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Integrated Energy Systems

Supervisory Control with Feasible Actuator Range Modifier (FARM)

FORCE Overview and Training
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1. FARM capability overview

- FARM: Feasible Actuator Range Modifier
  - FARM is a RAVEN plugin to meet the supervisory control needs.
  - FARM helps validate the issued actuator value, to meet both
    - Explicit constraints, and
    - Implicit constraints.

- Q1: What are these constraints?

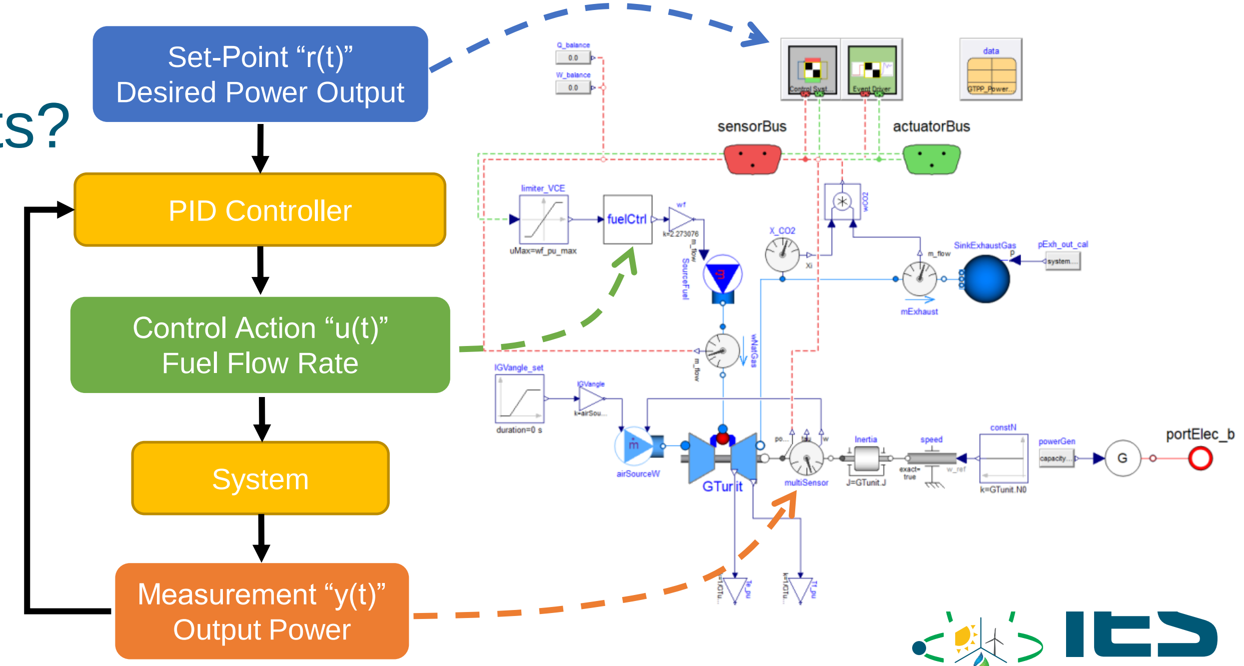
  Let's use a Gas Turbine to explain:

Explicit constraints:

- Power output to grid;
- Power ramp rate, etc.

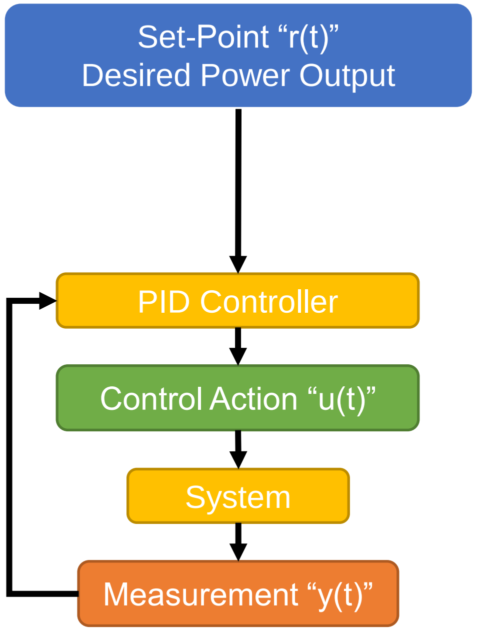
Implicit constraints:

- Firing Temperature, etc.

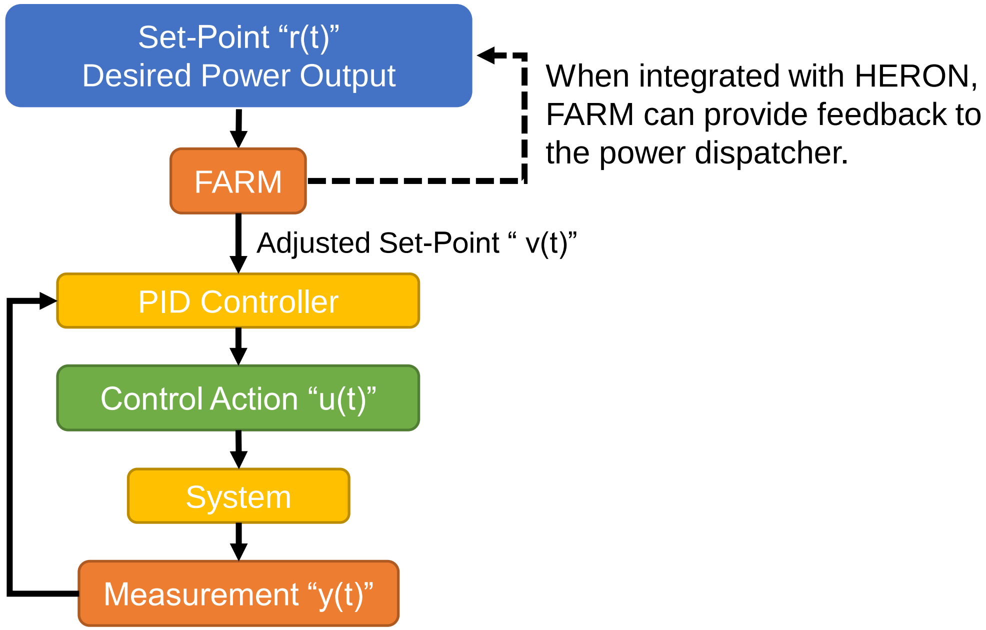


1. FARM capability overview

- FARM: Feasible Actuator Range Modifier
  - Q2: Where is FARM in the feedback loop control?



