A CHIL Validation of Machine Learning-Assisted Methods for Real-Time Controls of Solar PV for Grid Services

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Why do we need PHL estimations?

More Solar PV = More Variability = Higher Flexibility Requirement

A major challenge in integrating solar PV for grid services is evaluating the regulation reserves of curtailed solar inverters accurately. Estimating reserves, or the **potential high-limit (PHL)**, of curtailed inverters allows solar PV to perform grid services.

- ❑ A **controller- hardware-in-the-loop** framework has been designed and established for this work.
- ❑ Simulating real time controls allows us to validate the performance of a potential high limit-based flexible PV plant control in **supporting closed-loop automatic generation control (AGC).**

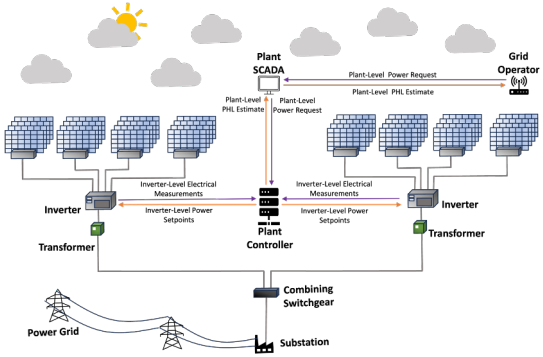

Fig. 1: Components of a typical utility-scale PV power plant

Solar PV CHIL Frameworks

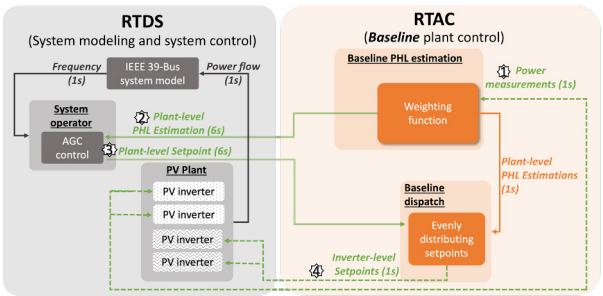

Fig. 2a: Baseline CHIL

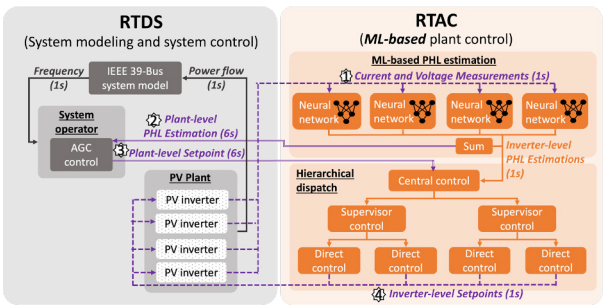

Fig. 2b:ML-based CHIL

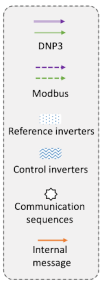

Fig. 2c: Legend

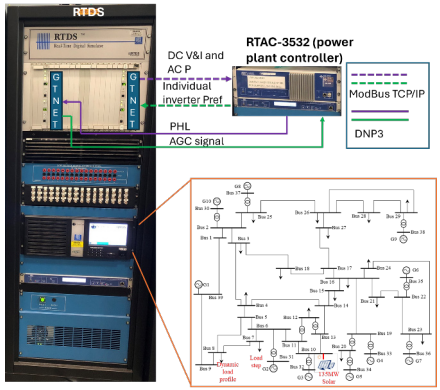

Fig. 3: Laboratory CHIL Setup (Credit: NREL)

- ❑ **RTDS** simulates the IEEE 39-bus power system, the PV inverters, and the closed-loop AGC, while the Schweitzer **RTAC** performs the controls.
- ❑ A **135-MW** PV plant has been incorporated at Bus 10 of the 39-bus system, with **27 inverters** modeled.
- ❑ A **100-MW** load step is triggered at Bus 7.
- ❑ Inverter dispatch setpoints, AGC plant-level setpoints, and measurements between RTAC and RTDS are transmitted via **MODBUS TCP/IP** and **DNP3 protocols.**

Performance Evaluation

Controls were implemented for **nine 9-minute weather scenarios.** Their performance was judged based on requirements for stand-alone PV taken from **Georgia Power's CARES 2023 RFP**, stating 1) PHL percentage error **<5% for ≥95% of the time** and 2) AGC plant-wide setpoint **RMSE <5MW.**

	Cloudy Phase			Sunny Phase			Transition Phase		
		R1	R2		R1	R2		R1	R2
Morning Ramp Up	ML	**0.00%**	**0.07**	ML	**0.00%**	**0.19**	ML	**2.20%**	**1.25**
	Baseline	**0.00%**	**0.01**	Baseline	**0.00%**	**0.72**	Baseline	**0.00%**	**0.75**
Afternoon Peak	ML	**0.00%**	**0.04**	ML	**100%**	**0.74**	ML	**95.60%**	**3.79**
	Baseline	**0.00%**	**0.01**	Baseline	**0.00%**	**0.54**	Baseline	**6.42**	**2.04**
Evening Ramp Down	ML	**0.00%**	**0.11**	ML	**99.27%**	**0.25**	ML	**50.46%**	**0.18**
	Baseline	**0.00%**	**0.01**	Baseline	**0.00%**	**0.52**	Baseline	**61.83%**	**0.16**

Table 1. All weather scenario results where R1 is the % of time PHL error <5%, and R2 is the AGC setpoint RMSE [MW].

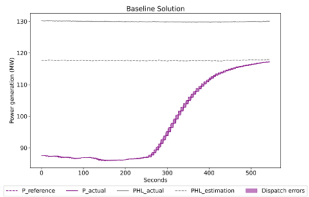

Fig. 5: Baseline performance during Sunny Peak

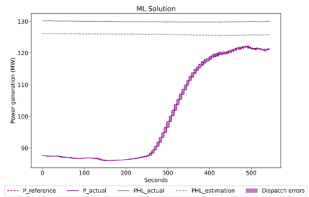

Fig. 6: ML-based performance during Sunny Peak

Conclusion · Application · Future Work

✓ Both methods meet requirements for AGC setpoint accuracy, while the ML method performs **31.03% better** in meeting the PHL accuracy requirements.

✓ Improvements in model training can be made to **enhance flexibility in cloudy situations.**

✓ Future work should evaluate the **techno-economic benefits** of the high-accuracy flexible performance of PV on AGC, a historically low-value grid controls instrument.

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