INFO 4000 - MP3 Instructions

Digital Twin of Centrifugal Pump with speed control and energy management

- ## The System

You're modeling a **centrifugal pump** driven by a **VFD (variable-frequency drive)**.
The controller tries to maintain a **target head (m)** by adjusting **pump speed (rpm)**.
The plant (piping) pushes back via a **system curve**, so the true operating point is where the **pump curve** intersects the **system curve**. Running slower for lower head saves energy versus running fixed-speed and throttling with valves.

Key components

- **Sensor:** measures head (with small bias + noise in the sim).
- **Controller:** PI (or hybrid) on head → outputs a speed command (rpm).
- **VFD/motor:** ramps speed with a slew rate; provides Hz & V (V/Hz).
- **Physics:** pump curve + system curve → flow & ideal head.
- **Accounting:** energy (kWh), volume (m^3), specific energy (kWh/m^3).

It's called the **system curve** because it's the **head the *system* (piping + fittings + elevation)** requires **as a function of flow**—independent of the pump.

- **What it is:** For any flow Q, the system needs a head

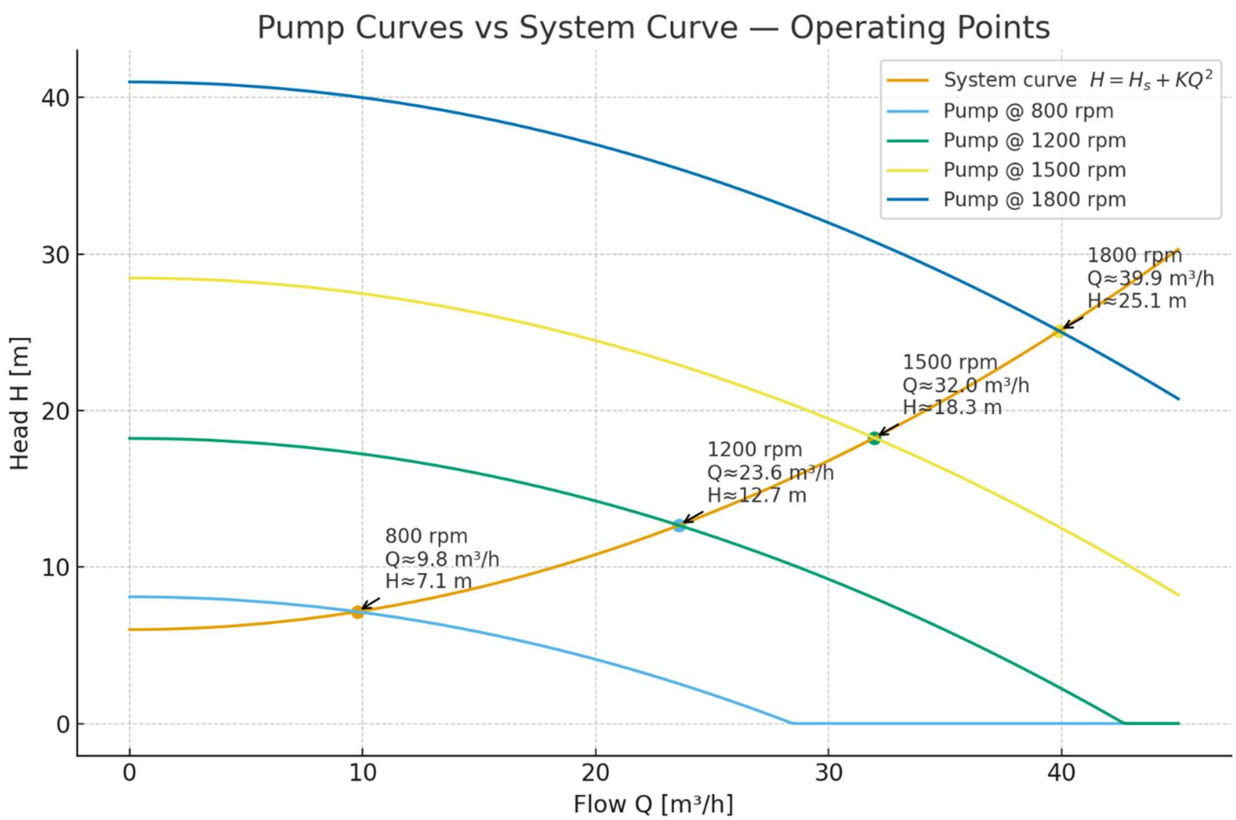
$$H_{\text{sys}}(Q) = H_{\text{static}} + H_{\text{loss}}(Q)$$

  With turbulent flow in pipes, losses scale roughly with Q^2, so we often model

$$H_{\text{sys}}(Q) = H_{\text{static}} + K_{\text{sys}}\, Q^2.$$

  - H_{static}: elevation (or pressure) difference to lift fluid even at zero flow.
  - $K_{\text{sys}}Q^2$: friction/minor losses in pipes, valves, bends, etc.

