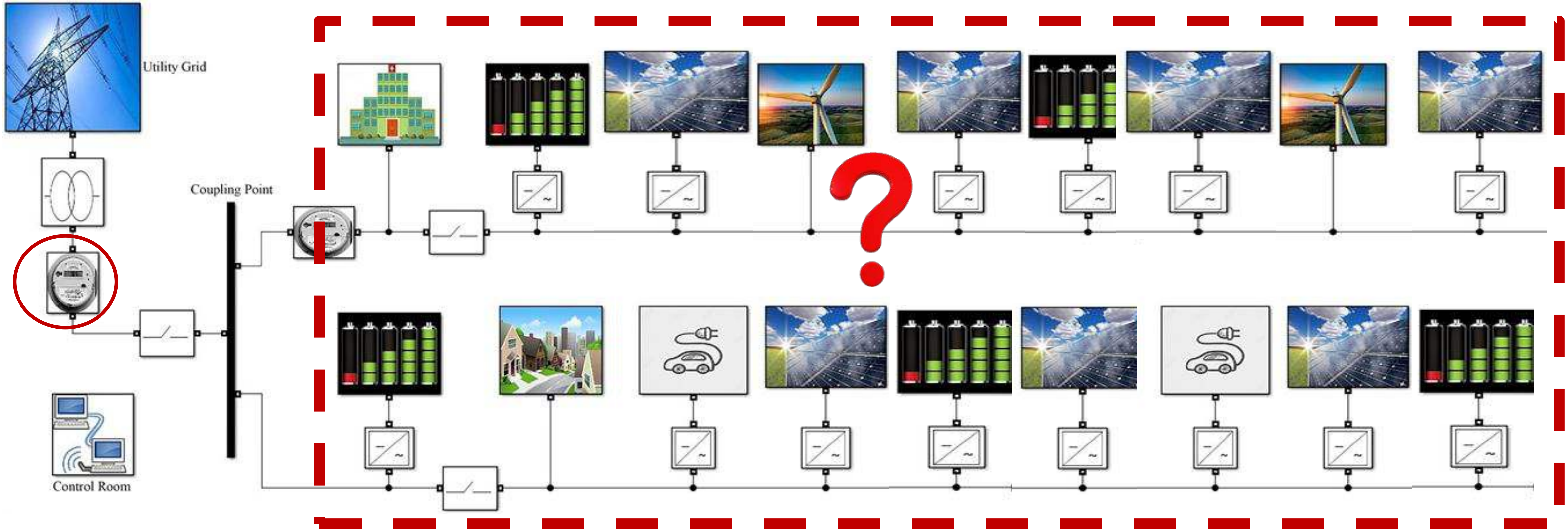
Future Work

Migrating platform commercial components in future efforts



Motivation


Growth of
Behind-The-Meter (BTM)
Renewable Energy Sources (RES)
at the grid edge
Reconfiguration of
Traditional Grid
Practices
Policy Changes
Infrastructure Upgrade
Market Redesign
Full visibility of BTM RES


Utility Grid
Coupling Point
Control Room

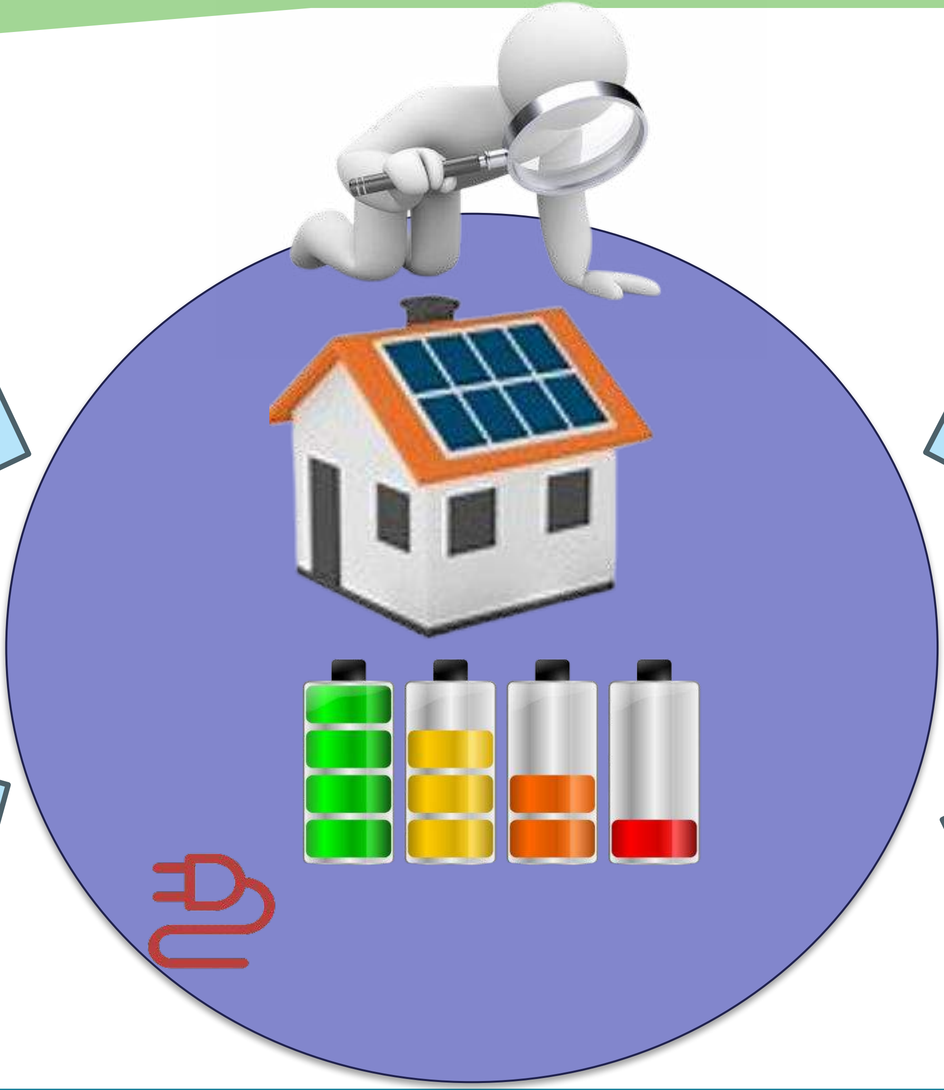
Motivation

DOE in 2020□Award amount: $6 million
Supporting projects that provide utilities better data about rooftop solar power generation

