CIGRÉ Generic Model for Single-Shaft Combined Cycle Power Plants

This model is located at system bus #_______IBUS
Machine #_______I
This model uses CONs starting with #_______J
and STATEs starting with #_______K
and VARs starting with #_______L
and ICONs starting with #_______M

CON	#	value	DESCRIPTION
J			R_p (s) Electrical power feedback droop
J+1			T_p (p.u.) Electrical power feedback time constant (>0)
J+2			R_v (p.u.) Governor feedback droop
J+3			K_{mwp} (p.u.) Proportional gain for outer loop MW control
J+4			K_{mwi} (s) Integral gain for outer loop MW control
J+5			rfmax (p.u.) Maximum limit on outer loop MW control loop
J+6			rfmin (p.u.) Minimum limit on outer loop MW control loop
J+7			dbd (p.u.) Intentional deadband
J+8			err (p.u.) intencional error limit
J+9			T_a (>0) (p.u.) Acceleration control time constant
J+10			a_{set} (p.u.) Acceleration limit set-point (see note 2)
J+11			K_{pg} (>0) Speed governor proportional gain (p.u.)
J+12			K_{ig} (>0) Speed governor integral gain (p.u.)
J+13			K_{dg} (p.u.) Speed governor derivative gain
J+14			T_{dg} (p.u.) Speed governor derivative time constant
J+15			K_{pa} (>0) Acceleration control proportional gain (p.u.)
J+16			K_{ia} (p.u.) Acceleration control integral gain
J+17			K_{pt} (>0) (p.u.) Temperature control proportional gain
J+18			K_{it} (p.u.) Temperature control integral gain
J+19			Fmax (p.u.) Maximum fuel flow command
J+20			Fmin (p.u.) Minimum fuel flow command
J+21			Tlimit (p.u.) Temperature limit (see note 4)

CON	#	value	DESCRIPTION
J+22			T_{thcp} (p.u.) Thermocouple time constant
J+23			T_n (p.u.) Heat transfer lead time constant
J+24			T_d (p.u.) Heat transfer lag time constant
J+25			T_v (>0) (p.u.) Fuel system time constant
J+26			V_{max} (p.u.) Maximum valve opening
J+27			V_{min} (p.u.) Minimum valve opening
J+28			F_m (p.u.) Fuel flow multiplier (see note 2)
J+29			W_{fo} (p.u.) Full-speed no-load fuel flow
J+30			K_t (>0) (p.u.) Turbine gain
J+31			T_{tn1} (p.u.) Turbine numerator time constant 1
J+32			T_{tn2} (p.u.) Turbine numerator time constant 2
J+33			T_{td1} (p.u.) Turbine denominator time constant 1
J+34			T_{td2} (>0) (p.u.) Turbine denominator time constant 2
J+35			x_1 – 1^{st} point of turbine characteristic curve (see note 3)
J+36			$F(x_1)$
J+37			x_2 – 2^{nd} point
J+38			$F(x_2)$
J+39			x_3 – 3^{rd} point
J+40			$F(x_3)$
J+41			Trate – turbine rating (MW) (see note 1)

CON	#	value	DESCRIPTION
J+42			P_{gt1} (p.u.) – point 1 (see notes 6 and 7)
J+43			Q_{g1} (p.u.)
J+44			P_{gt2} (p.u.) – point 2
J+45			Q_{g2} (p.u.)
J+46			P_{gt3} (p.u.) – point 3
J+47			Q_{g3} (p.u.)
J+48			P_{gt4} (p.u.) –point 4
J+49			Q_{g4} (p.u.)
J+50			P_{gt5} (p.u.) – point 5
J+51			Q_{g5} (p.u.)
J+52			P_{gt6} (p.u.) – point 6
J+53			Q_{g6} (p.u.)
J+54			P_{gt7} (p.u.) – point 7
J+55			Q_{g7} (p.u.)
J+56			T_{drum} (>0) – Drum time constant (s)
J+57			K_m – Pressure loss due to flow friction in the boiler tubes (p.u.)
J+58			T_{vs} (>0) – Actuator time constant for main steam (p.u.)
J+59			K_p – Pressure controller proportional gain (p.u.)
J+60			K_i – Pressure controller integral gain (p.u./s)
J+61			T_n –Turbine lead time constant (s)
J+62			T_d –Turbine lag time constant (s)
J+63			Q_s – heat from sSupplemental firing (p.u.)
J+64			B_v –Bypass valve opening (p.u.) (see notes 8 and 9)
J+65			P_{ref} – Minimum steam pressure reference (p.u.)
J+66			$Trate_{ST}$ – ST rating (MW) (see note 5)

