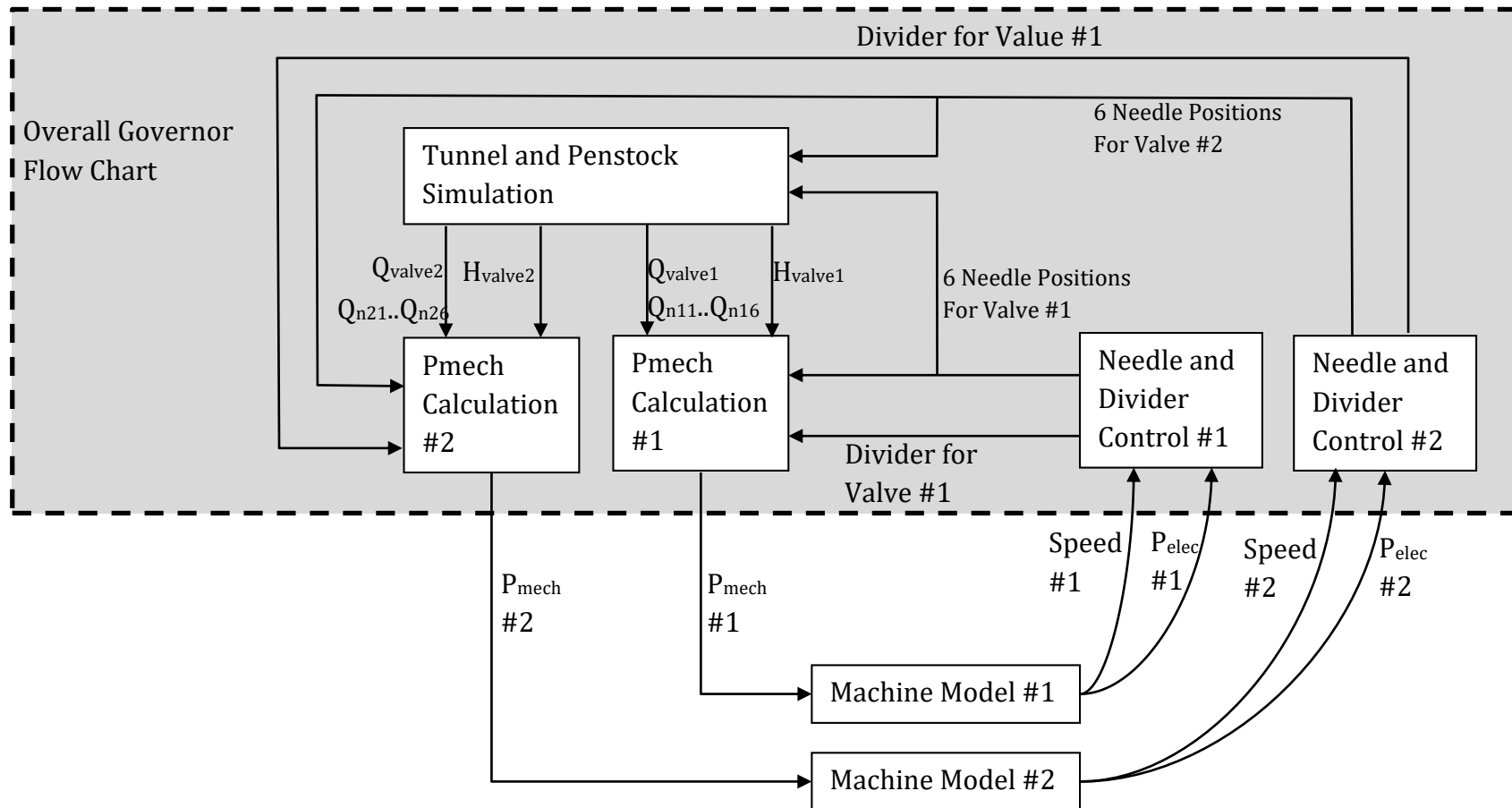


Governor HYGOV_Bradley

Governor HYGOV_Bradley Models P_{mech} control for 2 generators with a shared Water Resource