- **Why a "curve":** Plotting H_{sys}vs Qgives a rising, generally **quadratic** curve (not a straight line). Different valve positions or lineups give a **family of curves** (change K_{sys}).
- **How it's used:** The system curve intersects the **pump curve**; that intersection is the **operating point** (actual Q, H).
  - **Throttling** moves you along a *higher* system curve (bigger K_{sys}).
  - **VFD speed changes** move the **pump curve**, finding a new intersection—often more energy-efficient.

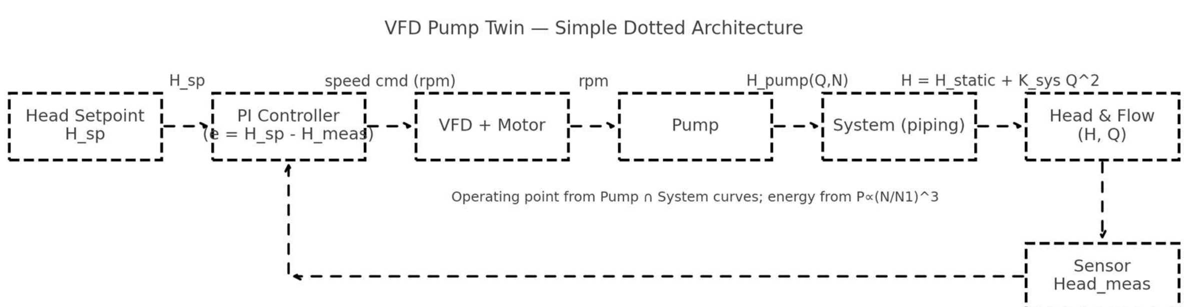


What it shows:

- The **system curve** $H = H_s + KQ^2$and **pump curves** at **800, 1200, 1500, 1800 rpm**.
- Black dots mark the **operating points** (intersection of pump and system curves), annotated with $Q$and H.
- It visually explains how increasing speed shifts the pump curve up, moving the operating point to **higher flow and head**. The reverse is also true.

So: the sensor measures **head**, but the physics and performance accounting still require **flow** Q to determine the operating point, compute ideal head, and calculate useful efficiency metrics.

System Architecture:



- ## Guidelines

    - These instructions and the slides with the explanations for the basis for developing the Digital Twin (DT).
    - Understanding the Physics and Math and how this system operates will be key to developing a robust solution
    - Demonstrating the successful operation of the DT with plots and other visual you deem appropriate will be a very important aspect of the solution you develop.
    - The reference to Classes / functions in the slides are all to help you build your solution, however, feel free to build it your way as along as it follows the main requirements.

- Grading Criteria

    - Completing the project and demonstrating its functionality – 70%
    - Writing a detailed, explanatory and meaningful report – 25%
    - Answering the questions below – 5%

- Questions
    - What were your biggest takeaways from this course and the certificate overall?
    - What were the parts of the course you enjoyed the most and what did you find challenging?
    - Give one recommendation as to what could be done to make the course better.

The assignment is due by midnight of November 25th, the solution will be provided by the 27th and reflections will be due by 30th November.

System Information:

Motor rating = 460V, 15KW, 60HZ

Parameters (use these)

- Pump: $H_0 = 41\ \mathrm{m},\ k = 0.010,\ N_1 = 1800\ \mathrm{rpm}$
- System: $H_{\mathrm{static}} = 6\ \mathrm{m},\ K_{\mathrm{sys}} = 0.012\ \mathrm{m}/(\mathrm{m}^3/\mathrm{h})^2$
- Controller: $K_p = 8.0,\ K_i = 1.0,\ \Delta t = 0.1\ \mathrm{s}$
- Speed limits: $N_{\min} = 800\ \mathrm{rpm},\ N_{\max} = 1800\ \mathrm{rpm}$
- VFD ramp: $2000\ \mathrm{rpm/s}$
- Rated power: $15\ \mathrm{kW}$
- Telemetry: poles $p = 4$, slip $s = 0.02$ (for Hz/V).