STATEs	#	Description
K		Machine electrical power measurement
K+1		Governor differential control
K+2		Governor integral control
K+3		Turbine actuator
K+4		Turbine acceleration limiter integral control
K+5		Turbine load limiter measurement
K+6		Turbine load limiter integral control
K+7		Supervisor load control
K+8		Acceleration control
K+9		Temperature detection lead-lag
K+10		First state of turbine second order transfer function
K+11		Second state of turbine second order transfer function
K+12		Drum pressure (P_d)
K+13		turbine lead-lag block
K+14		pressure control integral channel
K+15		valve position (v)

VARs	#	Description
L		Lset Load Reference
L+1		Output of load limiter PI control
L+2		Output of governor PID control
L+3		Low value select ouptut
L+4		Output of acceleration limiter PI control
L+5		Pf
L+6		Supervisory load controller setpoint, MWset
L+7		Input of deadband block
L+8		output of deadband block
L+9		Pg
L+10		h (heat)
L+11		A - coefficient of F(x)
L+12		B – coefficient of F(x)
L+13		C – coefficient of F(x)
L+14		Steam flow through bypass valve (q_b)
L+15		Steam mass flow (q_t)
L+16		Turbine inlet pressure (P_t)
L+17		$Q_{imbalance}$
L+18		Power output from GT (P_{gt})
L+19		Heat from GT exhaust (Q_g)
L+20		Calculated Bv

IBUS 'USRMDL' ID 'UCCPSS' 5 0 0 67 16 21 CONs from (J) to (J+66) /

notes:

1) model adopts generator MVA base as turbine rating if parameter TRATE = 0.0
2) the parameter CON(J+10) = a_{set} should be set to +99 to disregard the acceleration limit control loop
3) the CIGRÉ document suggests implementing F(x) as a look-up table or a piecewise linear function, that would require specific manufacturer's data to be defined. The present implementation of this model assumes a quadratic approximation of the characteristics similar to the one given in Figure C-1 of the CIGRÉ document. The user should enter three points [x_i, F(x_i)] of the turbine characteristics curve and the model will determine the coefficients of a quadratic equation given as $F(x)= A x^2 + B x + C$. The characteristic in Figure C-1 can be approximated by using the following points: [0.95, 0.95575], [1.0, 1.001], and [1.05, 0.97568].
4) Tlimit corresponds to fuel demand required for 1 p.u. turbine power i.e. = (1/Kt+Wfo). Conversely, Tlimit determines the (steady state) maximum power output of the turbine: Pmax = (Tlimit – Wf0) x Kt, expressed in per unit of turbine rating Trate.
5) model adopts generator MVA base as steam turbine rating if parameter $TRATE_{ST}$ = 0.0
6) Points in the look-up table should have Q_g greater or equal to zero and should monotonically increase. Once a decrease is detected, no more points are considered in the look-up table. Thus, the user can enter [0.0, 0.0] for those points not needed.
7) If less than 7 points are required in the look-up table, the remainder data points should be set to [0.0, 0.0]. The heat Q_g is considered constant and equal to the last value Q_{gi} when P_{gt} is greater than P_{gti}. **Heat is not extrapolated beyond the last point in the look-up table**.
8) The bypass valve opening B_v should be a number between 0 and 1. If a negative value is entered, the model will calculate the bypass valve opening to minimize any imbalances in heat
9) Setting B_v to 0.0 corresponds to no steam bypass and all available steam is used for electric power production
10) This model was proposed in CIGRÉ Technical Brochure on Modeling of Gas Turbines and Steam Turbines in Combined-Cycle Power Plants, Task Force 25 of Advisory Group 02 of Study Committee 38, April 2003.

