Hydro Governor Initialization: Change Hdam instead of At

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WECC MVS

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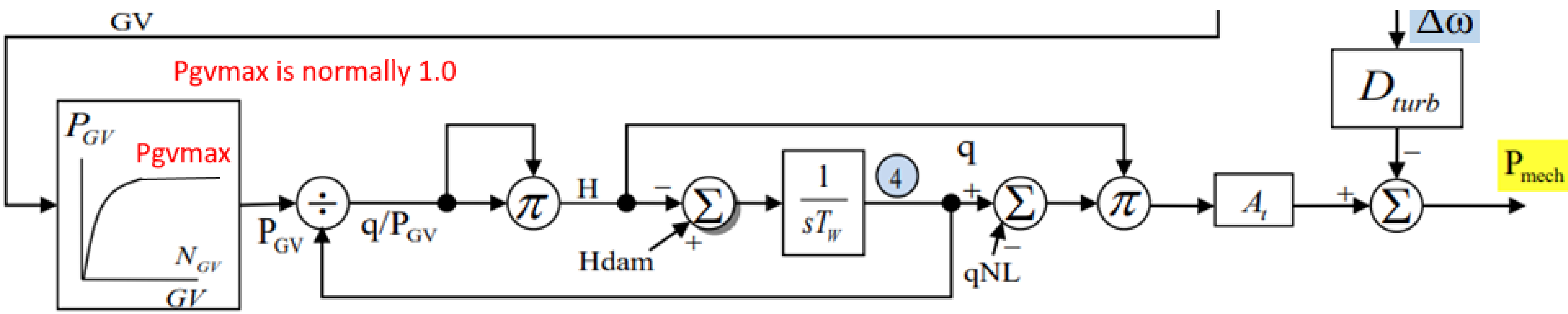
- Shawn Patterson from US Bureau of Reclamation pointed out a potential issue in how some hydro plants are initialized in our software tools
- When Initial Real Power Output in the Power Flow was larger than was possible based on the Hydro's dynamic governor model
  - software tools are modifying the input data by changing the Turbine Gain (At)
  - Shawn suggested that changing the Head (Hdam) was more appropriate
  - Turbine gain is a physical parameter of the governor that can not change without installing new equipment
  - Head represents the vertical height of the water reservoir which can change

Why worry about this now? Does this ever happen now?

- This rarely happens now! But…
  - Hdam (or H0) is almost always 1.0 in WECC cases
  - As drought conditions become more common and reservoirs drop, then Head (Hdam) is going to decrease and user will reduce it
    - When dropping Hdam in the stability model, you should also look at what that means for Pmax in the steady state power flow models
- This initialization situation may start happening more and more
- Rest of presentation goes into details

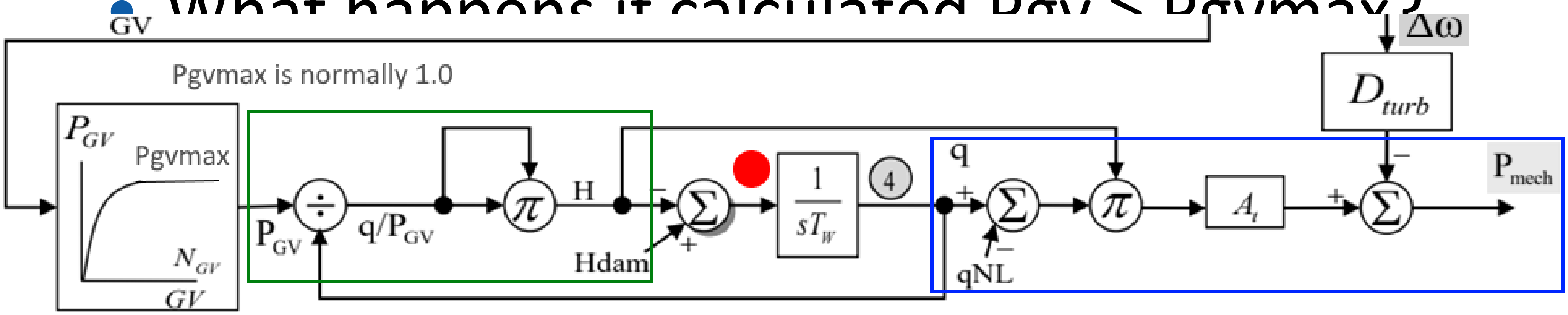
Hydro Models which include modeling Head and Water Time

- This presently impacts the following models
  - HYGOV, HYGOVD, HYGOVR, HYPID, HYG3, HYGOV4
- All these models have following portion that models the water dynamics
  - What happens when Pmech is larger than what this model is able to provide?
  - How do we know Pmech is too large?



Present Model Initialization: Finding when Pmech is too large

- Integrator Input: H = Hdam
- Pmech backwards: $q = \frac{P_{mech}}{A_t H_{dam}} + q_{nl}$
- Pgv forward: $P_{gv} = \frac{q}{\sqrt{H_{dam}}}$ (Note: H = Hdam)
- What happens if calculated Pgv > Pgvmax?