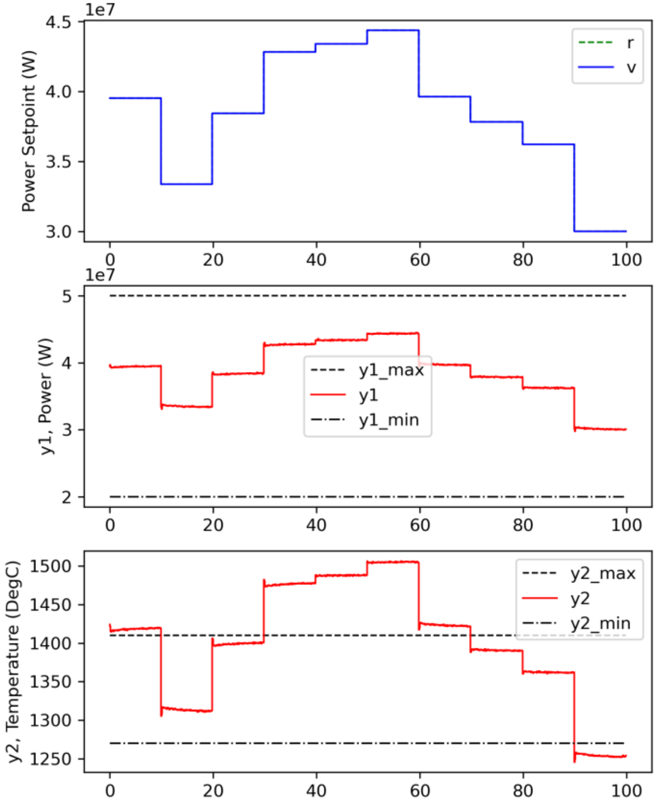
Without FARM



With FARM

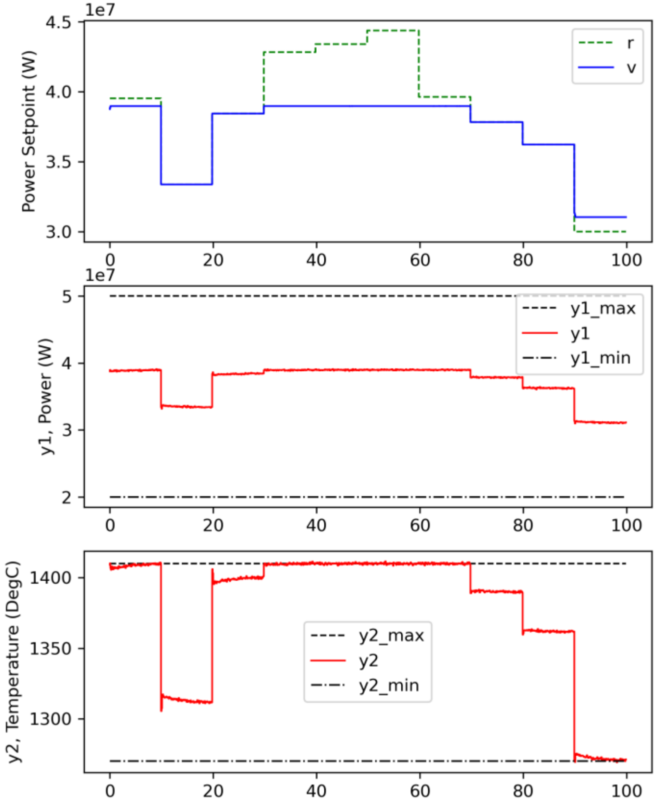
1. FARM capability overview

- FARM: Feasible Actuator Range Modifier
  - Q3: What’s the effects of FARM?



Without FARM:
- System run on original power setpoint
- Implicit constraints were violated (Firing temperature)

With FARM:
- Power setpoint was adjusted
- Implicit constraints were met (Firing temperature)



2. Software installation

- FARM is an open-source software
  - https://github.com/Argonne-National-Laboratory/FARM
  - In order to run FARM, RAVEN and HERON are pre-requisites.
- FARM installation can be done in 2 ways:
  - Install the submodule version of FARM within RAVEN

```
haoyuwang@p075722 MINGW64 /d/GitProjects/official_forks/raven (devel)
$ ./scripts/install_plugins.py -s FARM
```

  - Or: Download FARM source code using git

```
haoyuwang@p075722 MINGW64 /d/GitProjects/training
$ git clone https://github.com/Argonne-National-Laboratory/FARM.git
```

Then register FARM plugin in RAVEN

```
haoyuwang@p075722 MINGW64 /d/GitProjects/training/raven (devel)
$ ./scripts/install_plugins.py -s /d/GitProjects/training/FARM/
```

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3. Regular Usage: FARM as set-point regulator
3.a. Input creation and running the code

FARM

- FARM uses XML file as input
  - One example is in
    FARM / Training / 2023Apr06 / input_2_FARM_RG_para_SES.xml
  - We will focus on some key entries.

