Annexure- 3E

1. **Details of models in PSS/E for modelling hydro power generator including Constant speed/Conventional PSP:**

   (a) Synchronous Machine – HPP and Constant speed/Conventional PSP types

Category	Parameter Description	Data
Generator Nameplate	Rated apparent power in MVA	
	Rated terminal voltage	
	Rated power factor	
	Rated speed (in RPM)	
	Rated frequency (in Hz)	
	Rated excitation (in Amperes and Volts)	
Type of synchronous machine	Round rotor or salient pole No. of poles	
Generator capability curve	The generator capability curve shows the reactive capability of the machine and should include any restrictions on the real or reactive power range like under/over excitation limits, stability limits, etc. Capability curve should have properly labelled axis and legible data	
Generator Open Circuit and Short Circuit Characteristic	Graph of excitation current versus terminal voltage and stator current	
	No load excitation current – used to derive per unit values	
	Excitation current at rated stator current	
Generator vee-curves	Otherwise referred to as "V-curve". A plot of the terminal (armature) current versus the generating unit field voltage.	
Resistance values	Resistance measurements of field winding and stator winding to a known temperature	
Generator Data sheet	Direct axis synchronous reactance Xd in p.u. (Unsaturated or saturated)	
	Direct axis transient synchronous reactance Xd' in p.u. (Unsaturated or saturated)	
	Direct axis sub-transient synchronous reactance Xd'' in p.u. (Unsaturated or saturated)	
	Stator leakage reactance Xa in p.u. (Unsaturated or saturated)	
	Quadrature axis synchronous reactance Xq in p.u. (Unsaturated or saturated)	
	Quadrature axis transient synchronous reactance Xq' in p.u. (Unsaturated or saturated)	
	Quadrature axis sub-transient synchronous reactance Xq'' in p.u. (Unsaturated or saturated)	
	Direct axis open circuit transient time constant Tdo' in sec	
	Direct axis open circuit sub-transient time constant Tdo'' in sec	
	Quadrature axis open circuit transient time constant Tqo' in sec	
	Quadrature axis open circuit sub-transient time constant Tqo'' in sec	
	Inertia constant of total rotating mass (generator, AVR, turbo-governor set) H in MW. s/MVA	
	Speed Damping D	
	Saturation constant S (1.0) in p.u.	
	Saturation constant S (1.2) in p.u.	

Category	Parameter Description	Data
Generator step up transformer (GSUT)	Nameplate Rating - Rated primary and secondary voltage - Vector group - Impedance - Tap changer details (Number of taps, tap position, tap ratio etc.)	
Auxiliary power (i.e. active and reactive auxiliary load)	Value of auxiliary load (MW and Mvar) at rated power of the generating unit.	
	Whether or not the load trips if the generating unit trips.	
Test Reports	Factory acceptance test (FAT) reports	

(b) Site Load

	Low Output			High Output		
	kW	**kvar**	**kVA**	**kW**	**kvar**	**kVA**
Auxiliary Load						

(c) Excitation System

Category	Parameter Description	Data
Type of Automatic Voltage Regulator (AVR)	Manufacturer and product details (for example ABB UNITROL)	
	Type of control system: - Analogue or digital	
	Year of commissioning / Year of manufacture	
	As found settings (obtained either from HMI or downloaded from controller in digital systems)	
Type of excitation system	Static excitation system OR	
	Indirect excitation system (i.e. rotating exciter) - AC exciter, or - DC exciter	
Details of AVR converter	Rated excitation current (converter rating in Amperes)	
	Six pulse thyristor bridge or PWM converter	
Source of excitation supply	Excitation transformer or auxiliary supply (Details thereof)	
	If excitation transformer, nameplate information required	
Schematics	Saturation curves of the exciter (if applicable – see Type AC and DC)	
	Drawings of excitation system, typically prepared and supplied by the OEM	
	Single line diagram (i.e. one-line diagram) for the excitation system	
Excitation limiters	What excitation limiters are commissioned?	
	Under Excitation Limiters settings	
	Over Excitation Limiters settings	
	Voltage/frequency limiter	
	Stator current limiter	
	Minimum excitation current limiter	