Granular visibility into BTM RES

Data Standards &Quality

Stake Holder Obstacles



BTM Monitoring & Forecasting

Weather Sensing & Forecasting

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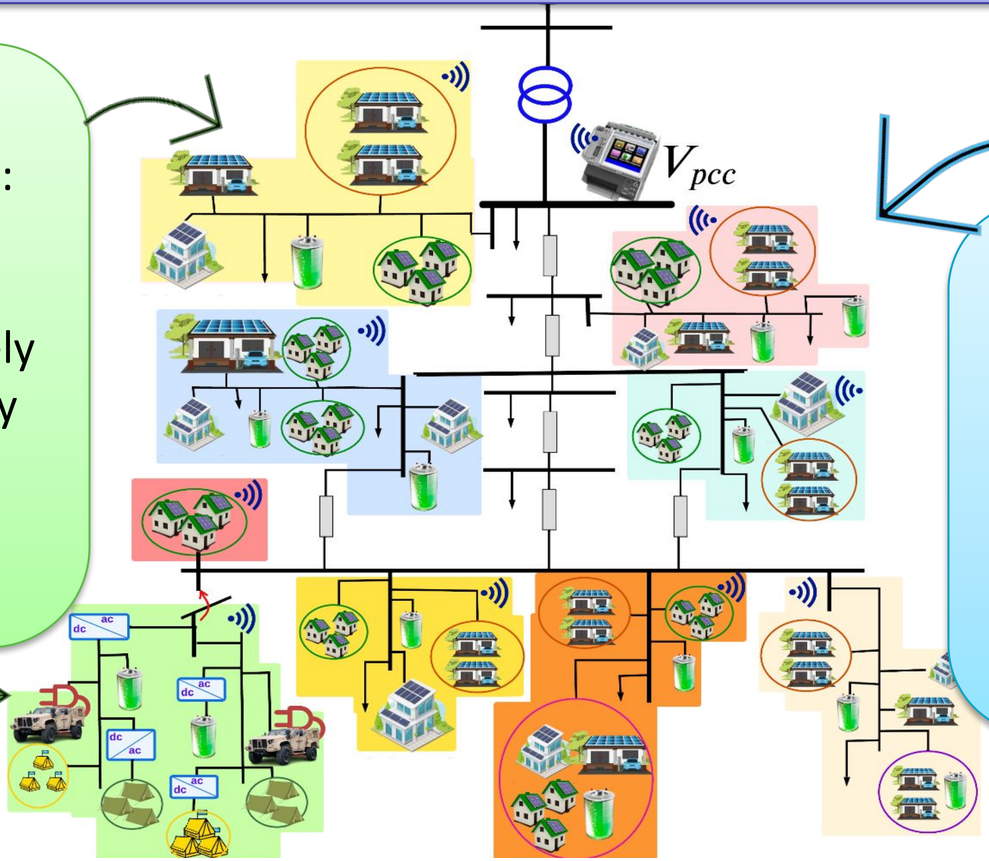
Objective of the project

Design of low-cost, scalable, multi-functional sensor packages for Enhanced Behind-the-Meter visibility to maximize the ancillary grid services of renewables energies

Impact

Utilizing the increased BTM visibility to:

- Implement customized VV & VW control algorithms for each DER zone
- Controlling all the BTM RES collectively as grid assets to further grid reliability and resiliency
- Reduce operation cost,
- Increase PV hosting capacity



Virtual Sensor Node

- Utilizing existing data of distributed inverters controllers as virtual sensing nodes with no additional hardware cost
- Cost-efficient &Reliable communication and coordination among distributed inverters

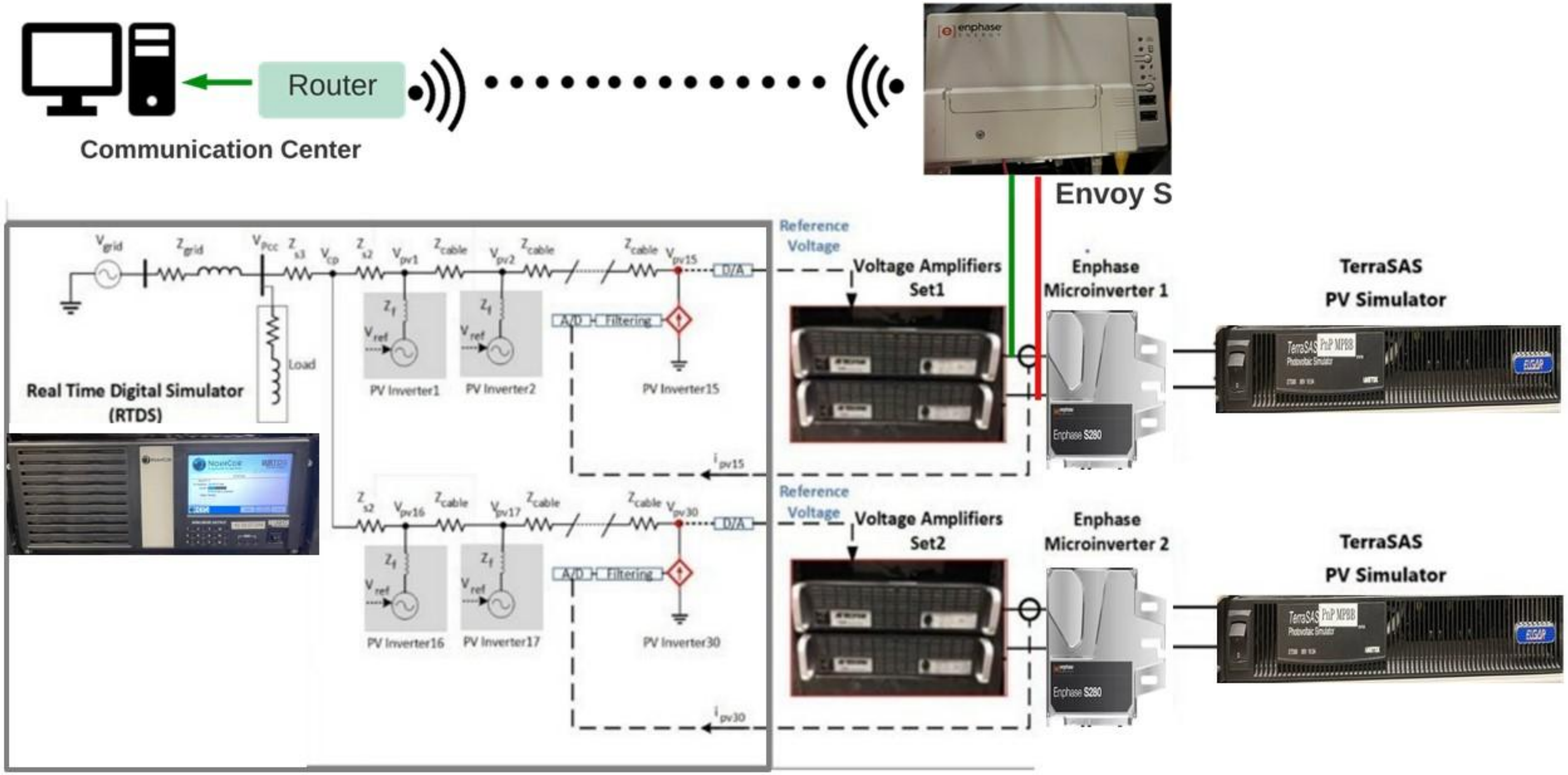
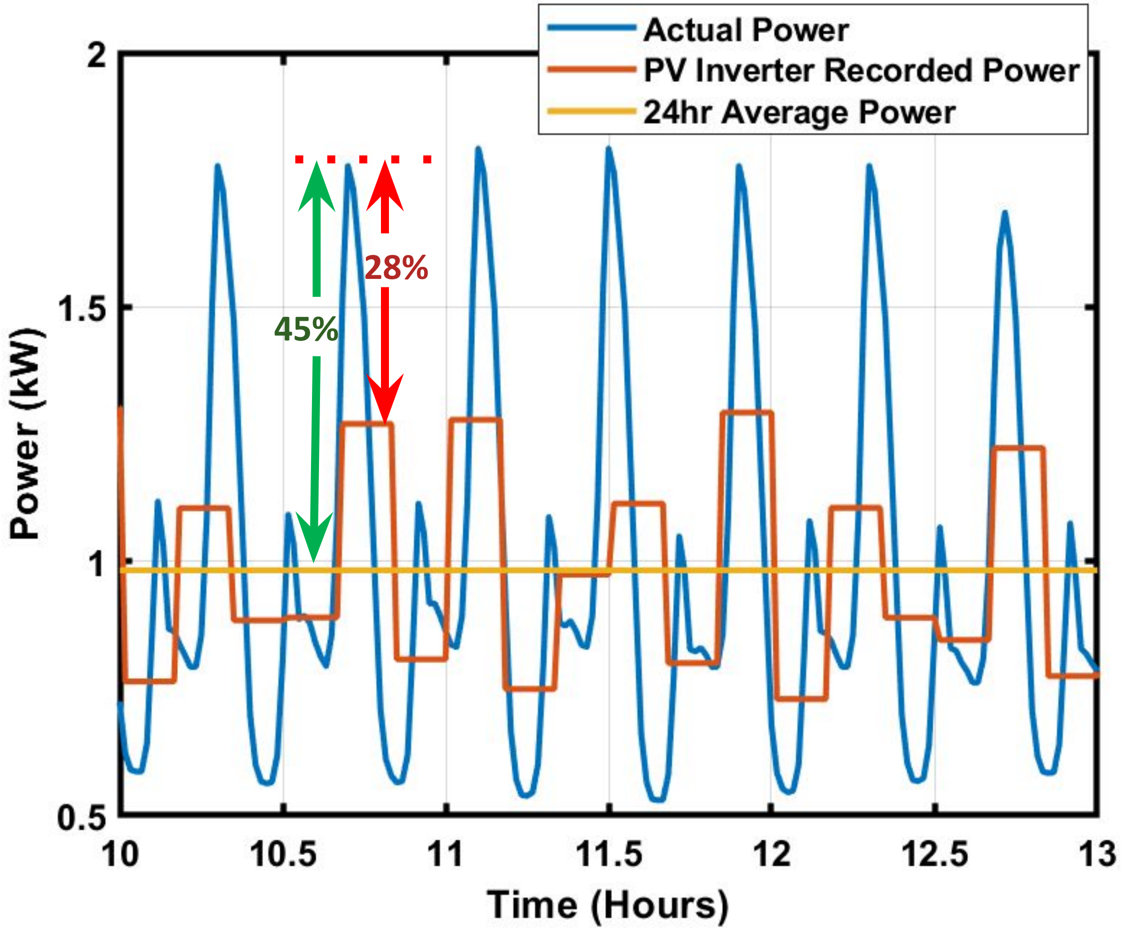
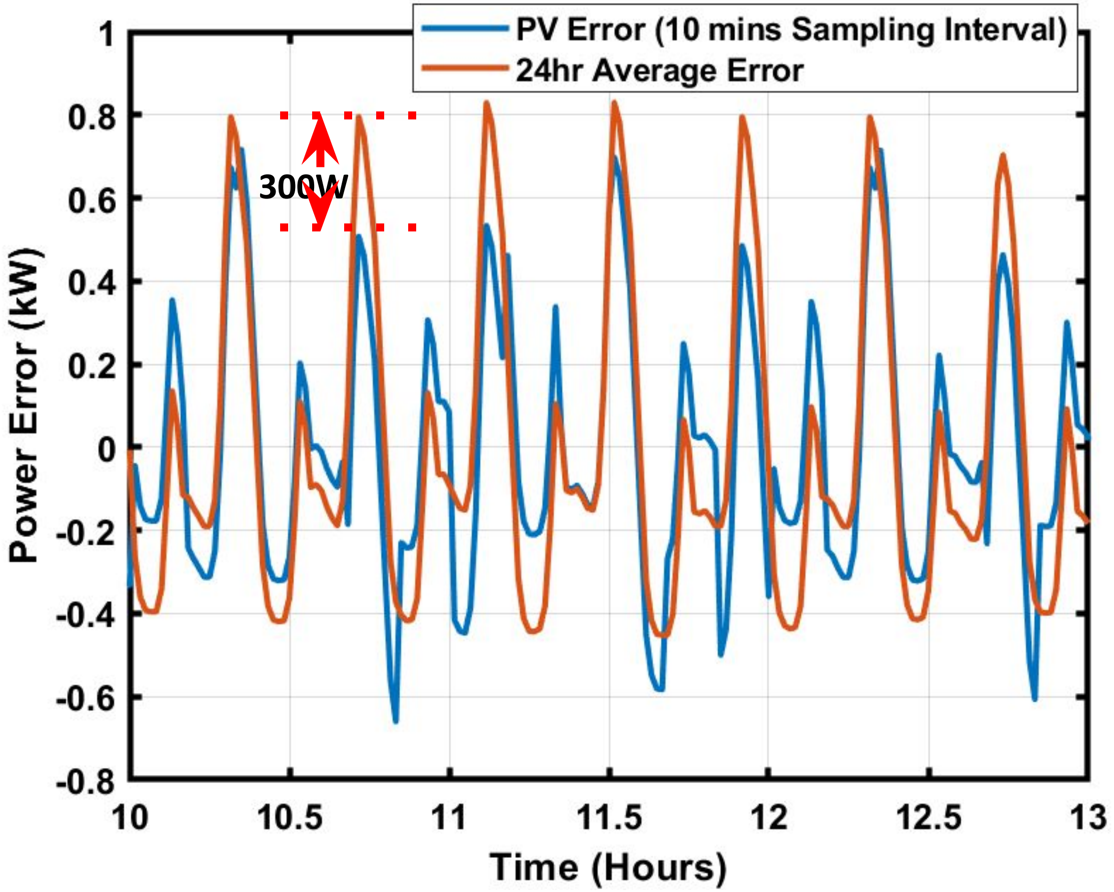