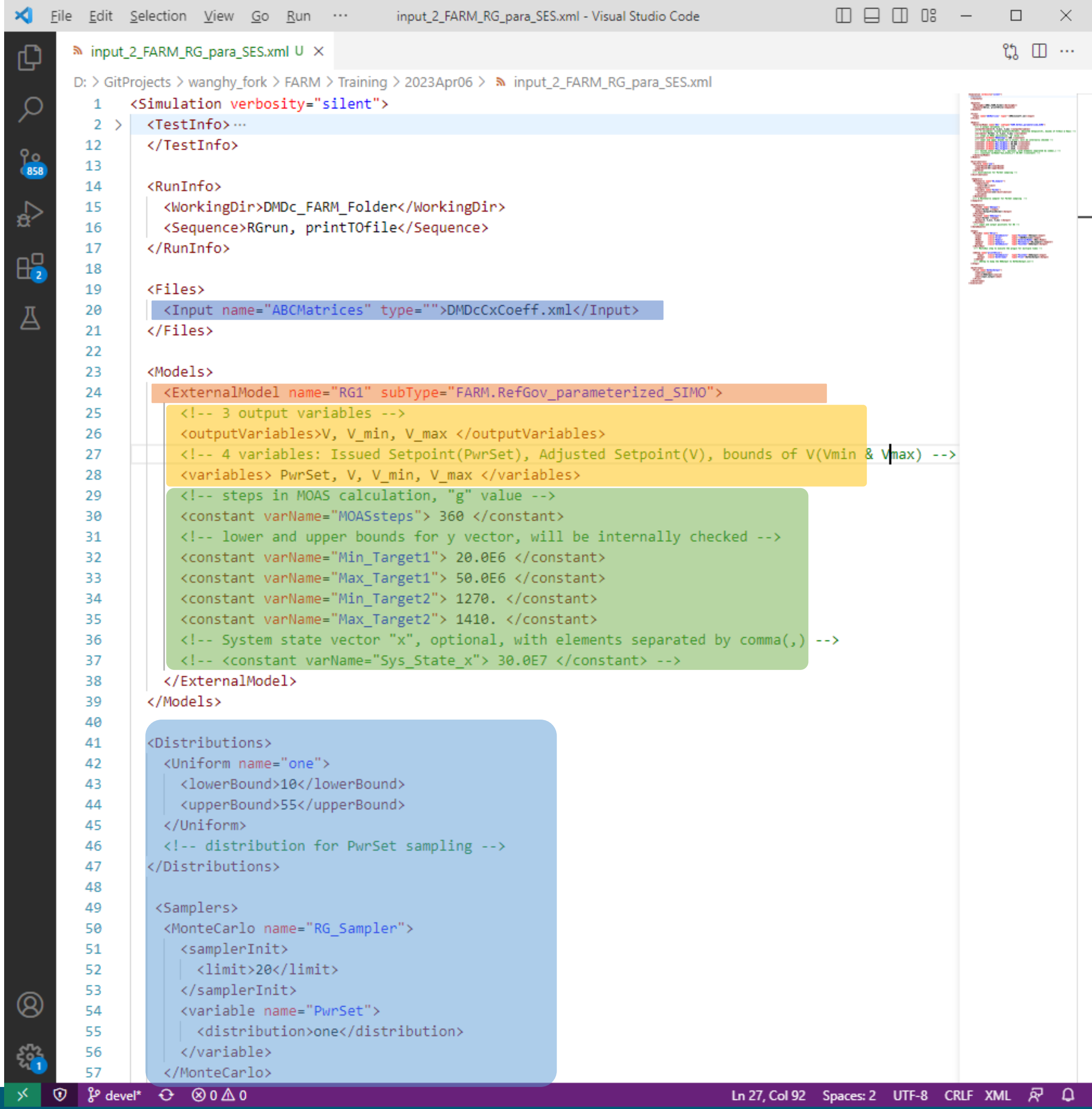
a1. An XML file containing the state-space representation matrices;

a2. FARM external model name;

a3. Input and output variables for FARM;

a4. Prediction time horizon, operational constraints, and system state;

a5. Random number generator for input variables creation



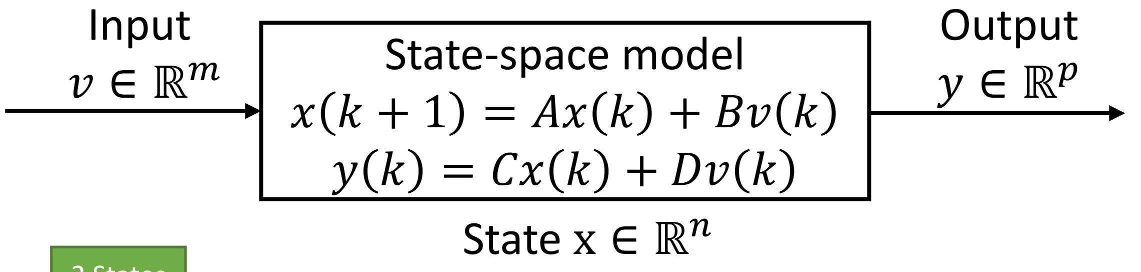
3. Regular Usage: FARM as set-point regulator
3.a. Input creation and running the code

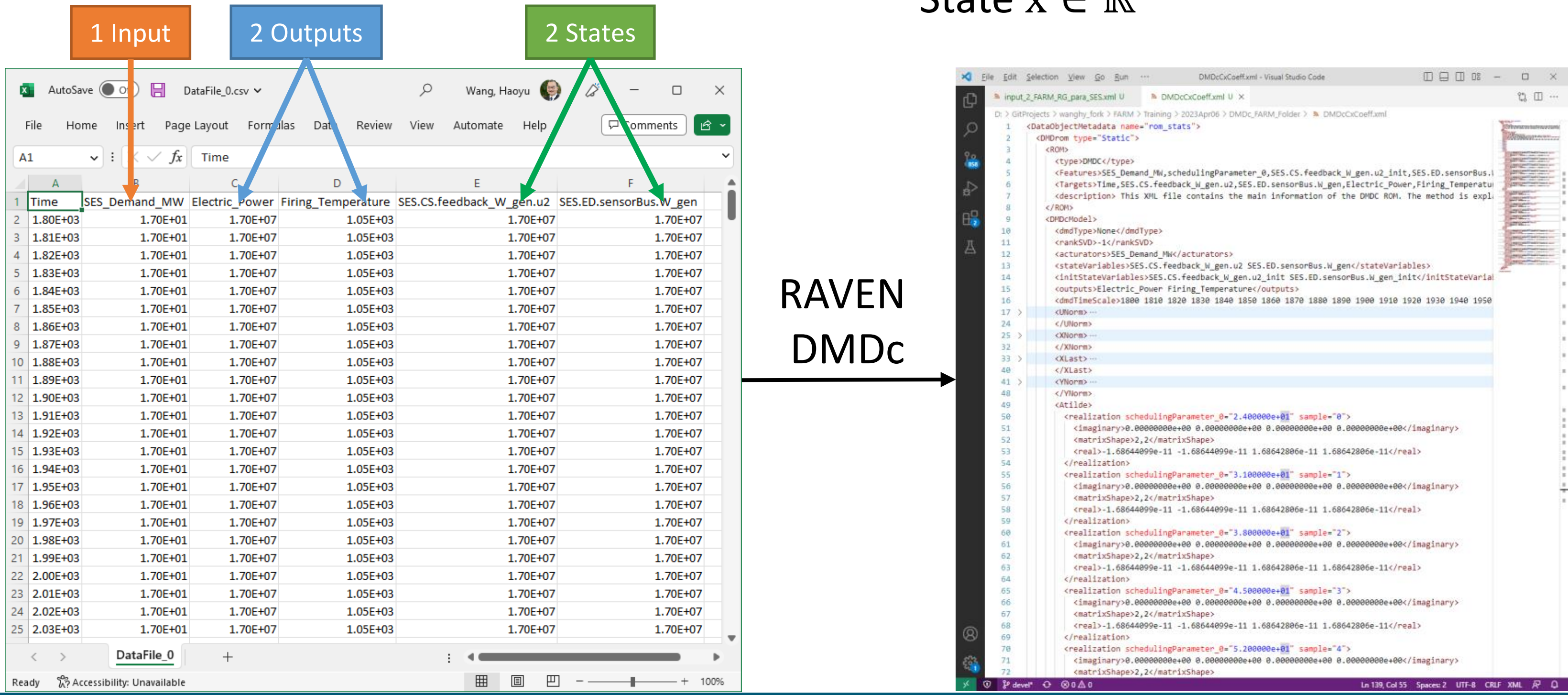
- a1. An XML file containing the state-space representation matrices
  - A state-space matrix set [A,B,C,D] is required to describe the system.
  - One example is available at