Category	Parameter Description	Data
PSS	Is the AVR equipped with a PSS?	
	How many input Channels does the PSS have? (speed, real power output or both	
	If the PSS uses speed, is this a derived speed signal (i.e. synthesized speed signal) or measured directly (i.e. actual rotor speed)?	
	Type of PSS Block Diagram of PSS and as commissioned parameters value (Gain, time constants, filter coefficients, output limits of the PSS)	
Test Reports	Factory acceptance test (FAT) reports	

(d) Turbine Details (to be filled in for the HPP and Constant Speed/Conventional PSP separately)

Category	Parameter Description	Data
Type of prime mover	Hydro-electric turbine Other (Pumped storage)	
Manufacturer of turbine	Manufacturer and name plate details	
Modes of operation	Type of modes of operation capable: - Generator - Pump storage - Synchronous condenser	
Governor	- Electro-mechanical governor (including settings and drawings) - Digital electric governor (including settings and drawings) - PID governor details and settings - Transient droop (dashpot) governor details and settings - Tacho-accelerometric governor details and settings - Input transducer details - Transfer function data	
	Digital electric governor	
Ramp rates	How fast can the turbine increase and/or decrease load, specified in MW/min Guide vane/wicket gate characteristic, including opening, closing rates/times and limits	
Droop	Droop setting (% on machine base)	
	Frequency influence limiters - Maximum frequency deviation limiter (eg +/-2 Hz) - Maximum influence limiter (eg 10% of rating)	
Dead band	Details of frequency dead band (typically in Hz or RPM)	
Hydro-electric turbine	Type of hydro turbine	
	- Impulse turbines : typical with high head plants (Pelton wheel)	
	- Reaction turbine : typical with low and medium head plants (such as Francis and Kaplan turbine	
	Head, water flow, velocity and pressure (e.g. intake and outtake/draft tube)	

Penstock	Length (m)	
	Area (m^2)	
	Internal penstock diameter	
	Pipe thickness, material or other characteristics (such as tapering)	
	Non-elastic or elastic	
	Linear or non-linear model (with or without relief valve) or Kaplan model	
	Flow of water through turbine (m^3/s) – with gates fully open	
	Number of penstocks supplied from common tunnel	
Pressure relief valve	Drawings/schematics	
	Settings	
	Operational descriptions	
Surge tank, reservoir and tail water (i.e. head)	Vertical distance between the upper reservoir and level of turbine (in meters)	
	Head at turbine admission (lake head minus tailrace head) – (in meters)	
	Head loss due to friction in conduit (in meters)	
	Surge tank height, diameter and other characteristics (e.g. restricted inlet orifice)	
Pump characteristics	Active power draw vs head (table)	
	PSS status when pumping (on/off/not used)	
Synchronous condenser	Dewatered when operating as Syncon (yes/no)	
	Losses when operating as Syncon: • Mechanical loss (0 Mvar): …… MW • Copper loss (table) MW loss as a function of MVar output	
Other	Details of protection schemes that could influence dynamics (if any)	
	Details of resonance chamber for pipes (if any)	
	Temperature (e.g. water, ambient, unit)	
	Characteristic curve of blade versus gate (from 0MW to maximum MW)	

(e) Details of models in PSS/E for modelling Adjustable Speed Pump Storage (AS-PSH):