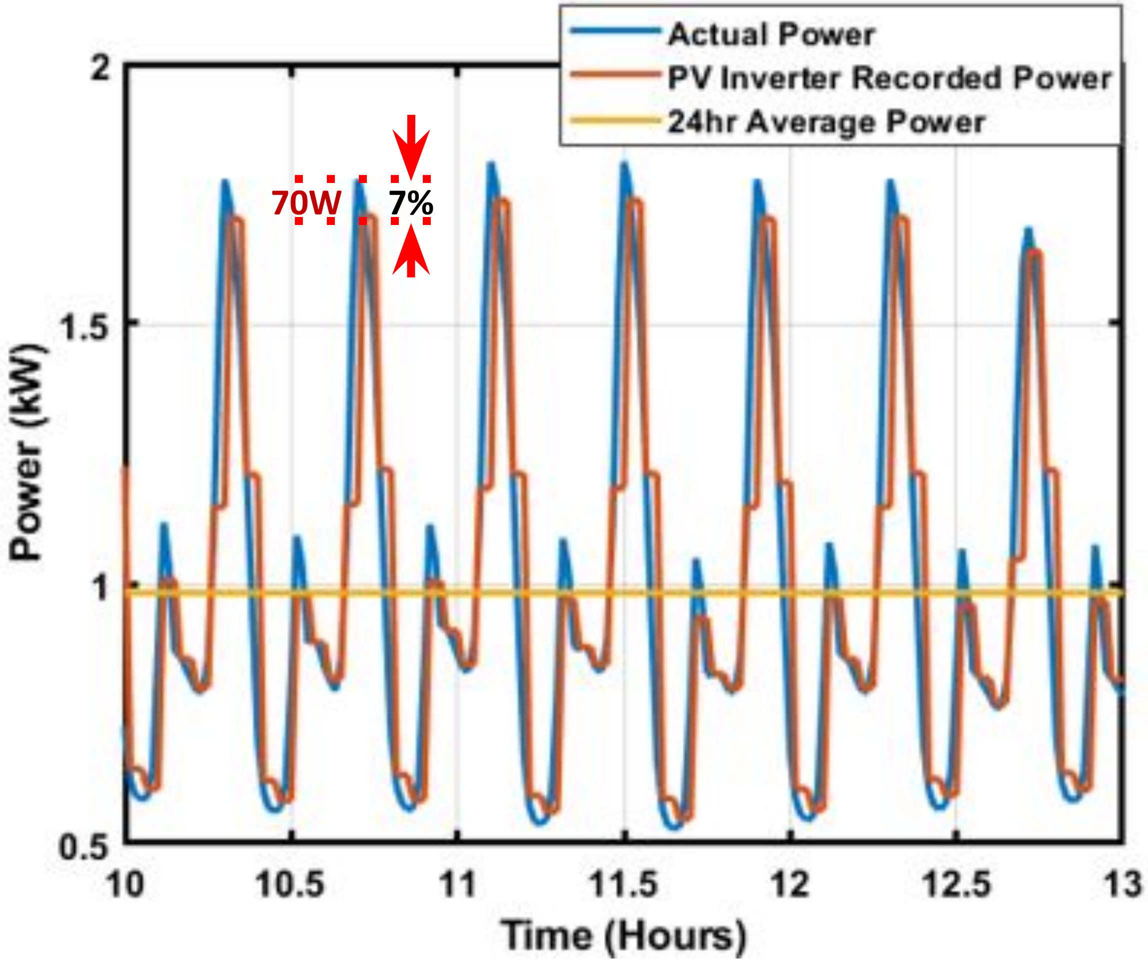
Fig.1 Power-Hardware-In-the Loop (PHIL) testbed for connecting Enphase microinverters to RTDS