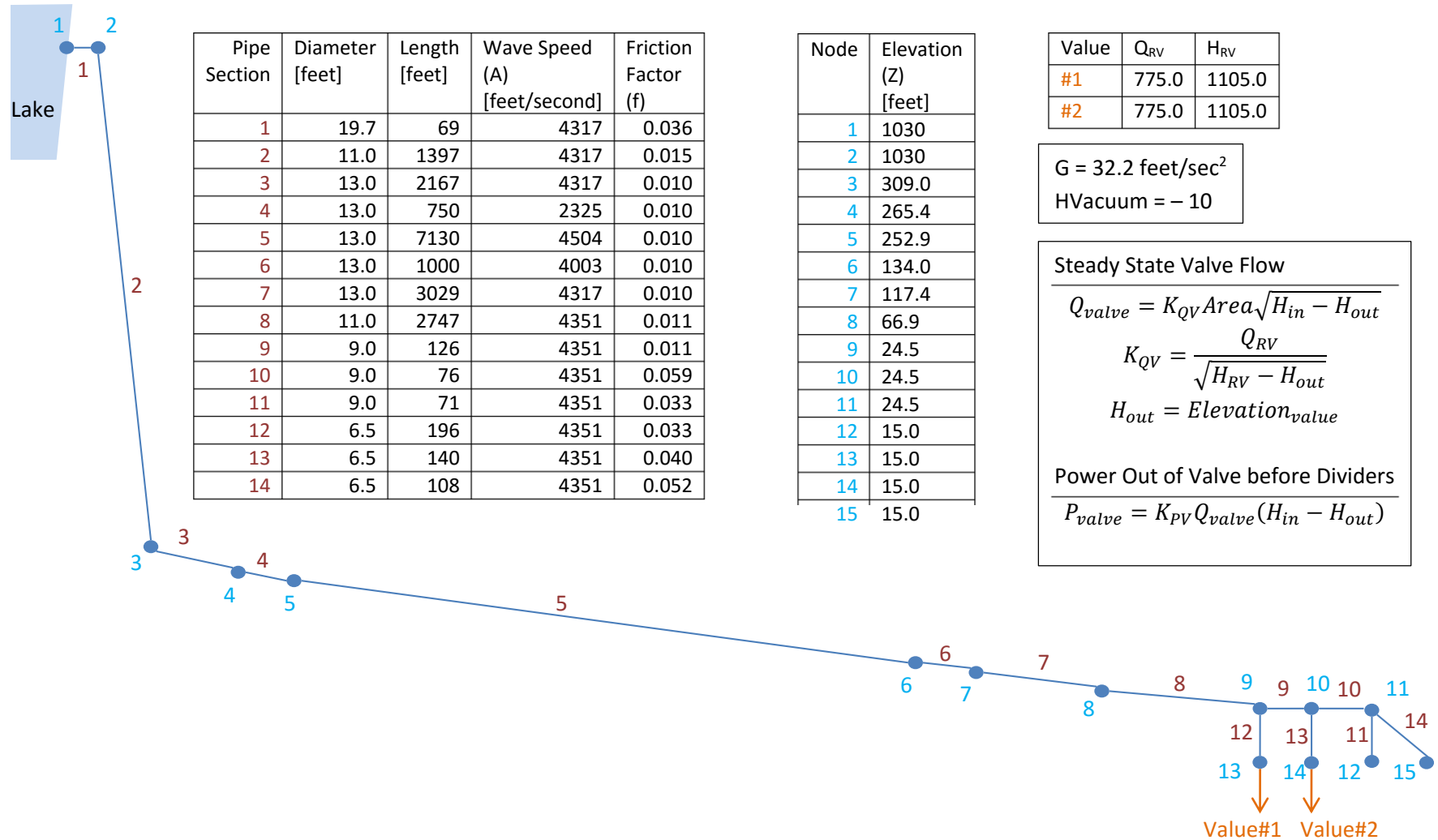


Tunnel and Penstock Model

Solution of the fluid dynamic equations of the tunnel and penstock are done as described in Chapter 3 of the book

M.H. Chaudhry, *Applied Hydraulic Transients, Third Edition*, Springer, 2014

Differential equations are then solved using the method of characteristics as described in that book. The tunnel and penstock model parameters are hard-coded in this model and cannot be changed by the user presently.