Category	**Parameter Description**	**Data**
	Generator/Motor data	
Generator Nameplate	Rated apparent power in MVA in Generation mode	
	Rated apparent power in MVA in Pump mode	
	Rated terminal voltage	
	Rated power factor	
	Rated speed (in RPM)	
Generator capability curve	The generator capability curve shows the reactive capability of the machine and should include any restrictions on the real or reactive power range like under/over excitation limits, stability limits, etc. Capability curve should have properly labelled axis and legible data	
Generators step up transformer (GSUT)	Nameplate Rating - Rated primary and secondary voltage - Vector group - Impedance	
Auxiliary power (i.e. active and reactive auxiliary load)	Value of auxiliary load (MW and MVAR) at rated power of the generating unit. Whether or not the load trips if the generating unit trips.	
Test Reports	Factory acceptance test (FAT) reports	
	Governor- Penstock data	
Manufacturer of turbine	Manufacturer and name plate details	
Modes of operation	Type of modes of operation capable: - Generator - Pump storage - Synchronous condenser	
Governor	- Electro-mechanical governor (including settings and drawings) - Digital electric governor (including settings and drawings) - PID governor details and settings - Transient droop (dashpot) governor details and settings - Tacho-accelerometric governor details and settings - Input transducer details - Transfer function data	
	Digital electric governor	
Ramp rates	How fast can the turbine increase and/or decrease load, specified in MW/min Guide vane/wicket gate characteristic, including opening, closing rates/times and limits	
Droop	Droop setting (% on machine base)	
	Frequency influence limiters - Maximum frequency deviation limiter (e.g. +/-2 Hz) - Maximum influence limiter (e.g. 10% of rating)	
Dead band	Details of frequency dead band (typically in Hz or RPM)	
Hydro-electric turbine	Type of hydro turbine - Impulse turbines: typical with high head plants (Pelton wheel) - Reaction turbines: typical with low and medium head plants (such as Francis and Kaplan turbine	

	Head, water flow, velocity and pressure (e.g. intake and outtake/draft tube)	
Penstock	Length (m)	
	Area (m2)	
	Internal penstock diameter	
	Pipe thickness, material or other characteristics (such as tapering)	
	Non-elastic or elastic	
	Linear or non-linear model (with or without relief valve) or Kaplan model	
	Flow of water through turbine (m3/s) – with gates fully open	
	Number of penstocks supplied from common tunnel	
	Number of unit supplied from same penstock	
Pressure relief valve	Drawings/schematics	
	Settings	
	Operational descriptions	
Surge tank, reservoir and tail water (i.e. head)	Vertical distance between the upper reservoir and level of turbine (in meters)	
	Head at turbine admission (lake head minus tailrace head) – (in meters)	
	Head loss due to friction in conduit (in meters)	
	Surge tank height, diameter and other characteristics (e.g. restricted inlet orifice)	
Pump characteristics	Active power draw vs head (table)	
Synchronous condenser	Losses when operating as SynCon: • Mechanical loss (0 Mvar): …… MW • Copper loss (table) MW loss as a function of MVar output	
Other	Details of protection schemes that could influence dynamics (if any)	
	Details of resonance chamber for pipes (if any)	
	Temperature (e.g. water, ambient, unit)	
	Characteristic curve of blade versus gate (from 0MW to maximum MW)	

2. Generic Models for synchronous machine

Hydro machines are multi-pole machines and depending upon the saturation characteristic of the machine they are classified in two groups:

- GENSAL – Salient pole machine with quadratic saturation function
- GENSAE – Salient pole machine with exponential saturation function

Category	Parameter Description	Data
GENERATOR model		
GENSAE OR **GENSAL**	Direct axis open circuit transient time constant Tdo' in sec	
	Direct axis open circuit sub-transient time constant Tdo'' in sec	
	Quadrature axis open circuit sub-transient time constant Tqo'' in sec	
	Inertia constant of total rotating mass H in MW. s/MVA	
	Speed Damping D	
	Direct axis synchronous reactance Xd in p.u. (Unsaturated or saturated)	
	Quadrature axis synchronous reactance Xq in p.u. (Unsaturated or saturated)	
	Direct axis transient synchronous reactance Xd' in p.u. (Unsaturated or saturated)	
	Direct axis sub-transient synchronous reactance Xd'' in p.u. (Unsaturated or saturated) = Quadrature axis sub-transient synchronous reactance Xq'' in p.u.	
	Stator leakage reactance Xl	
	Saturation constant S (1.0) in p.u.	
	Saturation constant S (1.2) in p.u.	

While entering the values in above table, following relationship must be kept:

Xd>Xq>Xq'≥Xd'>Xq" ≥Xd''

Tdo'>Td'>Tdo''>Td''

Tqo''>Tq'>Tqo''>Tq''

3. Excitation system model:

If a generic model is used, the first step must be to identify what type of exciter is present in the excitation system. The IEEE Std 421.5 (IEEE Recommended Practice for Excitation System Models for Power System Stability Studies published on 26th Aug 2016) has published several generic models, which are classified into three groups:

- Type DC: for excitation systems with a DC exciter
- Type AC: for excitation systems with an AC exciter
- Type ST: for excitation systems with a static exciter

The following table shows the types of models separated into their respective groups.