    FARM / Training / 2023Apr06 / DMDc_FARM_Folder / DMDcCxCoeff.xml

  - Can be generated through RAVEN DMDc*.
  - Example is available at

    FARM / Training / 2023Apr06 / input_1_DMDC_para_SES.xml





Time	SES_Demand_MW	Electric_Power	Firing_Temperature	SES.CS.feedback_W_gen.u2	SES.ED.sensorBus.W_gen
1.80E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.81E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.82E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.83E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.84E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.85E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.86E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.87E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.88E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.89E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.90E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.91E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.92E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.93E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.94E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.95E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.96E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.97E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.98E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
1.99E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
2.00E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
2.01E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
2.02E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07
2.03E+03	1.70E+01	1.70E+07	1.05E+03	1.70E+07	1.70E+07

*For more details, please refer to RAVEN user manual Section 15.3.11, DMDc

3. Regular Usage: FARM as set-point regulator
3.a. Input creation and running the code

FARM

- a2. FARM external model name;
  - To use FARM, “FARM.RefGov_parameterized_SIMO” need to be specified as the external model.
  - Source code* is available at

    FARM / src / RefGov_parameterized_SIMO.py
- a3. Input and output variables for FARM;
  - Input: “PwrSet”, the power setpoint before any adjustment;
    - “PwrSet” should share the same unit as the actuator signal in DMDc training data;
  - Output: “V”, adjusted power setpoint; “V_min” and “V_max”, the min & max allowed V value.
- a4. “MOASsteps” for the prediction time horizon;
  - $\text{MOASsteps} = \dfrac{\text{Time Horizon}}{\text{Matrices interval}}$
  - Example:
    - To predict the response for 1 hour;
    - Matrices are in 10s interval
    - MOASsteps = 3600s / 10s = 360.

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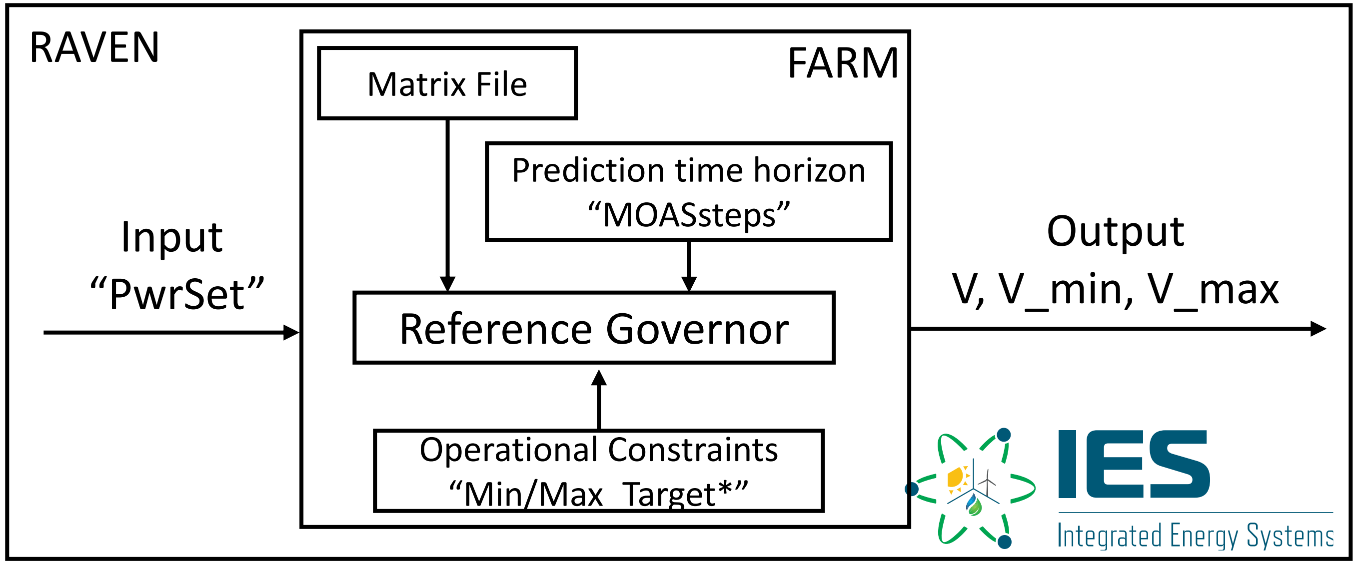
*For more details, please refer to FARM user manual Section 1.1