Mechanical Power Model

Each “Valve” in this model really represents several separate control variables which control the mechanical power imparted on the turbine. There are 6 separate needle valves arranged symmetrically around the buckets on the Pelton turbine, along with 6 dividers (also called deflectors) which can partially or completely interrupt the water jet. The 6 needle valves are treated as 6 separate control variables, while the 6 dividers all operate together and thus are treated as one control variable. This gives a total of 7 control variables for the governor control system for each valve. Under normal operation, the divider is kept outside of the water jet because using the dividers simply deflects water power away from the turbine and thus is inherently wasteful and inefficient. For slow variations in system conditions, the needle valve can be controlled to increase or decrease power output. Under sudden changes however, such as the loss of load, the needle cannot respond fast enough and this is what creates the need for the divider. The divider can respond within a couple seconds to divert energy away from the turbine in the event of a large loss of load.

To calculate the mechanical power imparted onto the machine model, involves a separate calculation for each generator. First the total water power developed through the needle valves is calculated. This is calculated by using the equation

$$P_{Water_{valve}} = K_{turb} Q_{valve} (H_{in} - H_{out})$$

We then must calculate the amount of power getting past the dividers as well. This is described in the next section but for now let’s assume we can define a function $PFRAC(Z,D)$ which defines the fraction of power output from one needle which then gets past the divider to apply mechanical power to the turbine. Then to calculate the total power which does hit the turbine we calculate

$$P_{turb} = \sum_{x=1}^6 [PFRAC(Z_x, D) K_{turb} Q_{nx} (H_{in} - H_{out})]$$

Finally we calculate the mechanical power reaching the generator by subtracting of some turbine losses

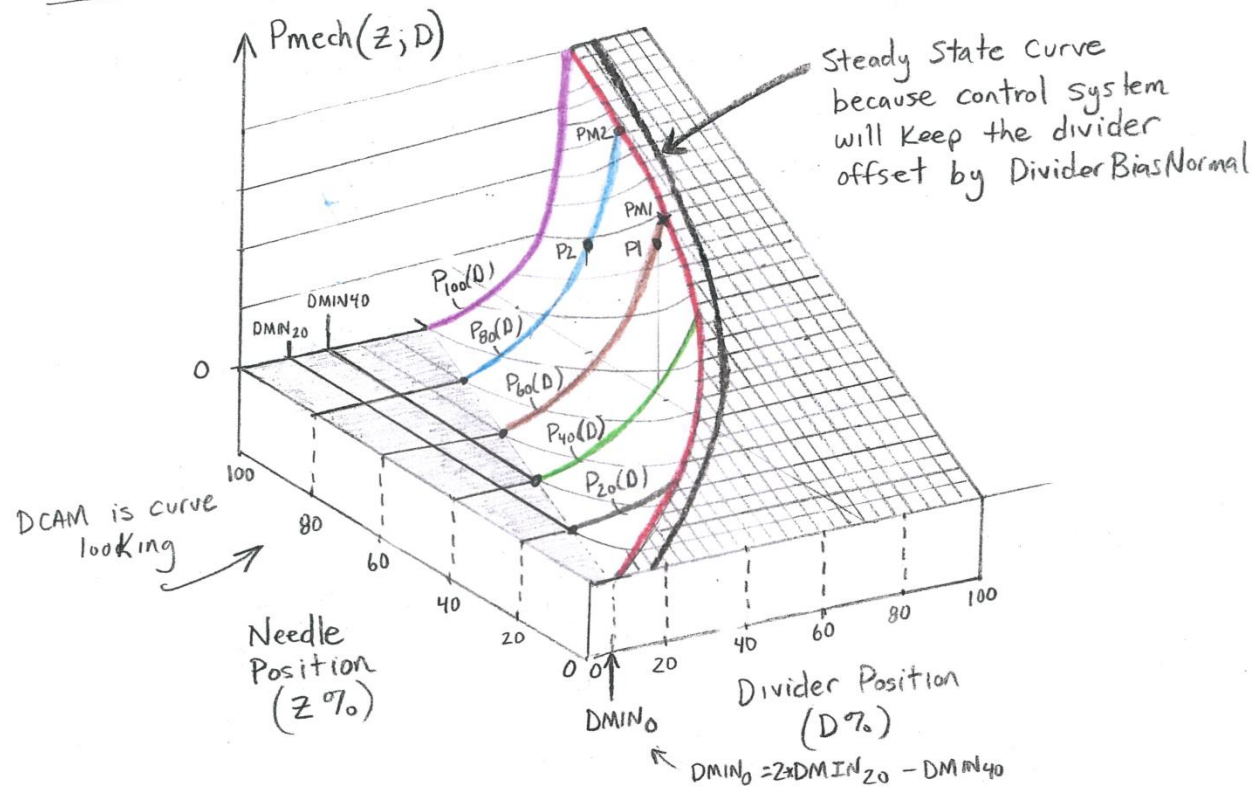
$$P_{mech} = P_{turb} - T_{loss} - T_{lossw} \omega^{LossExp}$$