DC exciter	AC exciter	Static excitation system
Type DC1A	Type AC1A	Type ST1A
Type DC2A	Type AC2A	Type ST2A
Type DC3A	Type AC4A	Type ST3A
Type DC4B	Type AC5A	Type ST4B
	Type AC6A	Type ST5B
	Type AC7B	Type ST6B
	Type AC8B	Type ST7B

Category	Parameter Description	Data
DC Exciter		
ESDC1 A OR ESDC2 A	TR regulator input filter time constant (sec)	
	KA (> 0) (pu) voltage regulator gain	
	TA (s), voltage regulator time constant	
	TB (s), lag time constant	
	TC (s), lead time constant	
	VRMAX (pu) regulator output maximum limit or Zero	
	VRMIN (pu) regulator output minimum limit	
	KE (pu) exciter constant related to self-excited field	
	TE (> 0) rotating exciter time constant (sec)	
	KF (pu) rate feedback gain	
	TF1 (> 0) rate feedback time constant (sec)	
	Switch	
	E1, exciter flux at knee of curve (pu)	
	SE(E1), saturation factor at knee of curve	
	E2, maximum exciter flux (pu)	
	SE(E2), saturation factor at maximum exciter flux (pu)	

Category	Parameter Description	Data
DC Exciter		
ESDC3A	TR regulator input filter time constant (sec)	
	KV (pu) limit on fast raise/lower contact setting	
	VRMAX (pu) regulator output maximum limit or Zero	
	VRMIN (pu) regulator output minimum limit	
	TRH (> 0) Rheostat motor travel time (sec)	
	TE (> 0) exciter time-constant (sec)	
	KE (pu) exciter constant related to self-excited field	
	VEMIN (pu) exciter minimum limit	
	E1, exciter flux at knee of curve (pu)	
	SE(E1), saturation factor at knee of curve	
	E2, maximum exciter flux (pu)	
	SE(E2), saturation factor at maximum exciter flux (pu)	
ESDC4B	TR regulator input filter time constant (sec)	
	KP (pu) (> 0) voltage regulator proportional gain	
	KI (pu) voltage regulator integral gain	
	KD (pu) voltage regulator derivative gain	
	TD voltage regulator derivative channel time constant (sec)	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
	KA (> 0) (pu) voltage regulator gain	
	TA voltage regulator time constant (sec)	
	KE (pu) exciter constant related to self-excited field	
	TE (> 0) rotating exciter time constant (sec)	
	KF (pu) rate feedback gain	
	TF (> 0) rate feedback time constant (sec)	
	VEMIN (pu) minimum exciter voltage output	
	E1, exciter flux at knee of curve (pu)	
	SE(E1), saturation factor at knee of curve	
	E2, maximum exciter flux (pu)	
	SE(E2), saturation factor at maximum exciter flux (pu)	

Category	Parameter Description	Data
AC Exciter		
ESAC1A	TR regulator input filter time constant (sec)	
	TB (s), lag time constant	
	TC (s), lead time constant	
	KA (> 0) (pu) voltage regulator gain	
	TA (s), voltage regulator time constant	
	VAMAX (pu) regulator output maximum limit	
	VAMIN (pu) regulator output minimum limit	
	TE (> 0) rotating exciter time constant (sec)	
	KF (pu) rate feedback gain	
	TF (> 0) rate feedback time constant (sec)	
	KC (pu) rectifier loading factor proportional to commutating reactance	
	KD (pu) demagnetizing factor, function of AC exciter reactance	
	KE (pu) exciter constant related to self-excited field	
	E1, exciter flux at knee of curve (pu)	
	SE(E1), saturation factor at knee of curve	
	E2, maximum exciter flux (pu)	
	SE(E2), saturation factor at maximum exciter flux (pu)	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
ESAC2A	TR regulator input filter time constant (sec)	
	TB (s), lag time constant	
	TC (s), lead time constant	
	KA (> 0) (pu) voltage regulator gain	
	TA (s), voltage regulator time constant	
	VAMAX (pu) regulator output maximum limit	
	VAMIN (pu) regulator output minimum limit	
	KB, Second stage regulator gain	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
	TE (> 0) rotating exciter time constant (sec)	
	VFEMAX, parameter of VEMAX, exciter field maximum output	
	KH, Exciter field current feedback gain	
	KF (pu) rate feedback gain	
	TF (> 0) rate feedback time constant (sec)	
	KC (pu) rectifier loading factor proportional to commutating reactance	
	KD (pu) demagnetizing factor, function of AC exciter reactance	
	KE (pu) exciter constant related to self-excited field	
	E1, exciter flux at knee of curve (pu)	
	SE(E1), saturation factor at knee of curve	
	E2, maximum exciter flux (pu)	
	SE(E2), saturation factor at maximum exciter flux (pu)	