3. Regular Usage: FARM as set-point regulator
3.a. Input creation and running the code

- a4. "Min/Max_Target*" for the operational constraints;
  - "Min_Target$_i$" and "Max_Target$_i$" defines the bounds for the i^th^ system output y_i.
  - Example:
  - In training data, y_1 is Electric Power (W), y_2 is Firing Temperature (℃)
  - Then in the FARM input file,
    - Min_Target$_1$=20.0E6, Max_Target$_1$=50.0E6 → 20.0MW < Electric Power < 50.0MW
    - Min_Target$_2$=1270.0, Max_Target$_2$=1410.0 → 1270℃ < Firing Temperature < 1410℃
  - Mind the units.
- The structure of entire FARM Plugin:



3. Regular Usage: FARM as set-point regulator
3.a. Input creation and running the code

- The FARM input file can be executed like other RAVEN input files:

```
haoyuwang@p075722 MINGW64 /d/GitProjects/wanghy_fork/FARM (devel)
$ ../raven/raven_framework Training/2023Apr06/input_2_FARM_RG_para_SES.xml
```

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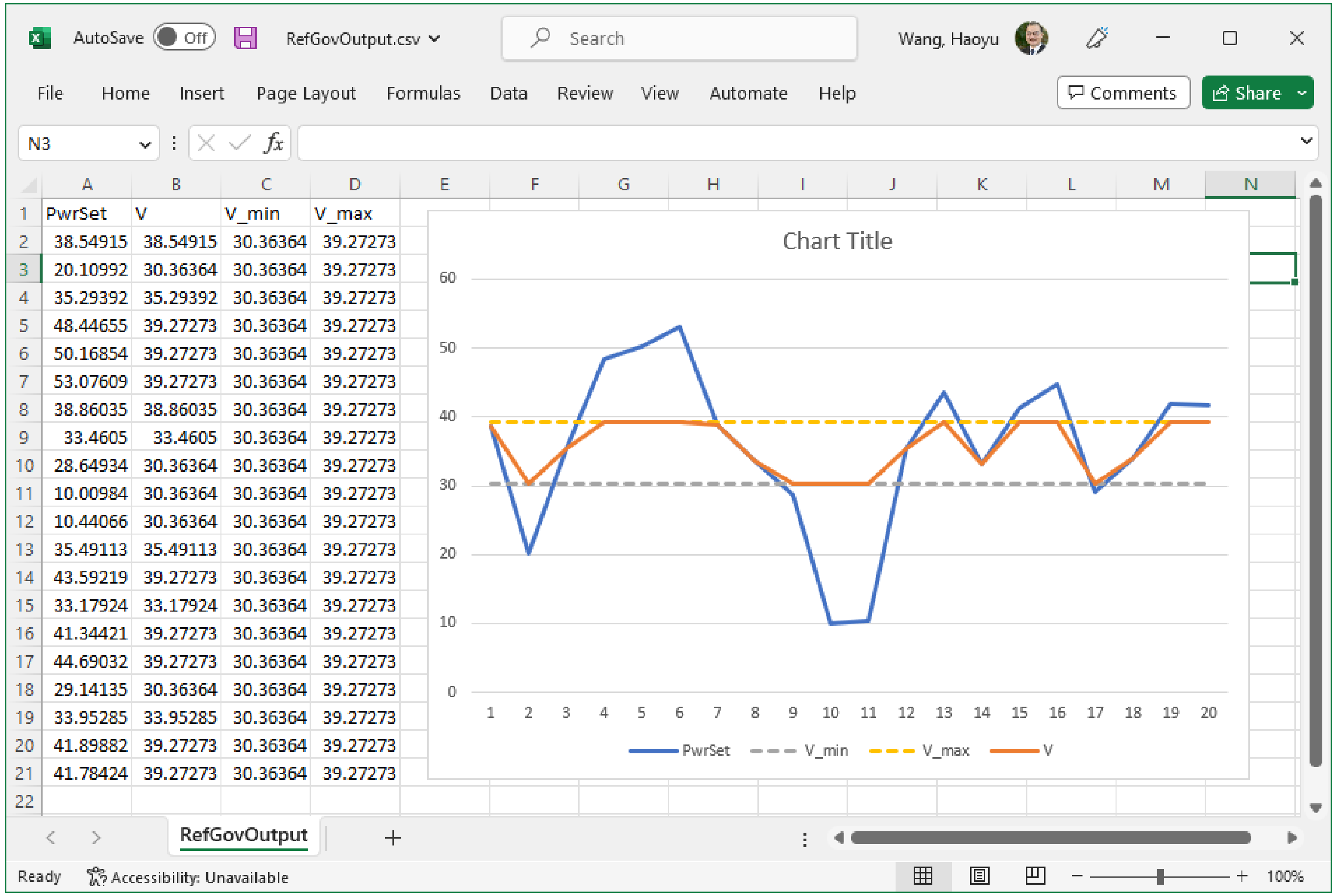
3. Regular Usage: FARM as set-point regulator
3.b. Output analysis