The actual PV power vs the recorded power



The error of the actual PV power vs. the recorded one every 10 mins



The error of the actual PV power vs. the recorded one every 3 mins

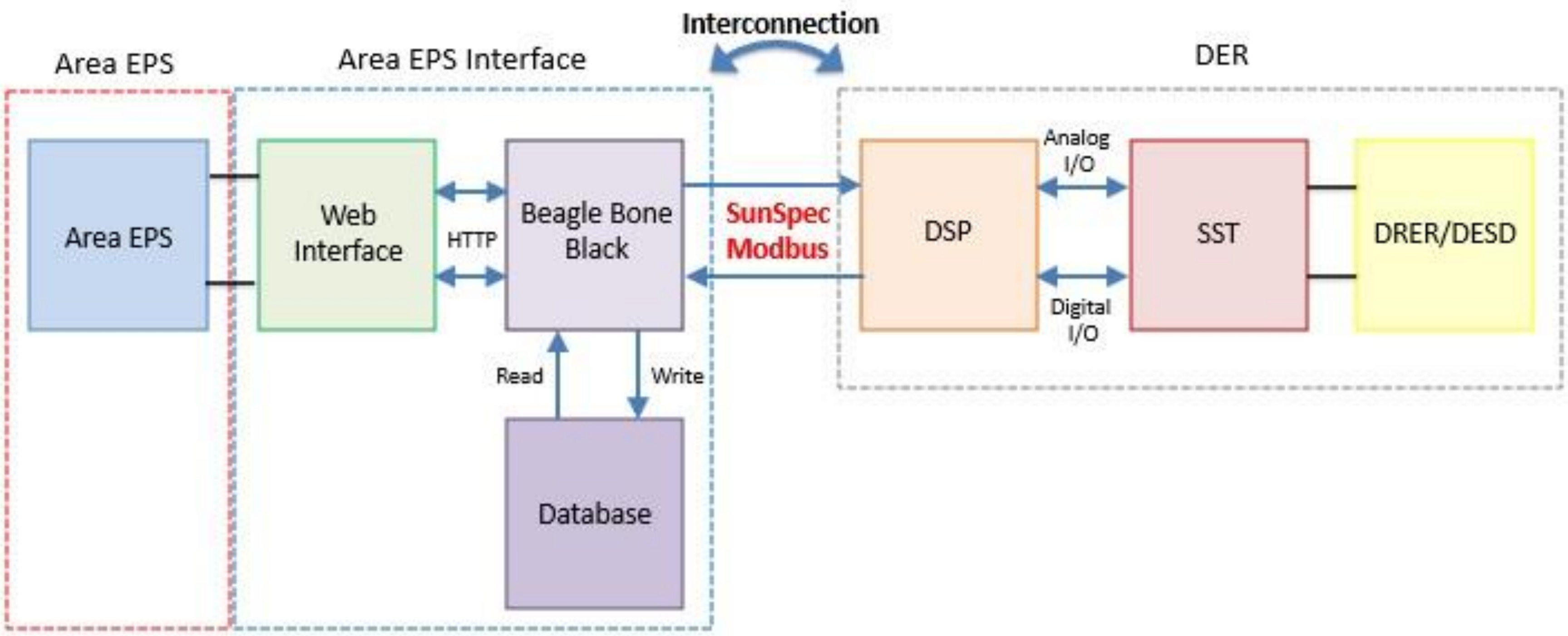
IMPACT

- The implemented wireless communication platform in a PHIL testbed to collect the BTM data (P, Q, V) of the PV inverter and send it to a virtual data aggregator as a web interface
- The testbed is used for clarifying both BTM and dispatch operation data and communication requirement

Wireless Communication platform for a PHIL testbed

IMPACT

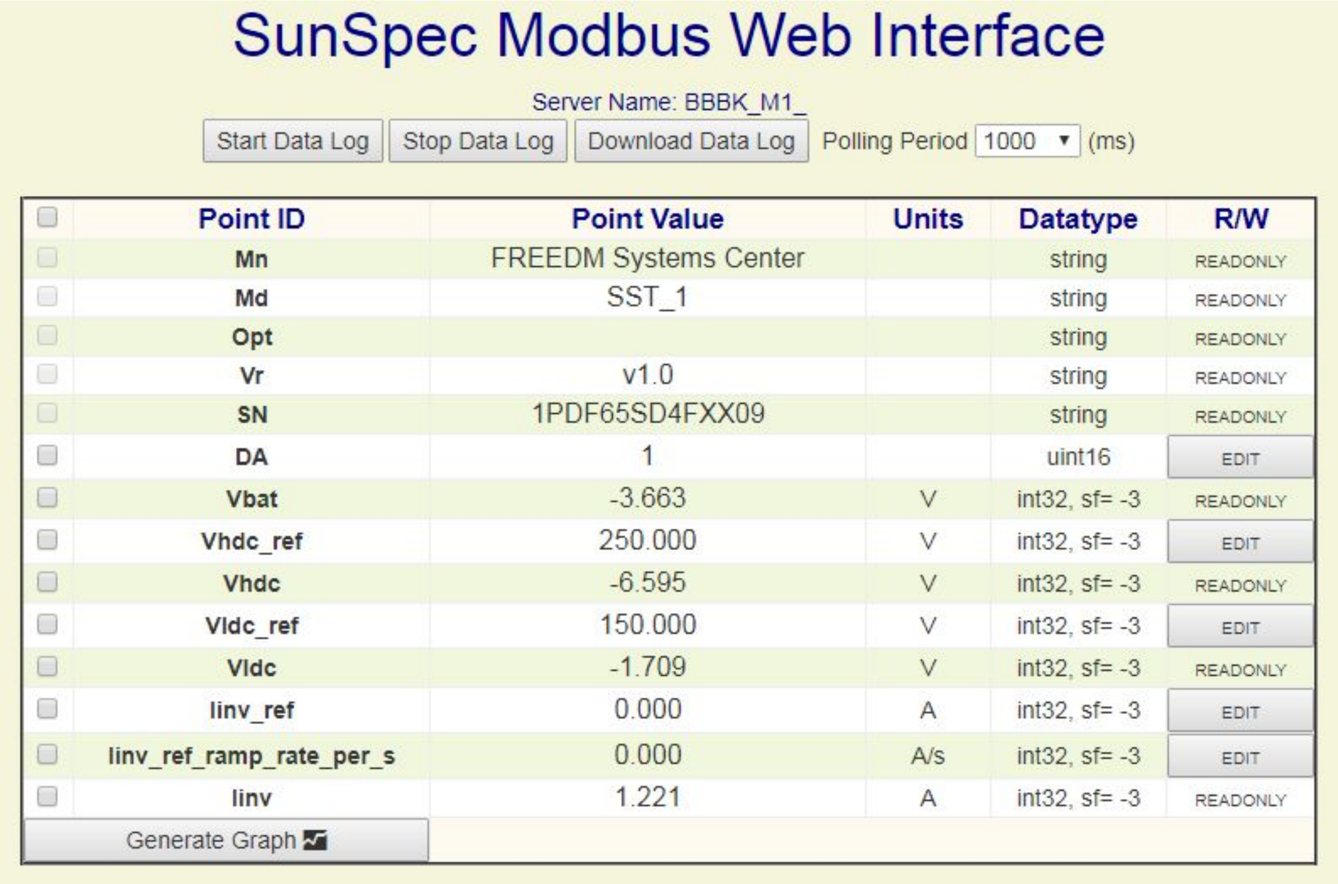
- The DER controller data will be sent to the Beagle Bone Black via SunSpec Modbus protocol. The BBB acts as a web server and the data could be written on or read from.