PFRAC(Z,D): Calculation of the fraction of water power which makes it past the dividers

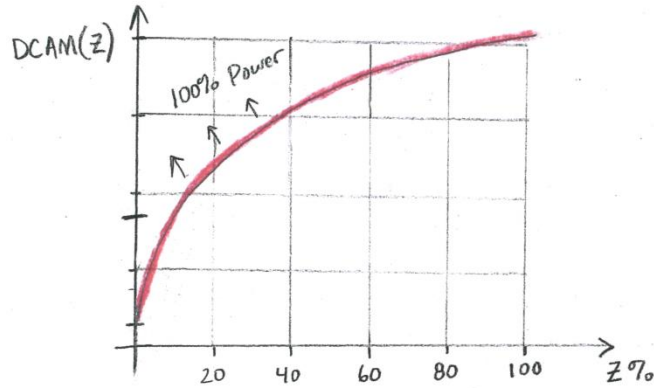
The input data defines a function which describes the mechanical power that reaches the turbine for variations in Needle Position (Z) and Divider Position (D). This function is depicted in the image as follows.

— CAM Curve $DCAM(Z)$. For a given needle position, this function gives the divider position which is on the jet edge. This also represents the D value for a given Z which is still recovering 100% of available waterpower

$P_{100}(D)$, $P_{80}(D)$, $P_{60}(D)$, $P_{40}(D)$, $P_{20}(D)$. For fixed values of Needle position (Z) of 100, 80, 60, 40, and 20 these curves represent the positive mechanical power reaching the wheel



When $Z = 0$, this means the needle valve is completely closed and no water passes through, while when $Z = 100$, this means the needle valve is completely open and the maximum amount of water can pass through. When $D = 0$, this means that the dividers are fully closed and are deflecting all the water away from the turbine, while when $D = 100$, this means all the dividers are fully open and all water is allowed to pass by them. For a fixed value of needle (Z), starting at divider position (D) of 100 the function $P_{mech}(Z,D)$ will be flat until the divider comes to the edge of the water jet. At this point the mechanical power reaching the turbine will drop very suddenly and then advance toward zero at some D . It is possible for each value of Z to define a D value that is exactly at the water jet edge. This is done in the input data by defining three coefficients ($A_{CAM}, B_{CAM}, C_{CAM}$) for a polynomial function $DCAM(Z) = A_{CAM}Z^2 + B_{CAM}Z + C_{CAM}$.



Any values D above this $DCAM(Z)$ function or Z values below the $DCAM$ function will represent a condition in which all of the water power reaches the turbine and thus $P_{mech} = P_{Water}$. Under normal operation, the jet dividers are operated so that they are biased at a D value slightly higher than the jet edge by an amount *DividerBiasNormal*. This keeps the divider nearby so it can quickly interrupt the water jet, but not in the water jet where it is wasting energy and efficiency.

The $DCAM(Z)$ function defines the boundary between where 100% of water power passes. To define points where the dividers are active, 5 additional sets of A, B, C coefficients define polynomial curves which specify P_{mech} for a fixed value of needle position Z . These curves are then.

$$P_{mech_{100}}(D) = A_{100}D^2 + B_{100}D + C_{100}$$

$$P_{mech_{080}}(D) = A_{080}D^2 + B_{080}D + C_{080}$$

$$P_{mech_{060}}(D) = A_{060}D^2 + B_{060}D + C_{060}$$

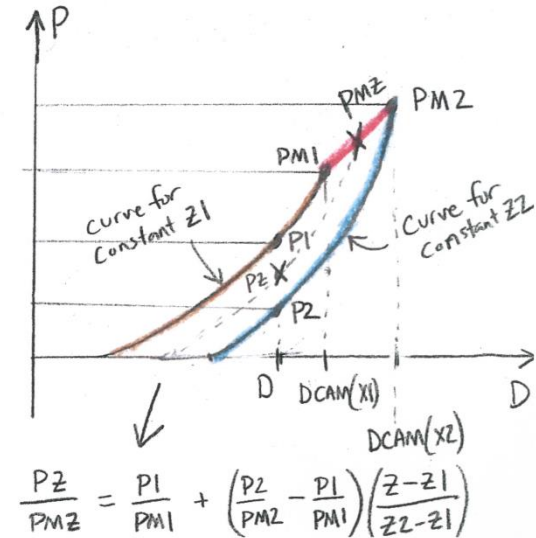
$$P_{mech_{040}}(D) = A_{040}D^2 + B_{040}D + C_{040}$$