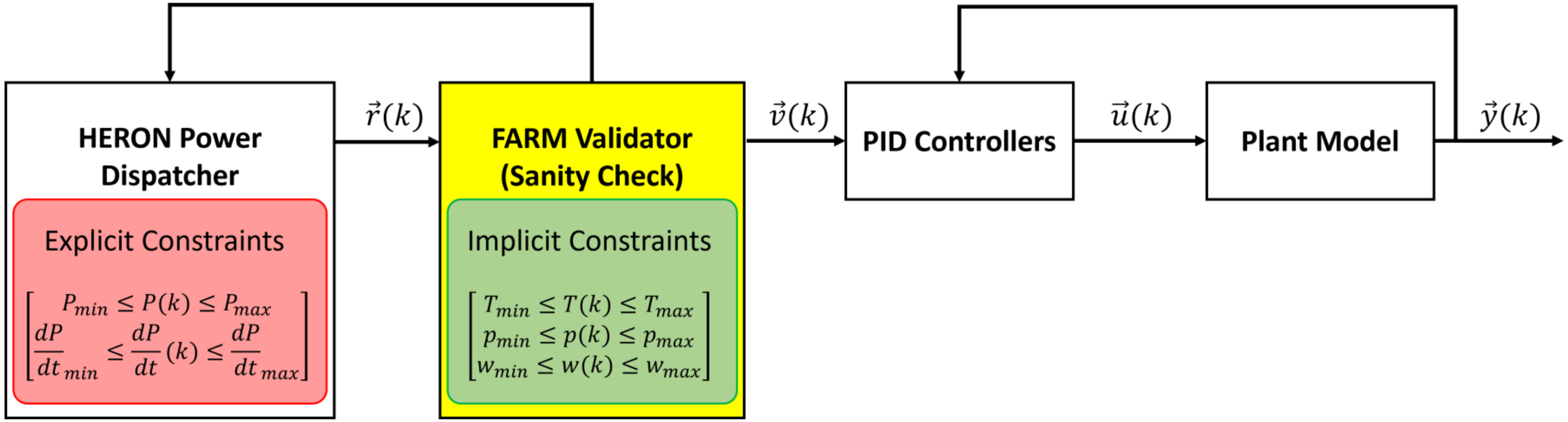
- The FARM output can be found in:
  - FARM / Training / 2023Apr06 / DMDc_FARM_Folder / RefGovOutput.csv
  - 20 entries, with 4 column in each entry
    - Issued power setpoint “PwrSet”;
    - Adjusted power setpoint “V”;
    - Minimum allowed value “V_min”;
    - Maximum allowed value “V_max”;
  - The “PwrSet” are regulated to “V”, to meet both explicit and implicit constraints.



PwrSet	V	V_min	V_max
38.54915	38.54915	30.36364	39.27273
20.10992	30.36364	30.36364	39.27273
35.29392	35.29392	30.36364	39.27273
48.44655	39.27273	30.36364	39.27273
50.16854	39.27273	30.36364	39.27273
53.07609	39.27273	30.36364	39.27273
38.86035	38.86035	30.36364	39.27273
33.4605	33.4605	30.36364	39.27273
28.64934	30.36364	30.36364	39.27273
10.00984	30.36364	30.36364	39.27273
10.44066	30.36364	30.36364	39.27273
35.49113	35.49113	30.36364	39.27273
43.59219	39.27273	30.36364	39.27273
33.17924	33.17924	30.36364	39.27273
41.34421	39.27273	30.36364	39.27273
44.69032	39.27273	30.36364	39.27273
29.14135	30.36364	30.36364	39.27273
33.95285	33.95285	30.36364	39.27273
41.89882	39.27273	30.36364	39.27273
41.78424	39.27273	30.36364	39.27273

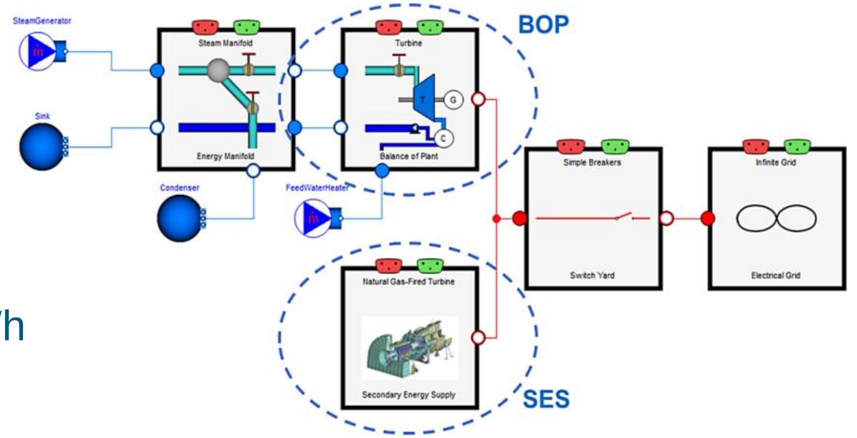
4. Advanced Usage: FARM as HERON validator
4.a. Overview

- FARM validates the power set-points issued by HERON:
  - Ensure the implicit constraints are met within the dispatch interval;
  - If not, provide feedback to HERON for re-optimization

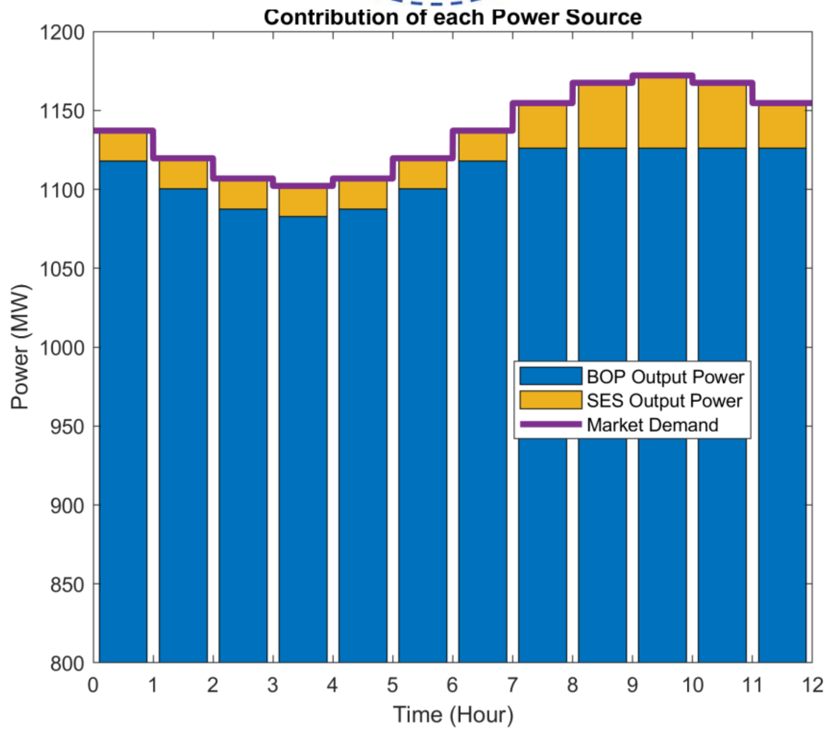


4. Advanced Usage: FARM as HERON validator
4.b. Example

- Two-plant IES unit:
  - Balance of Plant:
    - Steam Turbine, 1350MWe, Cost of Generation $100 USD / MWh
  - Secondary Energy Source:
    - Natural Gas Turbine, 50MWe, Cost of Generation $200 USD / MWh