Detailed block diagram of the implemented communication platform parts and protocols

IMPACT

- The DER controller data could be monitored on the designed web interface with a fixed IP address.
- The polling data frequency is selectable on the web interface.
- Freedom in choosing the rate of polling data will result in enhanced BTM visibility.
- Data could be downloaded as a .cvs file for further analysis



SunSpec Modbus Web Interface

Server Name: BBBK_M1_

Start Data Log | Stop Data Log | Download Data Log | Polling Period 1000 (ms)

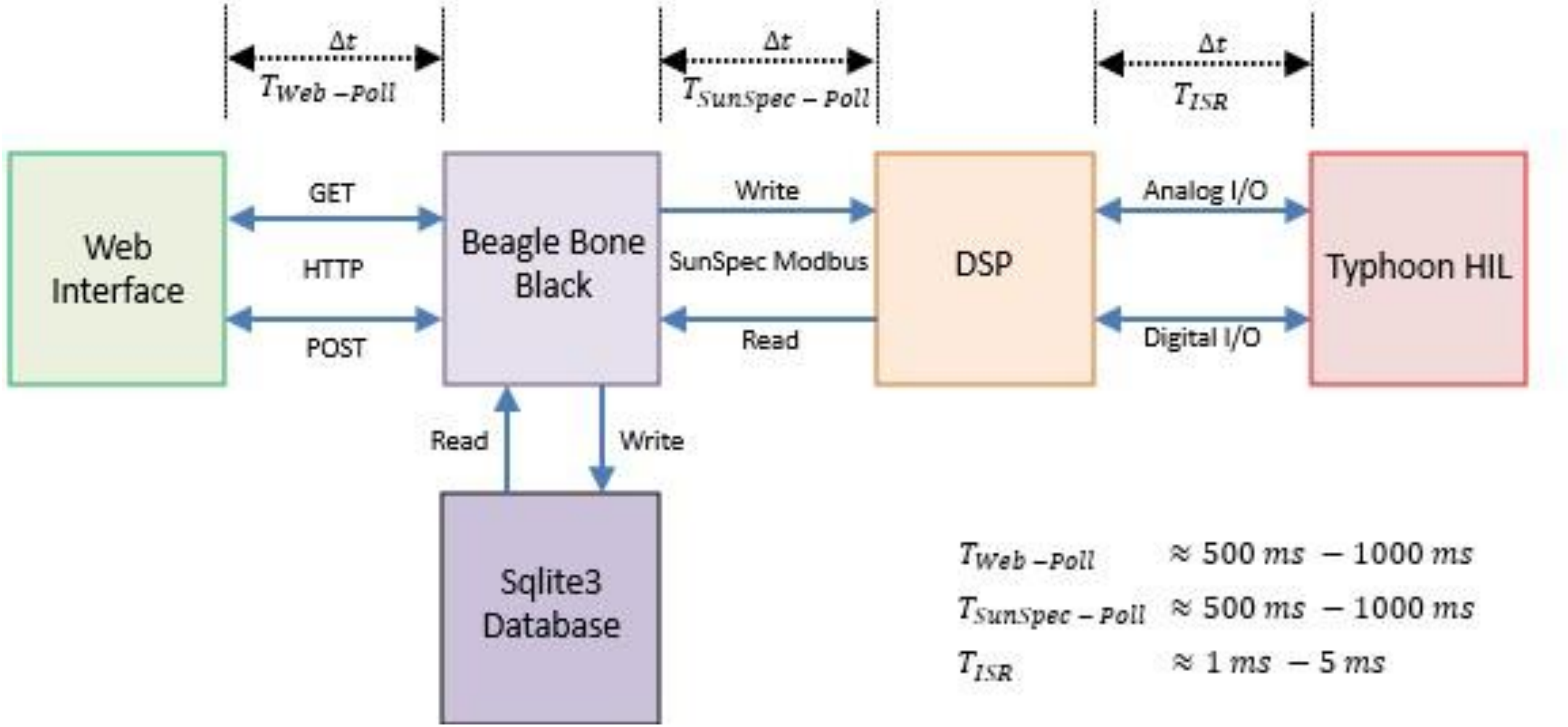
Point ID	Point Value	Units	Datatype	R/W
Mn	FREEDM Systems Center		string	READONLY
Md	SST_1		string	READONLY
Opt			string	READONLY
Vr	v1.0		string	READONLY
SN	1PDF65SD4FXX09		string	READONLY
DA	1		uint16	EDIT
Vbat	-3.663	V	int32, sf= -3	READONLY
Vhdc_ref	250.000	V	int32, sf= -3	EDIT
Vhdc	-6.595	V	int32, sf= -3	READONLY
Vldc_ref	150.000	V	int32, sf= -3	EDIT
Vldc	-1.709	V	int32, sf= -3	READONLY
Iinv_ref	0.000	A	int32, sf= -3	EDIT
Iinv_ref_ramp_rate_per_s	0.000	A/s	int32, sf= -3	EDIT
Iinv	1.221	A	int32, sf= -3	READONLY

Generate Graph

Web-interface for monitoring the DER data

IMPACT

- Analysis of communication delay between each stage of the testbed
- Maximum total delay from sender to receiver = 2 seconds



Communication latency of various parts of the communication platform

IMPACT

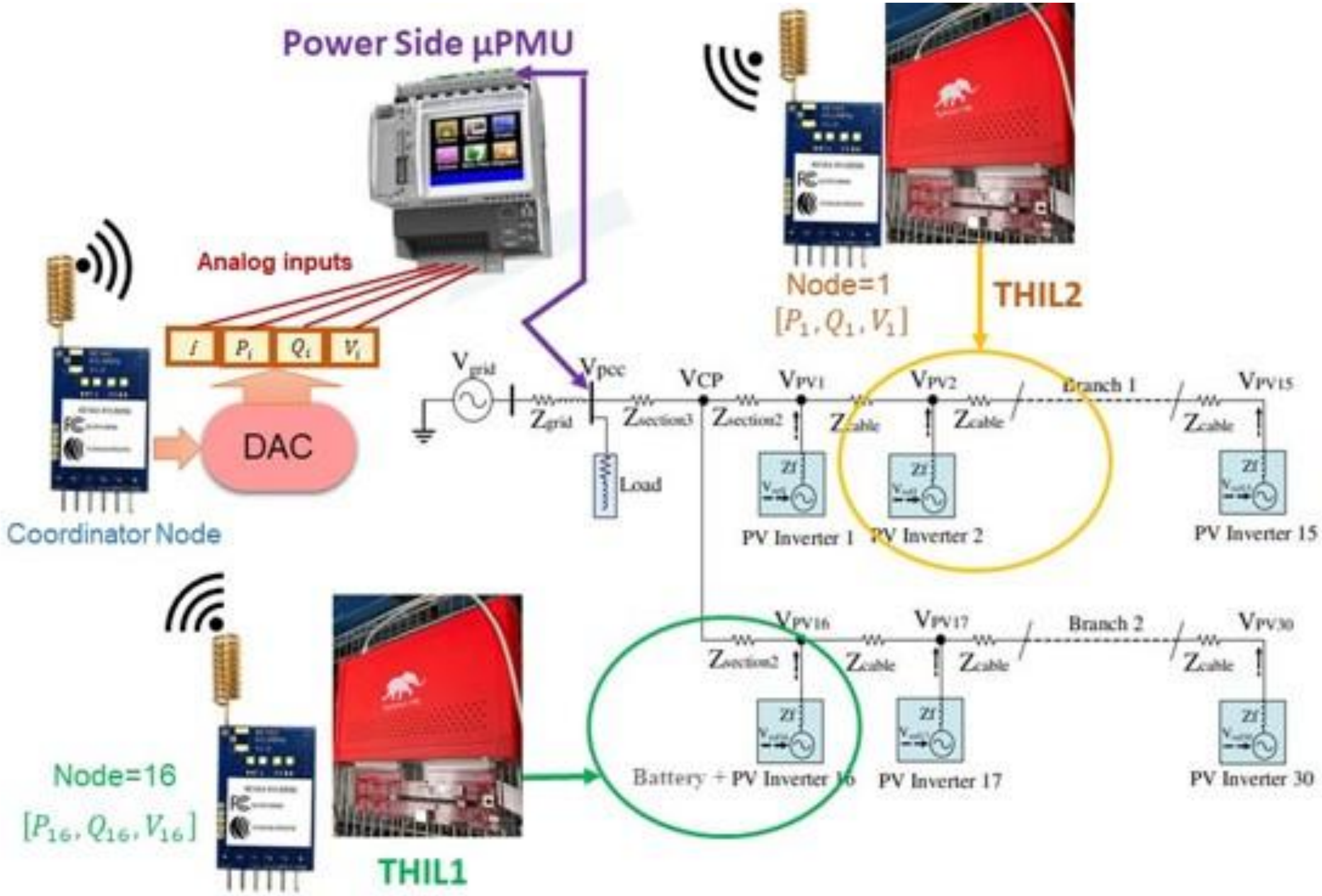
- Extension of the communication platform for three Typhoon HIL devices.
- Every typhoon HIL device □ real-time simulation of a different DER.
- Aggregation of data from all DERs on the BBB
- Monitoring and remote supervisory control of the system by the web-interface.