a) initialization in sliding mode

$$\begin{cases} q_t = P_{st} = P_t \\ q_b = B_v \sqrt{P_t} \\ Q_g = q_t + q_b - Q_s \end{cases} \Rightarrow Q_g = P_{st} + B_v \sqrt{P_{st}} - Q_s$$

$$Q_g = \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} \left(P_{gt} - P_{gt_A}\right) + Q_{g_A} = \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt} + \left(Q_{g_A} - \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt_A}\right)$$

$$P_{st} + B_v \sqrt{P_{st}} - Q_s = \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt} + \left(Q_{g_A} - \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt_A}\right)$$

$$P_{st} \cdot T_{rate_{st}} + P_{gt} \cdot T_{rate_{gt}} = P_{mech} \cdot M_{base} \quad \Rightarrow \quad P_{gt} = \frac{P_{mech} \cdot M_{base} - P_{st} \cdot T_{rate_{st}}}{T_{rate_{gt}}}$$

$$P_{st} + B_v \sqrt{P_{st}} - Q_s = \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} \left[\frac{P_{mech} \cdot M_{base} - P_{st} \cdot T_{rate_{st}}}{T_{rate_{gt}}}\right] + \left(Q_{g_A} - \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt_A}\right)$$

$$\left[1 + \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} \frac{T_{rate_{st}}}{T_{rate_{gt}}}\right] P_{st} + B_v \sqrt{P_{st}} = Q_s + \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{mech} \frac{M_{base}}{T_{rate_{gt}}} + \left(Q_{g_A} - \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt_A}\right)$$

b) if $P_t < P_{ref} \Rightarrow$ pressure control $\Rightarrow P_t = P_{ref}$

$$\begin{cases} q_t = P_{st} = P_{ref} \cdot v \\ q_b = B_v \sqrt{P_{ref}} \\ Q_g = q_t + q_b - Q_s \end{cases} \Rightarrow Q_g = P_{st} + B_v \sqrt{P_{ref}} - Q_s$$

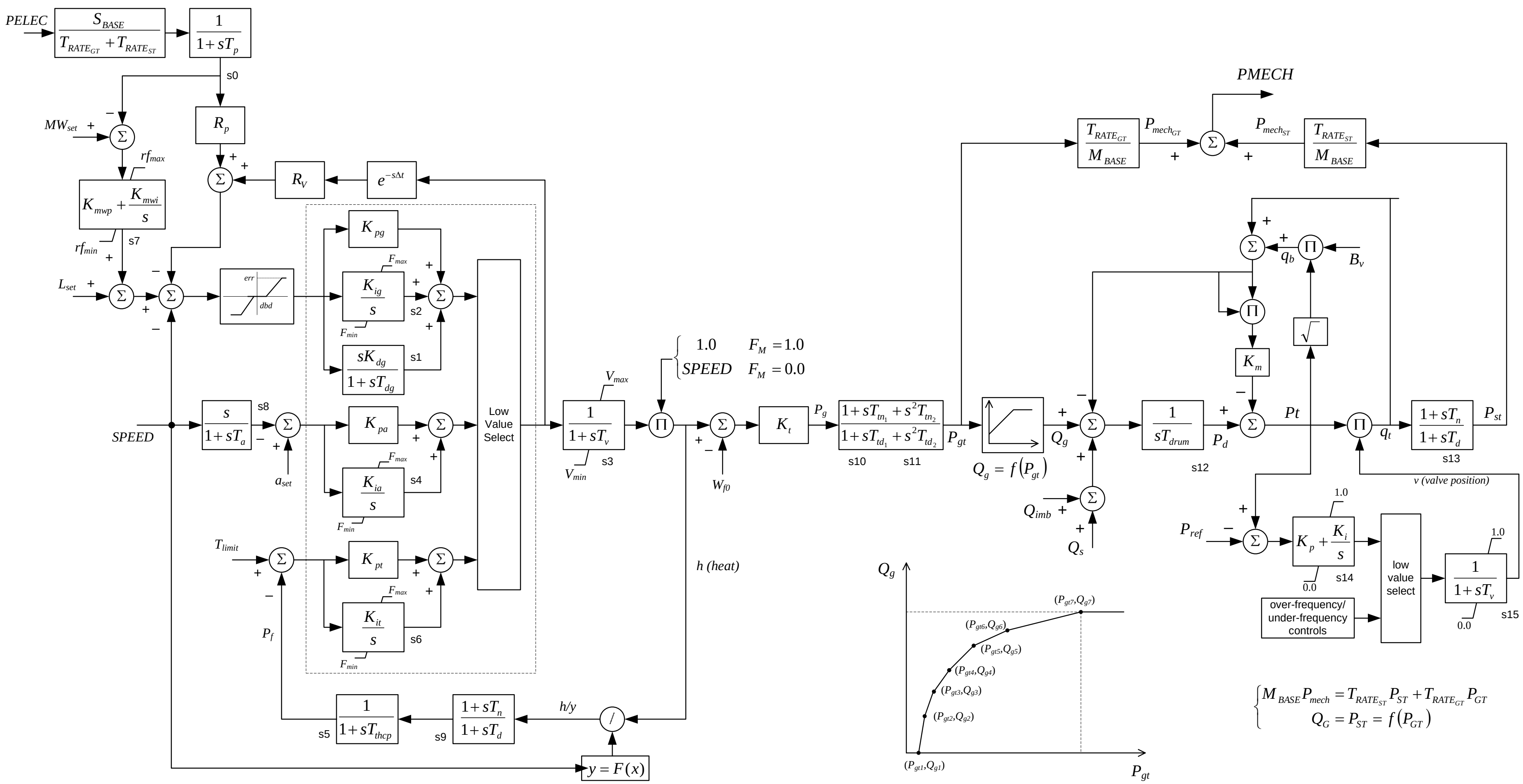
$$Q_g = \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} \left(P_{gt} - P_{gt_A}\right) + Q_{g_A} = \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt} + \left(Q_{g_A} - \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt_A}\right)$$