- Market Demand:
  - 12 hour-long sinusoidal trajectory
  - 1137±35 MW
  - Sale price: $400 USD / MWh

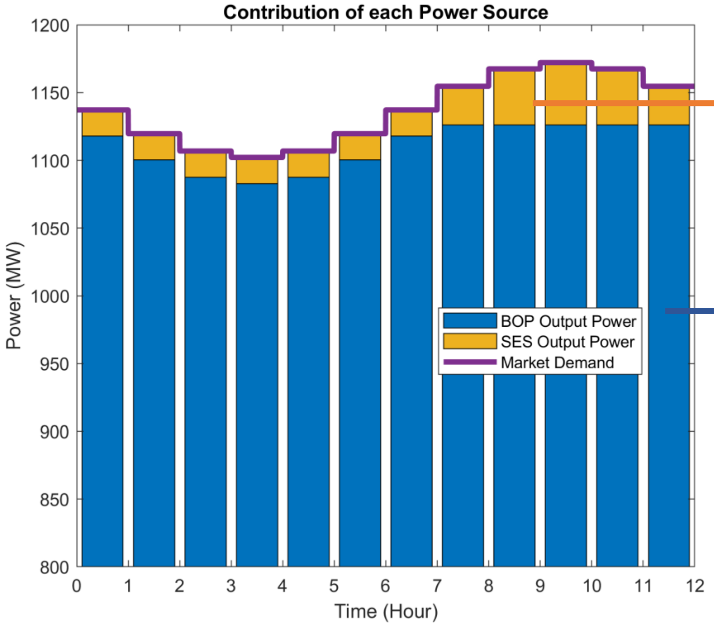


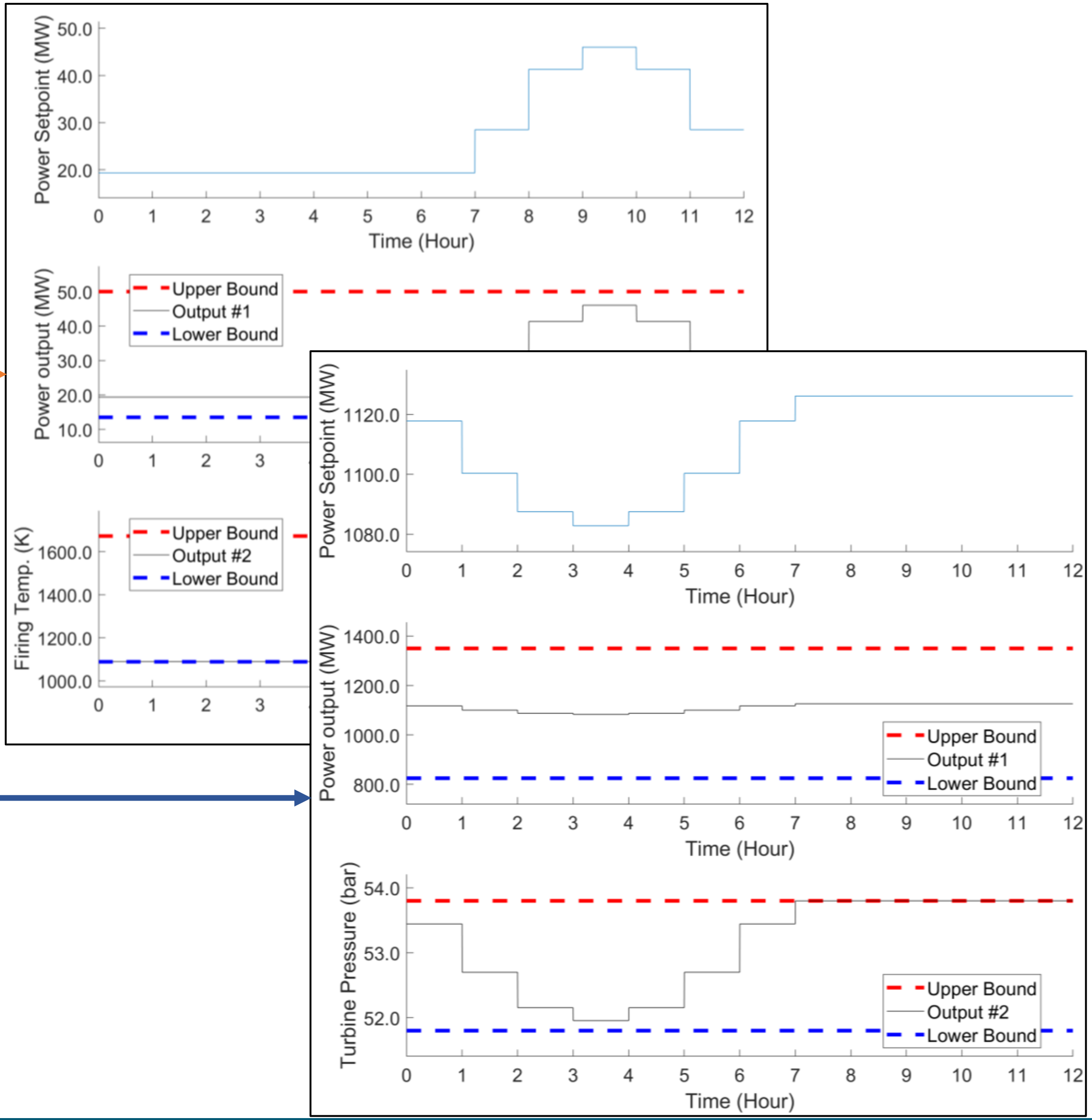
- Economically preferred solution:
  - Run BOP at maximum allowed power (due to low cost)
  - Use SES during peak demand

Question: Why is SES at non-zero power at low demand?