a. Three THIL of the testbed

b. The optical isolator and adaptor for RS-232 to RS-485

c. The BBB and the network switch

- The proposed communication network for collecting BTM DER data and monitor it on a microPMU as a data aggregator
- Collecting each inverter's data using the LORA modules and the analog inputs of the microPMU.



The proposed wireless communication platform for aggregating data on mPMU

Experimental Testbed

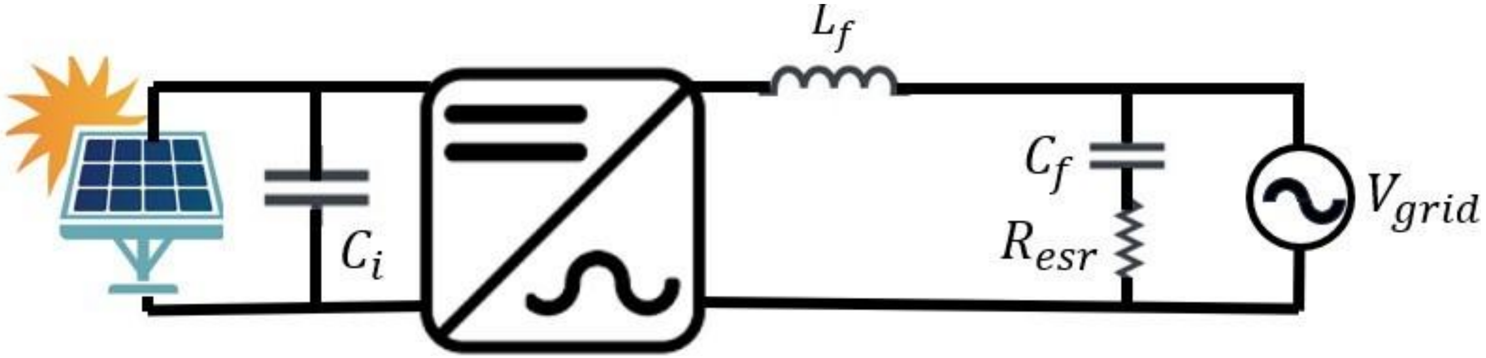