$$P_{mech_{020}}(D) = A_{020}D^2 + B_{020}D + C_{020}$$

Using these curves the fraction of water power that makes it past the dividers can be estimated for a given Z and D value. This is done generally as follows.

1. For the given value of D, calculate the value Z_{min} which is on the water jet edge using the inverse of the DCAM(Z) equation.
2. Using the given Z value determine which two equations you are between $P_{mech_{100}}$, $P_{mech_{80}}$, $P_{mech_{60}}$, $P_{mech_{40}}$, and $P_{mech_{20}}$. Call the 2 curves you are between $P_{mech_{low}}$ and $P_{mech_{high}}$ and represent curves for Z_{low} and Z_{high} .
3. If $Z_{low} < Z_{min}$, then $F1 = 1.0$ and $Z_{low} = Z_{min}$. Otherwise, calculate $F1 = P1/PM1$ using $P1 = P_{mech_{low}}(D)$ and $PM1 = P_{mech_{low}}(DCAM(Z_{low}))$. P1 represents the mechanical power for Z_{low} and the present D value. PM1 represents the maximum mechanical power for Z_{low} regardless of D.
4. Calculate $F2 = P2/PM2$ using $P2 = P_{mech_{high}}(D)$ and $PM2 = P_{mech_{high}}(DCAM(Z_{high}))$. P2 represents the mechanical power for Z_{high} and the present D value. PM1 represents the maximum mechanical power for Z_{high} regardless of D.
5. Then for the existing value of Z, linearly interpolate between ratios as follows and as shown in the following figure.

$$\frac{P_{mech}(Z, D)}{P_{mech}(Z, DCAM(Z))} = F1 + (F2 - F1) * \left(\frac{Z - Z_{low}}{Z_{high} - Z_{low}} \right)$$



You also need to do a little trick if $Z < 20$ in which case we don't have a P_{mech} curve for $Z = 0$ since that would just be always zero. To do this, calculate the intersection of the surface with the D axis. This is done by determine a value $D_{min_{20}}$ and $D_{min_{40}}$ at which the curves $P_{mech_{020}}(D)$ and $P_{mech_{040}}(D)$ cross zero. We then linearly interpolate to get $D_{min_0} = 2 * D_{min_{20}} - D_{min_{40}}$. Then for $Z < 20$, use the following

$$Z_{low} = 0$$

If $0.0 < Z_{min}$, then $F1 = 1.0$ and $Z_{low} = Z_{min}$.

Else If $D < D_{min_0}$, then $F1 = 0.0$

Else if $D > DCAM(0)$ then $F1 = 1.0$

$$\text{Else } F1 = \frac{D - D_{min_0}}{DCAM(0) - D_{min_0}}$$

This is just way to linearly interpolate down to the zero point.

Needle and Divider Control

The first complication of the Needle and Divider Control is that there are 5 distinct desired steady-state modes of each unit.