Category	Parameter Description	Data
AC Exciter		
ESAC3A	TR regulator input filter time constant (sec)	
	TB (s), lag time constant	
	TC (s), lead time constant	
	KA (> 0) (pu) voltage regulator gain	
	TA (s), voltage regulator time constant	
	VAMAX (pu) regulator output maximum limit	
	VAMIN (pu) regulator output minimum limit	
	TE (> 0) rotating exciter time constant (sec)	
	VEMIN (pu) minimum exciter voltage output	
	KR (>0), Constant associated with regulator and alternator field power supply	
	KF (pu) rate feedback gain	
	TF (> 0) rate feedback time constant (sec)	
	KN, Exciter feedback gain	
	EFDN, A parameter defining for which value of UF the feedback gain shall change from KF to KN	
	KC, rectifier regulation factor (pu)	
	KD, exciter regulation factor (pu)	
	KE (pu) exciter constant related to self-excited field	
	VFEMAX, parameter of VEMAX, exciter field maximum output	
	E1, exciter flux at knee of curve (pu)	
	SE(E1), saturation factor at knee of curve	
	E2, maximum exciter flux (pu)	
	SE(E2), saturation factor at maximum exciter flux (pu)	
ESAC4A	TR regulator input filter time constant (sec)	
	VIMAX, Maximum value of limitation of the integrator signal VI in p. u	
	VIMIN, Minimum value of limitation of the signal VI in p.u.	
	TB (s), lag time constant	
	TC (s), lead time constant	
	KA (> 0) (pu) voltage regulator gain	
	TA (s), voltage regulator time constant	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
	KC, rectifier regulation factor (pu)	

Category	Parameter Description	Data
	AC Exciter	
ESAC5A	TR regulator input filter time constant (sec)	
	KA (> 0) (pu) voltage regulator gain	
	TA (s), voltage regulator time constant	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
	KE (pu) exciter constant related to self-excited field	
	TE (> 0) rotating exciter time constant (sec)	
	KF (pu) rate feedback gain	
	TF1 (sec), Regulator stabilizing circuit time constant in seconds	
	TF2 (sec), Regulator stabilizing circuit time constant in seconds	
	TF3 (sec), Regulator stabilizing circuit time constant in seconds	
	E1, exciter flux at knee of curve (pu)	
	SE(E1), saturation factor at knee of curve	
	E2, maximum exciter flux (pu)	
	SE(E2), saturation factor at maximum exciter flux (pu)	
AC6A	TR regulator input filter time constant (sec)	
	KA (> 0) (pu) voltage regulator gain	
	TA (s), voltage regulator time constant	
	TK (sec), Lead time constant	
	TB (s), lag time constant	
	TC (s), lead time constant	
	VAMAX (pu) regulator output maximum limit	
	VAMIN (pu) regulator output minimum limit	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
	TE (> 0) rotating exciter time constant (sec)	
	VFELIM, Exciter field current limit reference	
	KH, Damping module gain	
	VHMAX, damping module limiter	
	TH (sec), damping module lag time constant	
	TJ (sec), damping module lead time constant	
	KC, rectifier regulation factor (pu)	
	KD, exciter regulation factor (pu)	
	KE (pu) exciter constant related to self-excited field	
	E1, exciter flux at knee of curve (pu)	
	SE(E1), saturation factor at knee of curve	
	E2, maximum exciter flux (pu)	
	SE(E2), saturation factor at maximum exciter flux (pu)	