Fig.1 Block diagram of the simulated PV system in Typhoon HIL

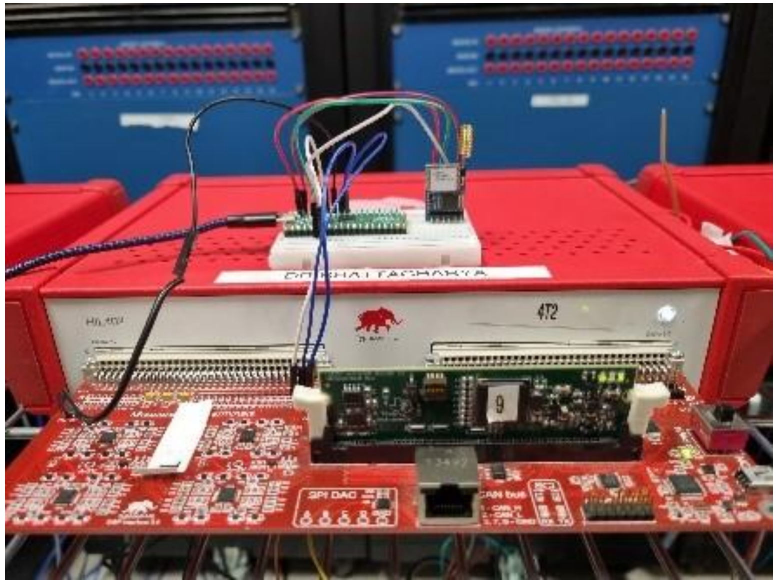


Fig.2a. LORA module 1 & THIL at node1

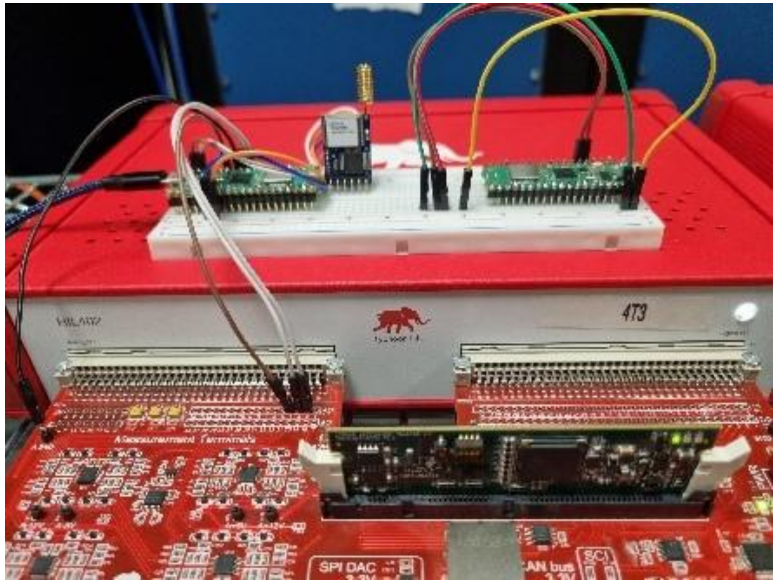


Fig.2b. LORA module 2 & THIL at node2

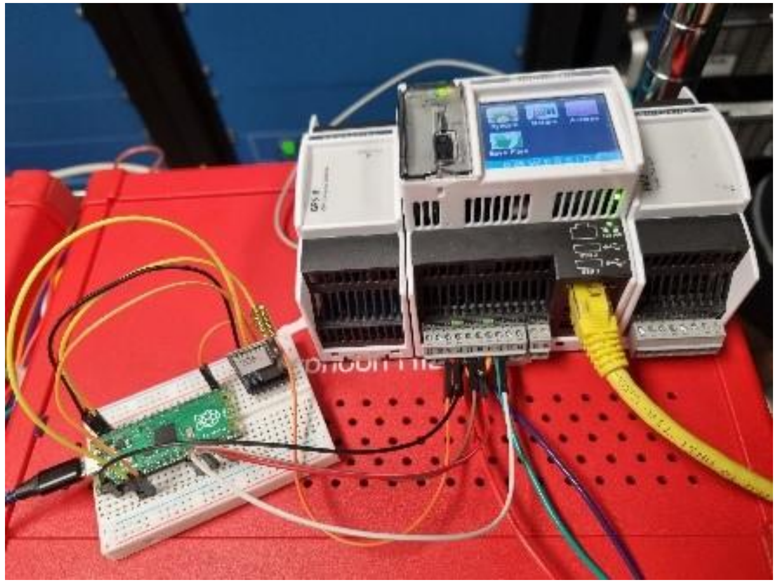


Fig.2c. LORA module 3, raspberry pi, and μPMU at the coordinator node

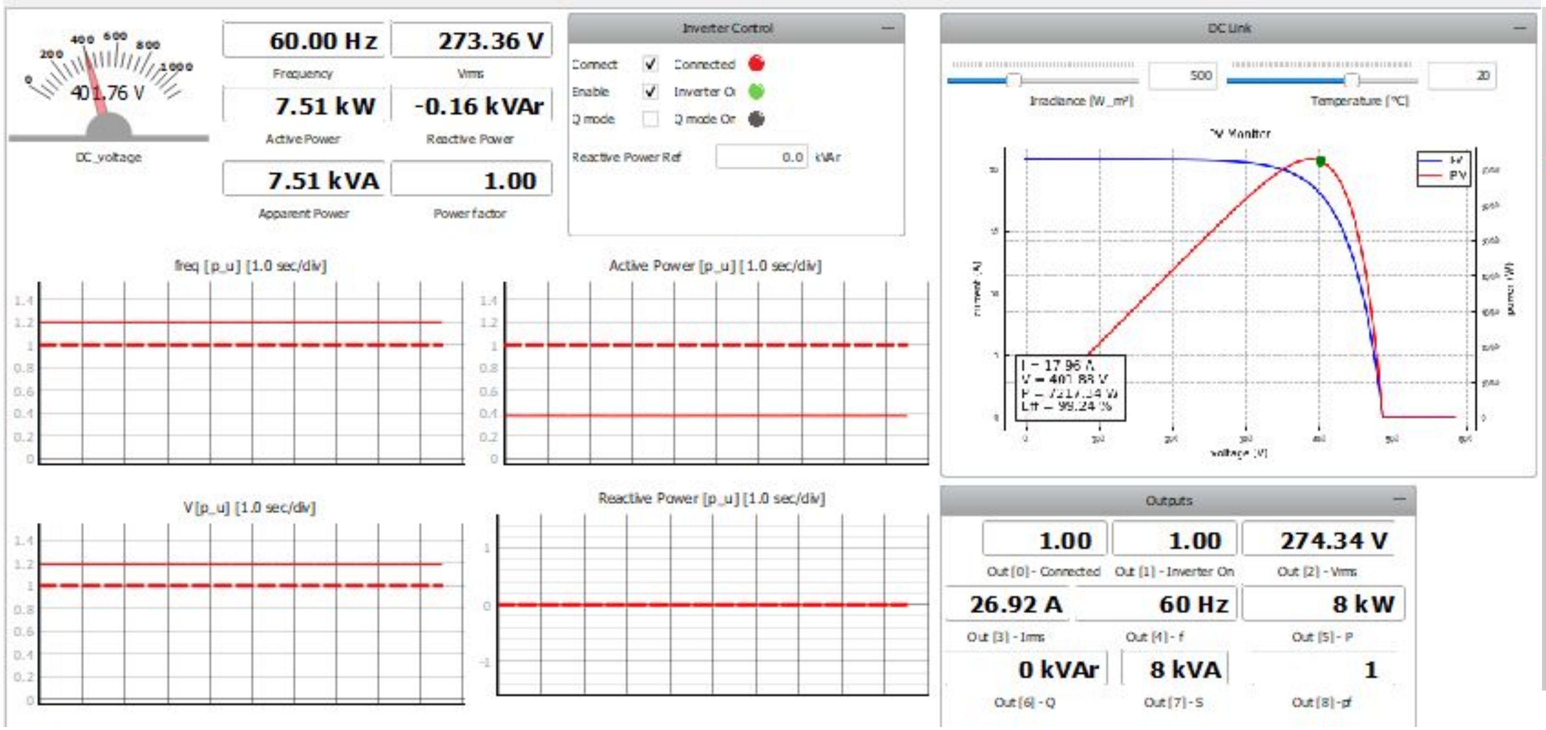


Fig. 3. Typhoon SCADA data measurement and monitoring at node1.

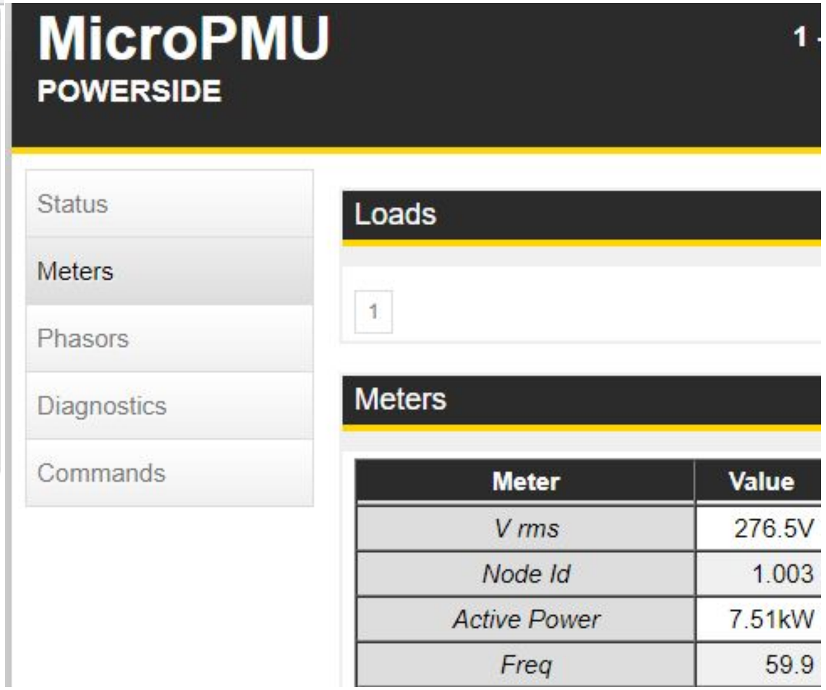
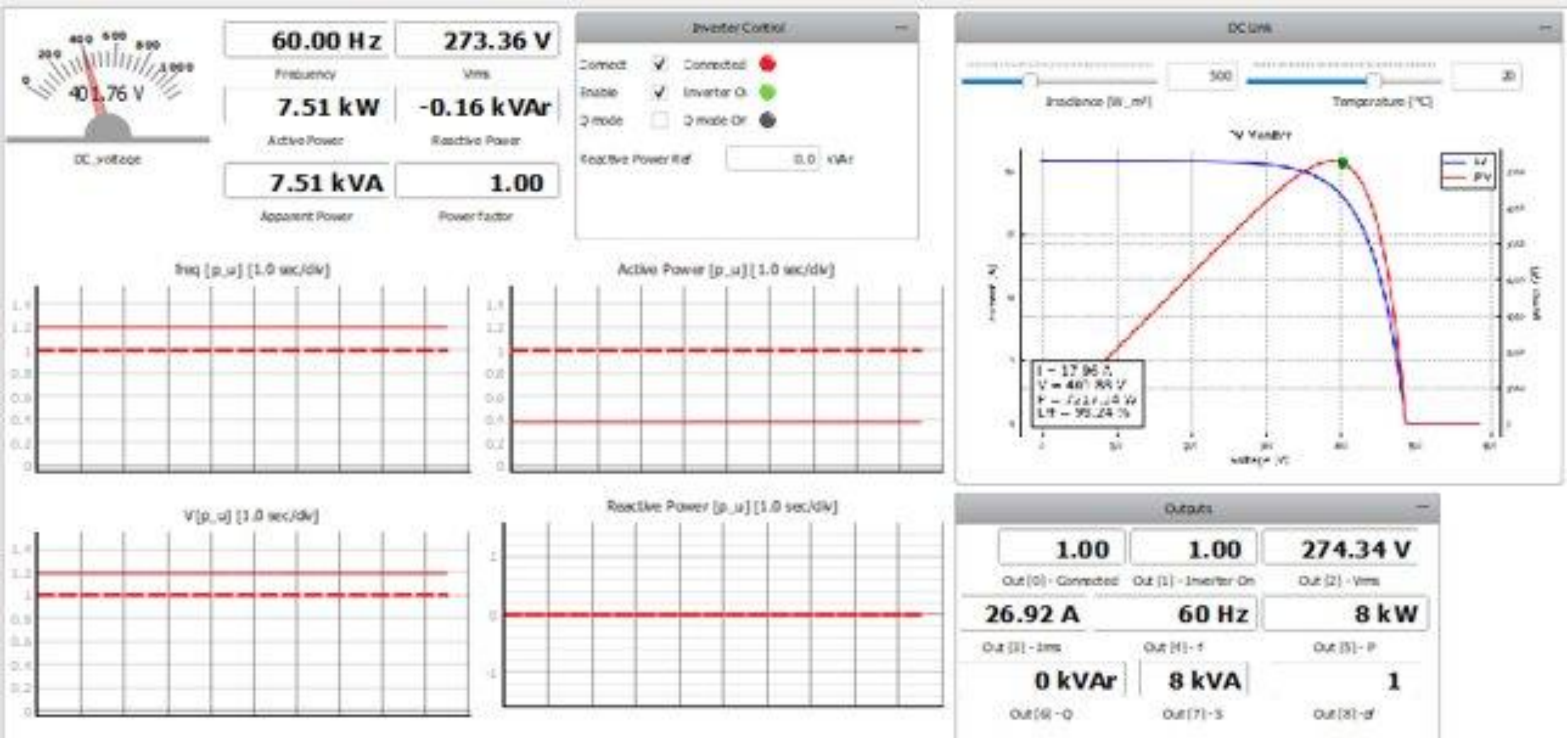