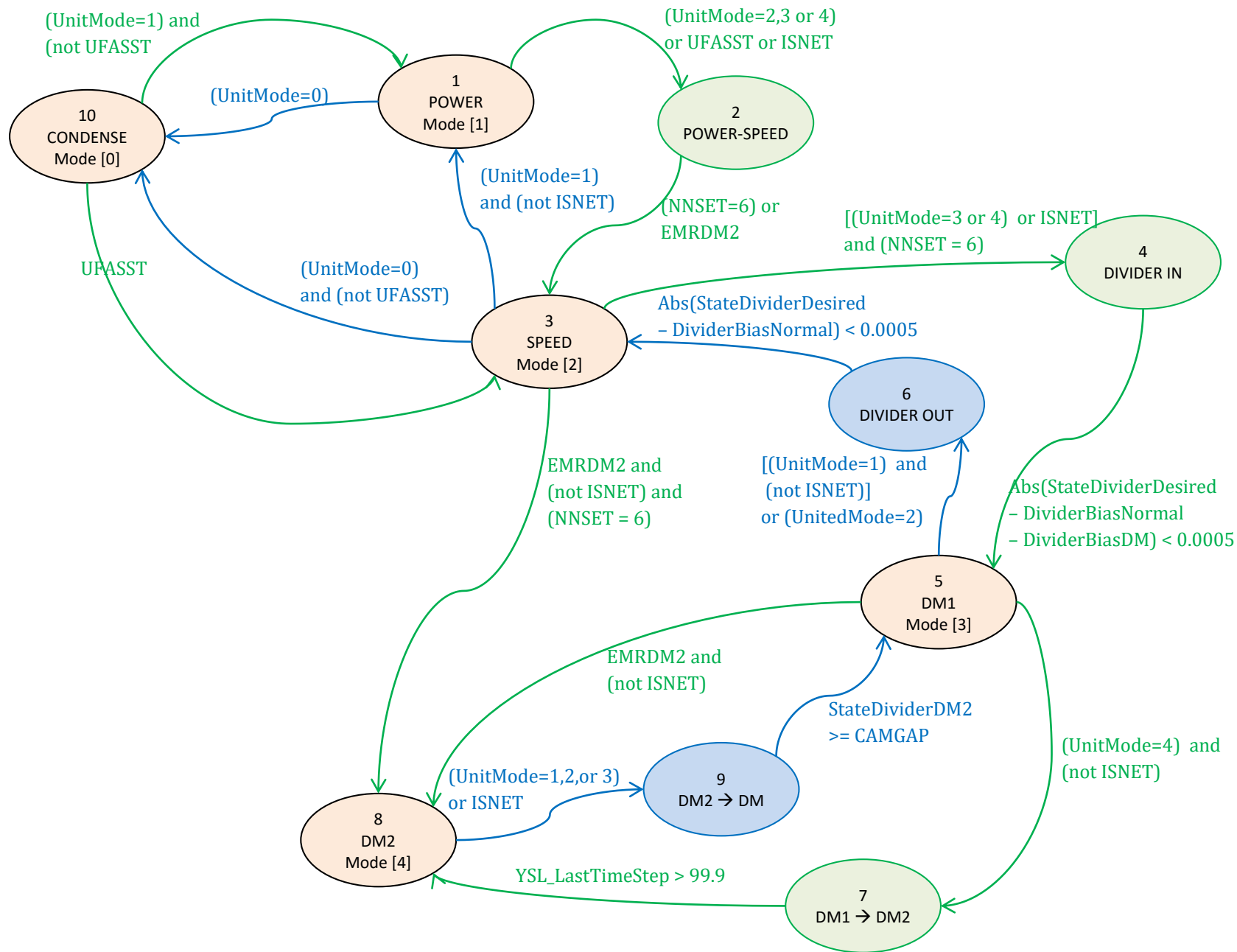
0. Condense (acts as a synchronous condenser)
1. Power. I suspect this is the normal operation mode to control power output.
2. Speed. Needles will move to control speed. This mode is initiated automatically by a minor under-speed event.
3. Divider Mode 1. In this mode, the needles are still under control, but the divider is initiated as well. This model will be automatically entered by the model during an over-speed event likely caused by the islanding of the Kenai Peninsula.
4. Divider Mode 2. Needles will be at maximum opening, and the Divider will provide control. This gives the fastest and largest up and down MW control range, but also wastes enormous amounts of water to achieve this. As a result the model will automatically enter this mode during a major under-speed event.