Category	Parameter Description	Data
	AC Exciter	
AC7B	TR (sec) regulator input filter time constant	
	KPR (pu) regulator proportional gain	
	KIR (pu) regulator integral gain	
	KDR (pu) regulator derivative gain	
	TDR (sec) regulator derivative block time constant	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
	KPA (pu) voltage regulator proportional gain	
	KIA (pu) voltage regulator integral gain	
	VAMAX (pu) regulator output maximum limit	
	VAMIN (pu) regulator output minimum limit	
	KP (pu)	
	KL (pu)	
	KF1 (pu)	
	KF2 (pu)	
	KF3 (pu)	
	TF3 (sec) time constant (> 0)	
	KC (pu) rectifier loading factor proportional to commutating reactance	
	KD (pu) demagnetizing factor, function of AC exciter reactance	
	KE (pu) exciter constant related to self-excited field	
	TE (pu) exciter time constant (>0)	
	VFEMAX (pu) exciter field current limit (> 0)	
	VEMIN (pu)	
	E1, exciter flux at knee of curve (pu)	
	SE(E1), saturation factor at knee of curve	
	E2, maximum exciter flux (pu)	
	SE(E2), saturation factor at maximum exciter flux (pu)	

Category	Parameter Description	Data
AC Exciter		
AC8B	TR (sec) regulator input filter time constant	
	KPR (pu) regulator proportional gain	
	KIR (pu) regulator integral gain	
	KDR (pu) regulator derivative gain	
	TDR (sec) regulator derivative block time constant	
	VPIDMAX (pu) PID maximum limit	
	VPIDMIN (pu) PID minimum limit	
	KA (pu) voltage regulator proportional gain	
	TA (sec) voltage regulator time constant	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
	KC (pu) rectifier loading factor proportional to commutating reactance	
	KD (pu) demagnetizing factor, function of AC exciter reactance	
	KE (pu) exciter constant related to self-excited field	
	TE (pu) exciter time constant (>0)	
	VFEMAX (pu) max exciter field current limit (> 0)	
	VEMIN (pu),	
	E1, exciter flux at knee of curve (pu)	
	SE(E1), saturation factor at knee of curve	
	E2, maximum exciter flux (pu)	
	SE(E2), saturation factor at maximum exciter flux (pu)	
Static Exciter		
ST1A	TR (sec) regulator input filter time constant	
	VIMAX, Controller Input Maximum	
	VIMIN, Controller Input Minimum	
	TC (s), Filter 1st Derivative Time Constant	
	TB (s), I Filter 1st Delay Time Constant	
	TC1 (s), Filter 2nd Derivative Time Constant	
	TB1 (s), Filter 2nd Delay Time Constant	
	KA (pu) voltage regulator proportional gain	
	TA (sec) voltage regulator time constant	
	VAMAX (pu) regulator output maximum limit	
	VAMIN (pu) regulator output minimum limit	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
	KC (pu) rectifier loading factor proportional to commutating reactance	
	KF (pu) rate feedback gain	
	TF (> 0) rate feedback time constant (sec)	
	KLR, Current Input Factor	
	ILR, Current Input Reference	