Fig. 4. μPMU data monitoring at node1

*The installed PV capacity = 15kW at 1000W/m2 solar irradiation and 20◦C.

***Node 1**: solar irradiation= 500W/m2 & P = 7.5kW

Node 1	µPMU	THIL	Error%
V(V)	276.6	273.36	1.18
P(kW)	7.51	7.51	0
F(Hz)	60	59.9	0.16



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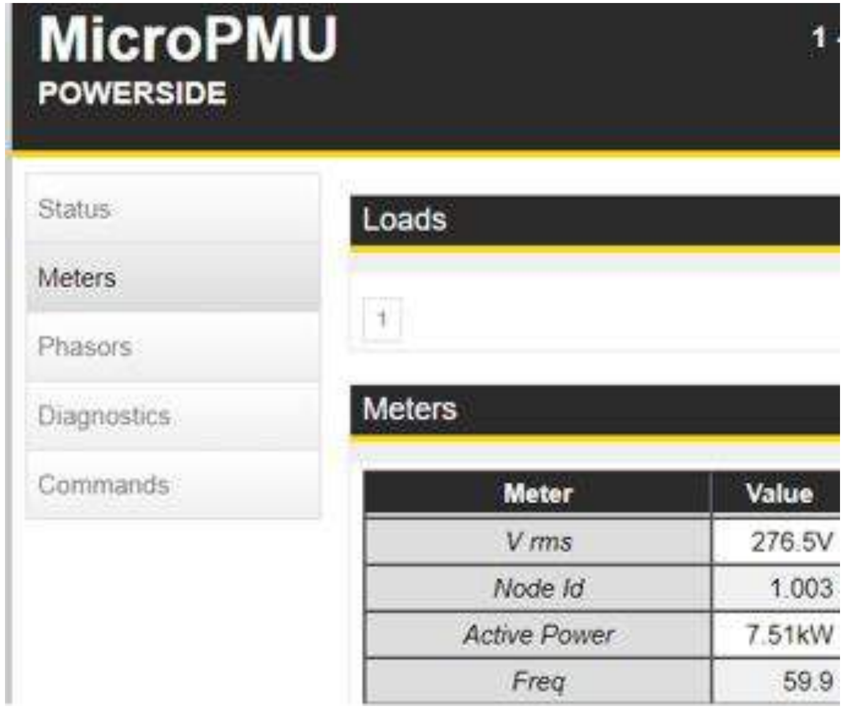

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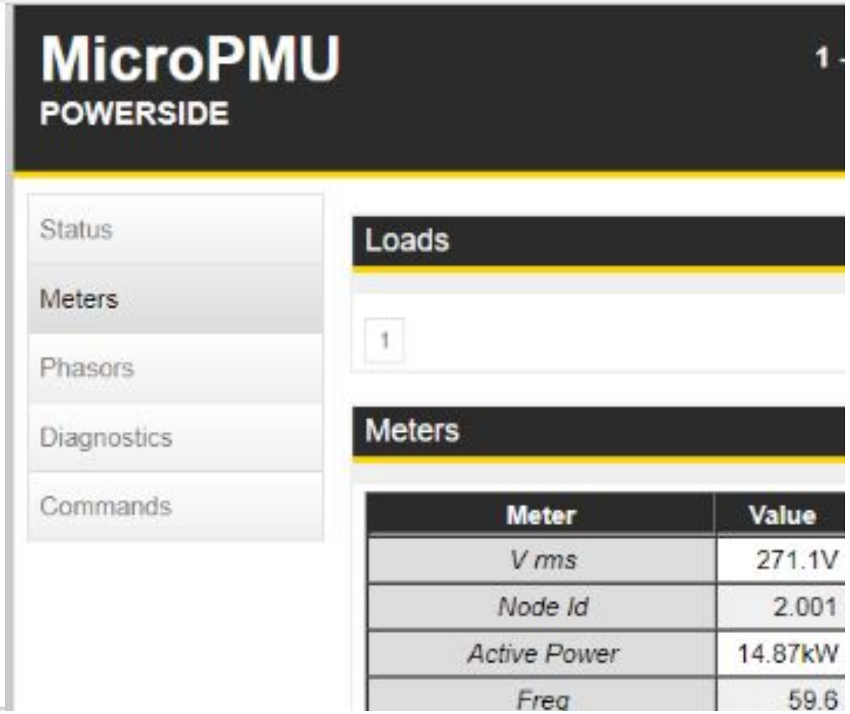

Fig. 5. Typhoon SCADA data measurement and monitoring at node2.

Fig. 6. μPMU data monitoring at node2

*The installed PV capacity = 15kW at 1000W/m2 solar irradiation and 20◦C.

***Node 2**: solar irradiation= 1000W/m2 & P = 15kW

Node 2	µPMU	THIL	Error%
V(V)	271.7	273.47	0.65
P(kW)	15.05	14.87	1.19
F(Hz)	60	59.5	0.83

Fig. 5. Typhoon SCADA data measurement and monitoring at node2.

Fig. 6. µPMU data monitoring at node2

FUTURE PLAN

- Using Commercial microinverters for validating the virtual sensor concept
- Implementing a virtual data aggregator and data management platform to collect the BTM sources data
- Utilizing the increased BTM visibility to implement customized VV & VW control algorithms for each DER zone