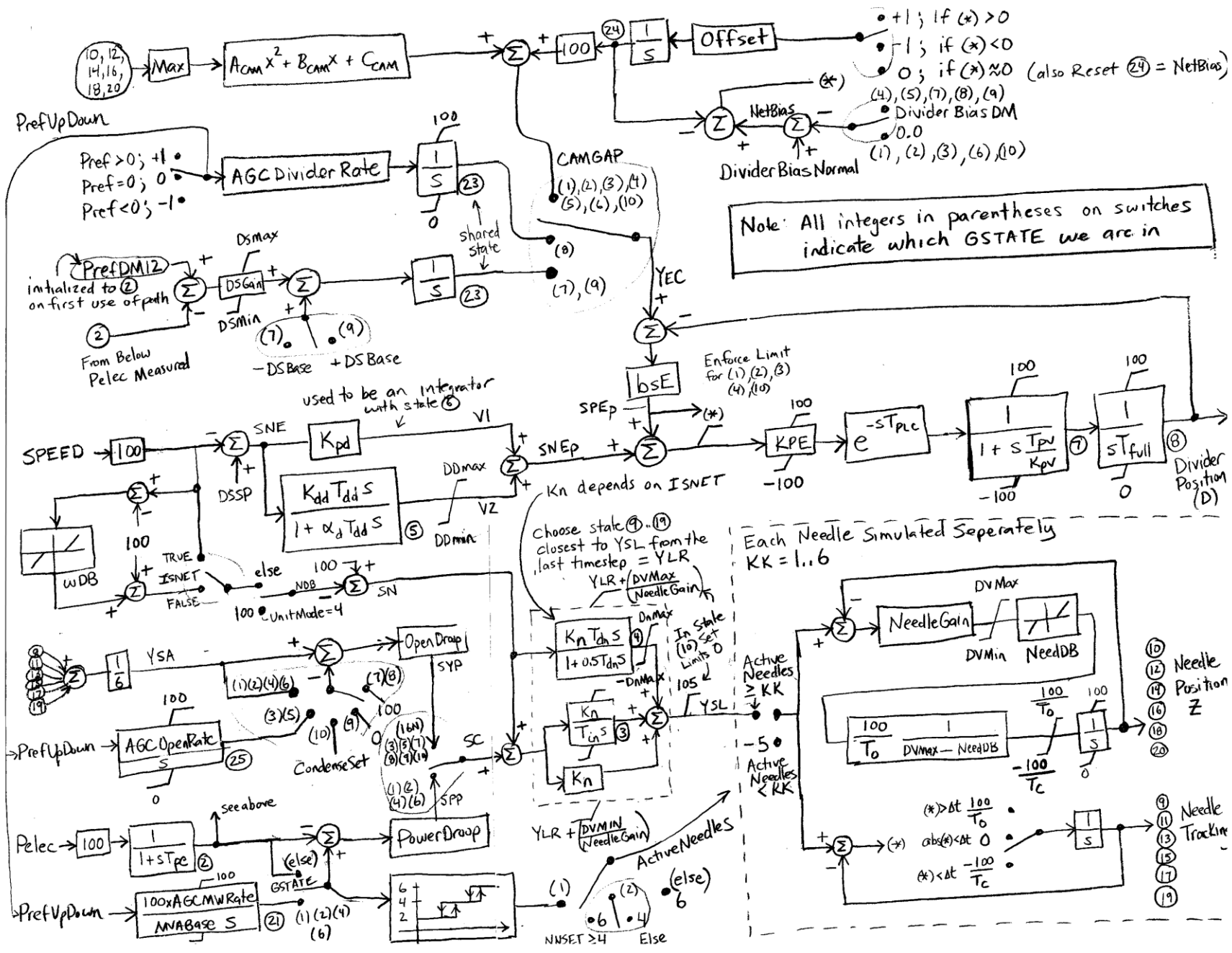
The governor model also includes 5 transitional states between these 5 unit modes giving a total of 10 transient stability states of the model. At the beginning of each time step, the model will evaluate whether to transition between these 10 states.

Boolean variable ISNET, UFASST, and EMRDM2 are updated based on the generator speed.

Boolean	Condition when TRUE	What Happens
UFASST	Speed < SpeedUFAsst	When TRUE, state transitions toward Unit Mode 2 (State 3)
ISNET	Speed > SpeedIsoNet	When TRUE, state transitions push toward Unit Mode 3 (State 5)
EMRDM2	Speed < SpeedEmerDM2	When TRUE, state transitions push toward Unit Mode 4 (State 8)

Using these 3 boolean along with tests of the other various numerical values in the block diagram, the state transition diagram for these 10 states is described as follows.





Generator Information for Current Case

Bus Number101Find By Number

Bus NameGENFind By Name

ID1Find ...