4. Advanced Usage: FARM as HERON validator
4.b. Example

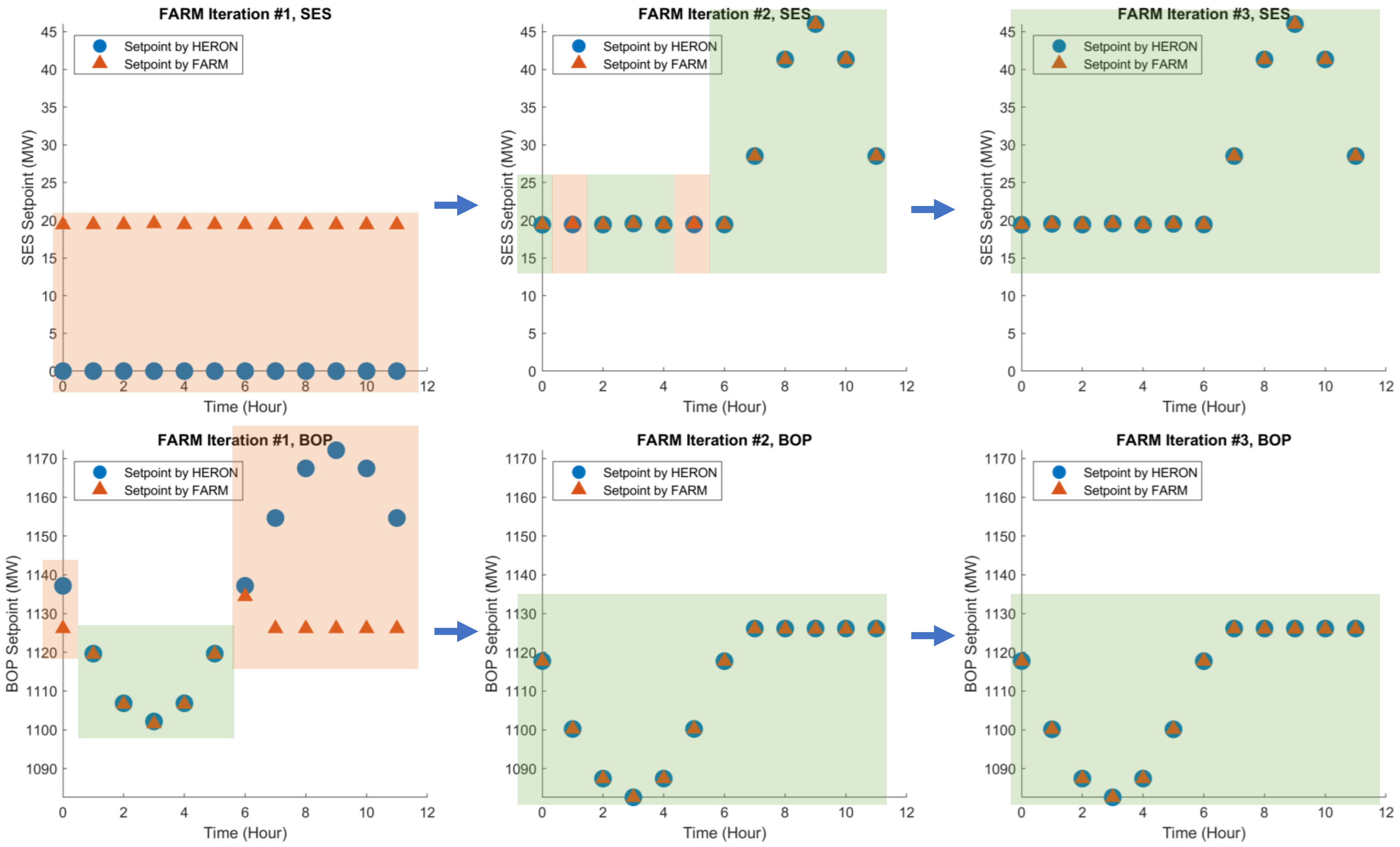
- Constraint Enforcement
  - SES:
    - Electrical Power: 13.5 MW – 50.0 MW
    - Firing Temperature: 1089.0 K – 1673.0 K
  - BOP:
    - Electrical Power: 825 MW – 1350 MW
    - Turbine Pressure: 51.8 bar – 53.8 bar

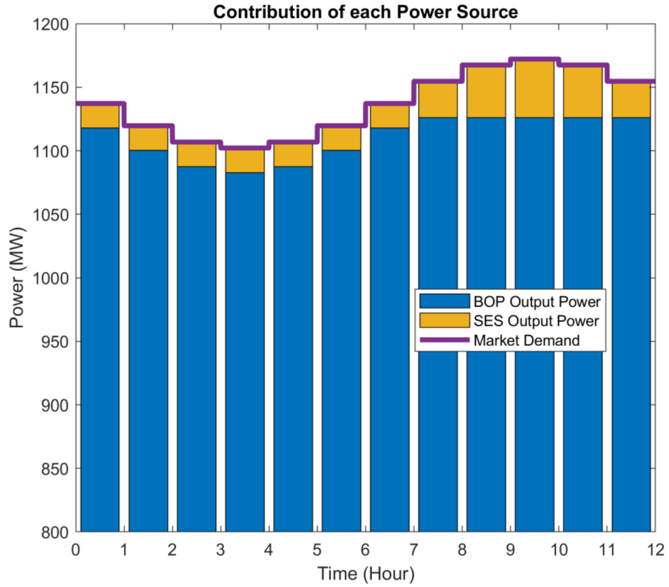




4. Advanced Usage: FARM as HERON validator
4.b. Example

- Optimal solution is achieved after multiple feedback iterations





Example is available at: FARM / tests / heron_validator / FARM_Gamma_FMU / heron_input_FARM_gammaFMU_BOP_SES.xml

5. Future Directions

- Multi-Input-Multi-Output version of FARM will be implemented as set-point regulator (ETA: June 2023)
  - The prototype is developed as HERON validator (“FARM-Delta”[1]);
  - Some redundancy reduction algorithms need to be optimized.
- FARM will aid operations in experimental facilities (ETA: 2024)

References

[1] Haoyu Wang, Roberto Ponciroli, Akshay J. Dave, and Richard B. Vilim. Control system for multi-system coordination via a single reference governor. No. ANL/NSE-22/26. Argonne National Lab.(ANL), Argonne, IL (United States), 2022.

Thank you!

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