What is done now when $P_{gv} > P_{gvmax}$

- We increase Turbine Gain (At) inside software
- Assume $P_{gv} = P_{gvmax}$
- Solve equation for a new Turbine Gain
  - $P_{gvmax} = \frac{q}{\sqrt{H_{dam}}}$
  - $P_{gvmax} = \frac{1}{\sqrt{H_{dam}}}\left(\frac{P_{mech}}{A_t H_{dam}} + q_{nl}\right)$
  - $P_{gvmax}\sqrt{H_{dam}} = \frac{P_{mech}}{A_t H_{dam}} + q_{nl}$
  - $P_{gvmax}\sqrt{H_{dam}} - q_{nl} = \frac{P_{mech}}{A_t H_{dam}}$
  - $A_t = \frac{P_{mech}}{H_{dam}}\left(\frac{1}{P_{gvmax}\sqrt{H_{dam}} - q_{nl}}\right)$: New At value used
  - Also must update $q = P_{gvmax}\sqrt{H_{dam}}$

Alternative for $P_{gv} > P_{gvmax}$ Change Hdam instead

- Start with equation: $P_{gvmax}\sqrt{H_{dam}} = \frac{P_{mech}}{A_t H_{dam}} + q_{nl}$
- Solve for a new H_{dam} instead
  - $P_{gvmax} H_{dam}\sqrt{H_{dam}} = \frac{P_{mech}}{A_t} + H_{dam} q_{nl}$
  - $+P_{gvmax}\left(\sqrt{H_{dam}}\right)^3 - q_{nl}\left(\sqrt{H_{dam}}\right)^2 - \frac{P_{mech}}{A_t} = 0$
- This is a cubic equation which can be solved using the following nomenclature
  - $a = P_{gvmax}$
  - $b = -q_{nl}$
  - $c = 0$
  - $d = -\frac{P_{mech}}{A_t}$
  - $x = \sqrt{H_{dam}}$
- Solve the cubic equation $ax^3 + bx^2 + cx + d = 0$

How to solve cubic

- This can be solved using Cardano's Formula (https://proofwiki.org/wiki/Cardano%27s_Formula)
- Our equation has c=0: this means
  - 1 real number solution
  - 2 imaginary number solutions (which we ignore)
- We'll skip the details, but a memo has been sent to WECC MVS and also distributed to other software vendors

Solution to the cubic equation

- Solution is to solve equations

$$m = \frac{P_{mech}}{2A_t P_{gvmax}}$$

$$n = \frac{q_{nl}}{3P_{gvmax}}$$

$$R = +m + n^3$$

$$Q^3 + R^2 = m^2 + 2mn^3$$

$$S = \sqrt[3]{R + \sqrt{Q^3 + R^2}}$$

$$T = \sqrt[3]{R - \sqrt{Q^3 + R^2}}$$

$$H_{dam\,new} = (S + T + n)^2$$

$$P_{gv} = P_{gvmax}$$

$$q = P_{gvmax}\sqrt{H_{dam}}$$

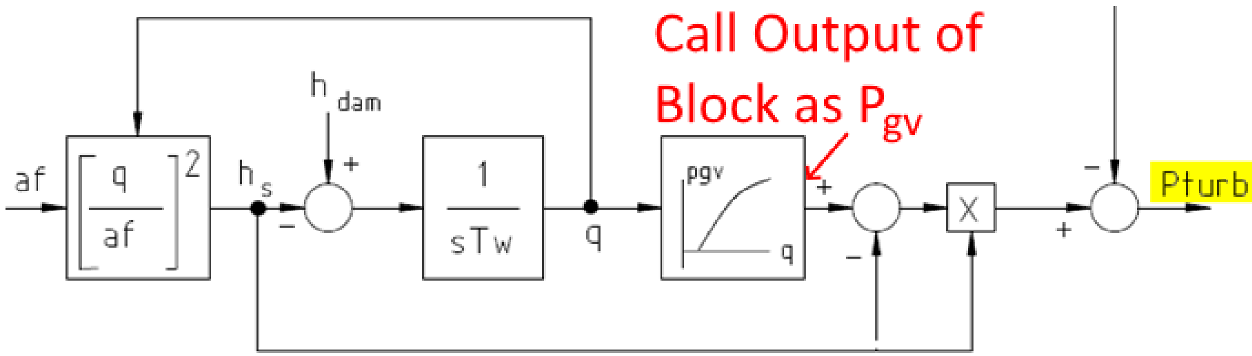
Pseudo-Code for this for Clarity

```
InputPmech          : Present Pmech initializing governor too
Pgvmax, Qnl, At,    : input parameters to model
Hdam
NewPgv, NewQ        : Make sure you update these values
M, N, Q3R2, S, T : local variables to this function

Procedure FixHdamPgvQToAchieveInputPMech
          (InputPmech : Input
           Pgvmax, Qnl, At : Input
           Hdam : Output
           NewPgv, NewQ : Output)
{
  M    = InputPmech/(2*At*Pgvmax)
  N    = Qnl/(3*Pgvmax)
  Q3R2 = M*(M + 2*N*sqr(N))
  R    = M + N*sqr(N)
  S    = Power(R + sqrt(Q3R2), 1/3)
  T    = Power(R - sqrt(Q3R2), 1/3)
  ??? Add some logging to let user know what is being changed
  Hdam = sqr( S + T + N )      // change value of Hdam
  NewPgv = Pgvmax              // update Pgv value
  NewQ   = Pgvmax*sqrt(Hdam)  // update Q value
}
```

Special Case of H6E (much easier)

- Non-linear Pgv block is in different place



- $P_{turb} = P_{gv} H_{dam}$
- If we end up calculating that $P_{gv} > P_{gvmax}$ then we change the value of
- $H_{dam} = \frac{P_{turb}}{P_{gvmax}}$

Summary

- Please tell us what you would like software vendors to do