Area NameWECC (1)

Labels ...no labels

Generator MVA Base1000.00

Status

☐ Open☒ Closed

☐ NO (Offline)☒ YES (Online)

Fuel TypeUnknown

Unit TypeUN (Unknown)

Power and Voltage ControlCostsOPFFaultsOwners, Area, etc.CustomStability

Machine ModelsExitorsGovernorsStabilizersOther ModelsStep-up TransformerTerminal and State

InsertDelete

Gen MVA Base1000.0

Show Block DiagramCreate VCurve

TypeActive - Hydro_BradleyActive (only one may be active)Set to Defaults

ParametersPU values shown/entered using device base of 1000.0 MVA

Gen 2noneChoose...

UnitMode_11.0000	B100_1-0.1900	DDmin_1-20.0000	Tdn_10.5000	B40_2-0.1600	DSMax_20.3300	OpenDroop_20.0500
Kt_10.0000	C100_10.4000	Bse_10.0500	Tin_12.0000	C40_2-1.1000	DSMin_2-0.3300	N24_231.7000
Tloss_10.3484	Aaz_10.4620	Kpe_110.0000	DnMax_150.0000	A60_20.0089	DSBase_20.1500	N42_228.7000
Tlossw_10.2983	Baz_11.4620	TDelay_10.0500	Needdb_15.0000	B60_2-0.2320	Dssp_2100.0000	N46_263.5000
TlossExp_12.5000	SpeedIsoNet_1101.0000	KPV_110.0000	NeedleGain_150.0000	C60_20.4000	Alphad_20.2000	N64_257.5000
Acam_1-0.0029	SpeedUFASST_199.6670	TPV_10.1700	DVmax_1100.0000	A80_20.0077	Kdd_21.0000	Wdb_20.1000
Bcam_10.5724	SpeedEmerDM2_10.0000	Tf_11.1000	DVmin_1-100.000	B80_2-0.0420	Tdd_21.5000	KnOn_26.0000
Ccam_162.9200	AGCDividerRate_12.0000	AGCMWRate_11.3300	To_1116.0000	C80_2-3.2000	Kpd_21.0000	KnIso_20.5000
A20_10.0086	DividerBiasNormal_10.0010	AGCOpenRate_12.0000	Tc_188.0000	A100_20.0095	DDmax_220.0000	Alphan_20.5000
B20_1-0.4870	DividerBiasDM_10.1000	CondenseSet_110.0000	UnitMode_21.0000	B100_2-0.1900	DDmin_2-20.0000	Tdn_20.5000
C20_16.9000	Offset_10.0010	Tpe_10.8000	Kt_20.0000	C100_20.4000	Bse_20.0500	Tin_22.0000
A40_10.0072	DSGain_10.0600	PowerDroop_10.0500	Tloss_20.3484	Aaz_20.4620	Kpe_210.0000	DnMax_250.0000
B40_1-0.1600	DSMax_10.3300	OpenDroop_10.0500	Tlossw_20.2983	Baz_21.4620	TDelay_20.0500	Needdb_25.0000
C40_1-1.1000	DSMin_1-0.3300	N24_131.7000	TlossExp_22.5000	SpeedIsoNet_2101.0000	KPV_210.0000	NeedleGain_250.0000
A60_10.0089	DSBase_10.1500	N42_128.7000	Acam_2-0.0029	SpeedUFASST_299.6670	TPV_20.1700	DVmax_2100.0000
B60_1-0.2320	Dssp_1100.0000	N46_163.5000	Bcam_20.5724	SpeedEmerDM2_20.0000	Tf_21.1000	DVmin_2-100.000
C60_10.4000	Alphad_10.2000	N64_157.5000	Ccam_262.9200	AGCDividerRate_22.0000	AGCMWRate_21.3300	To_2105.0000
A80_10.0077	Kdd_11.0000	Wdb_10.1000	A20_20.0086	DividerBiasNormal_20.0010	AGCOpenRate_22.0000	Tc_2105.0000
B80_1-0.0420	Tdd_11.5000	KnOn_16.0000	B20_2-0.4870	DividerBiasDM_20.1000	CondenseSet_210.0000	Lake Elevation1150.000
C80_1-3.2000	Kpd_11.0000	KnIso_10.5000	C20_26.9000	Offset_20.0010	Tpe_20.8000	Outlet Elevation15.0000
A100_10.0095	DDmax_120.0000	Alphan_10.5000	A40_20.0072	DSGain_20.0600	PowerDroop_20.0500	

OKSaveCancelHelpPrint