$$P_{st} + B_v \sqrt{P_{ref}} - Q_s = \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt} + \left(Q_{g_A} - \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt_A}\right)$$

$$P_{st} \cdot T_{rate_{st}} + P_{gt} \cdot T_{rate_{gt}} = P_{mech} \cdot M_{base} \quad \Rightarrow \quad P_{gt} = \frac{P_{mech} \cdot M_{base} - P_{st} \cdot T_{rate_{st}}}{T_{rate_{gt}}}$$

$$P_{st} + B_v \sqrt{P_{ref}} - Q_s = \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} \left[\frac{P_{mech} \cdot M_{base} - P_{st} \cdot T_{rate_{st}}}{T_{rate_{gt}}}\right] + \left(Q_{g_A} - \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt_A}\right)$$

$$\left[1 + \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} \frac{T_{rate_{st}}}{T_{rate_{gt}}}\right] P_{st} = Q_s + \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{mech} \frac{M_{base}}{T_{rate_{gt}}} + \left(Q_{g_A} - \frac{Q_{g_B} - Q_{g_A}}{P_{gt_B} - P_{gt_A}} P_{gt_A}\right) - B_v \sqrt{P_{ref}}$$



PELEC
PMECH
SPEED
MWset
Lset
rfmax
rfmin
s0
s1
s2
s3
s4
s5
s6
s7
s8
s9
s10
s11
s12
s13
s14
s15
Low Value Select
Vmax
Vmin
Fmax
Fmin
Tlimit
aset
Pf
h (heat)
h/y
y = F(x)
1.0 FM = 1.0
SPEED FM = 0.0
Wf0
Pg
Pgt
Qg = f(Pgt)
Qg
Qimb
Qs
Pd
Pt
qb
Bv
qt
Pst
Pmech GT
Pmech ST
v (valve position)
Pref
1.0
0.0
low value select
over-frequency/ under-frequency controls
(Pgt1,Qg1)
(Pgt2,Qg2)
(Pgt3,Qg3)
(Pgt4,Qg4)
(Pgt5,Qg5)
(Pgt6,Qg6)
(Pgt7,Qg7)
$M_{BASE} P_{mech} = T_{RATE_{ST}} P_{ST} + T_{RATE_{GT}} P_{GT}$
$Q_G = P_{ST} = f(P_{GT})$