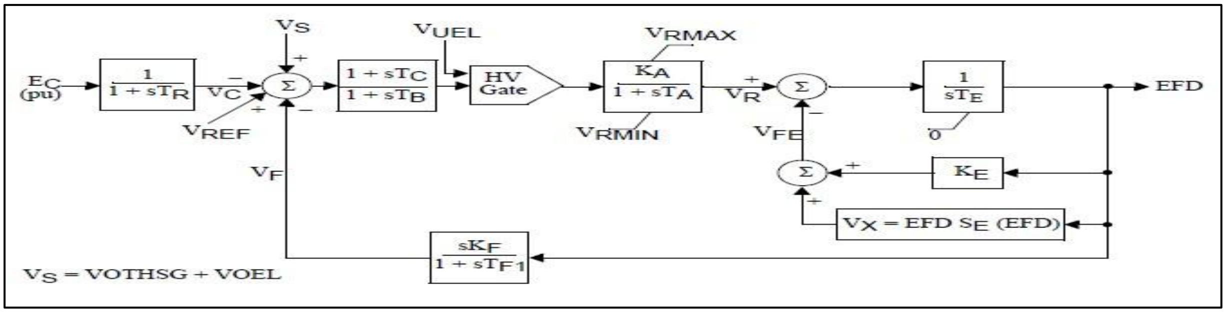
Category	Parameter Description	Data
	Static Exciter	
ST2A	TR (sec) regulator input filter time constant	
	KA (pu) voltage regulator proportional gain	
	TA (sec) voltage regulator time constant	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
	KE (pu) exciter constant related to self-excited field	
	TE (pu) exciter time constant (>0)	
	KF (pu) rate feedback gain	
	TF (> 0) rate feedback time constant (sec)	
	KP (pu) voltage regulator proportional gain	
	KI (pu) voltage regulator integral gain	
	KC (pu) rectifier loading factor proportional to commutating reactance	
	EFDMAX	
ST3A	TR (sec) regulator input filter time constant	
	VIMAX, Maximum value of limitation of the signal VI in p.u.	
	VIMIN, Minimum value of limitation of the signal VI in p.u.	
	KM, Forward gain constant of the inner loop field regulator	
	TC (s), lag time constant	
	TB (s), lead time constant	
	KA (pu) voltage regulator proportional gain	
	TA (sec) voltage regulator time constant	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
	KG, Feedback gain constant of the inner loop field regulator	
	KP (pu) voltage regulator proportional gain	
	KI (pu) voltage regulator integral gain	
	VBMAX, Maximum value of limitation of the signal VB in p.u.	
	KC (pu) rectifier loading factor proportional to commutating reactance	
	XL, Reactance associated with potential source	
	VGMAX, Maximum value of limitation of the signal VG in p. u	
	Θ_P (degrees)	
	TM (sec), Forward time constant of the inner loop field regulator	
	VMMAX, Maximum value of limitation of the signal VM in p. u	
	VMMIN, Minimum value of limitation of the signal VM in p.u.	

Category	Parameter Description	Data
Static Exciter		
ST4B	TR (sec) regulator input filter time constant	
	KPR (pu) regulator proportional gain	
	KIR (pu) regulator integral gain	
	VRMAX (pu) regulator output maximum limit	
	VRMIN (pu) regulator output minimum limit	
	TA (sec) voltage regulator time constant	
	KPM, Regulator gain	
	KIM, Regulator gain	
	VMMAX, Maximum value of limitation of the signal in p.u.	
	VMMIN, Minimum value of limitation of the signal in p.u.	
	KG	
	KP (pu) voltage regulator proportional gain	
	KI (pu) voltage regulator integral gain	
	VBMAX	
	KC (pu) rectifier loading factor proportional to commutating reactance	
	XL	
	Θ_P (degrees)	
ST5B	TR regulator input filter time constant (sec)	
	TC1 lead time constant of first lead-lag block (voltage regulator channel) (sec)	
	TB1 lag time constant of first lead-lag block (voltage regulator channel) (sec)	
	TC2 lead time constant of second lead-lag block (voltage regulator channel)	
	TB2 lag time constant of second lead-lag block (voltage regulator channel)	
	KR (>0) (pu) voltage regulator gain	
	VRMAX (pu) voltage regulator maximum limit	
	VRMIN (pu) voltage regulator minimum limit	
	T1 voltage regulator time constant (sec)	
	KC (pu)	
	TUC1 lead time constant of first lead-lag block (under-excitation channel) (sec)	
	TUB1 lag time constant of first lead-lag block (under-excitation channel) (sec)	
	TUC2 lead time constant of second lead-lag block (under-excitation channel)	
	TUB2 lag time constant of second lead-lag block (under-excitation channel)	
	TOC1 lead time constant of first lead-lag block (over-excitation channel) (sec)	
	TOB1 lag time constant of first lead-lag block (over-excitation channel) (sec)	
	TOC2 lead time constant of second lead-lag block (over-excitation channel)	
	TOB2 lag time constant of second lead-lag block (over-excitation channel)	

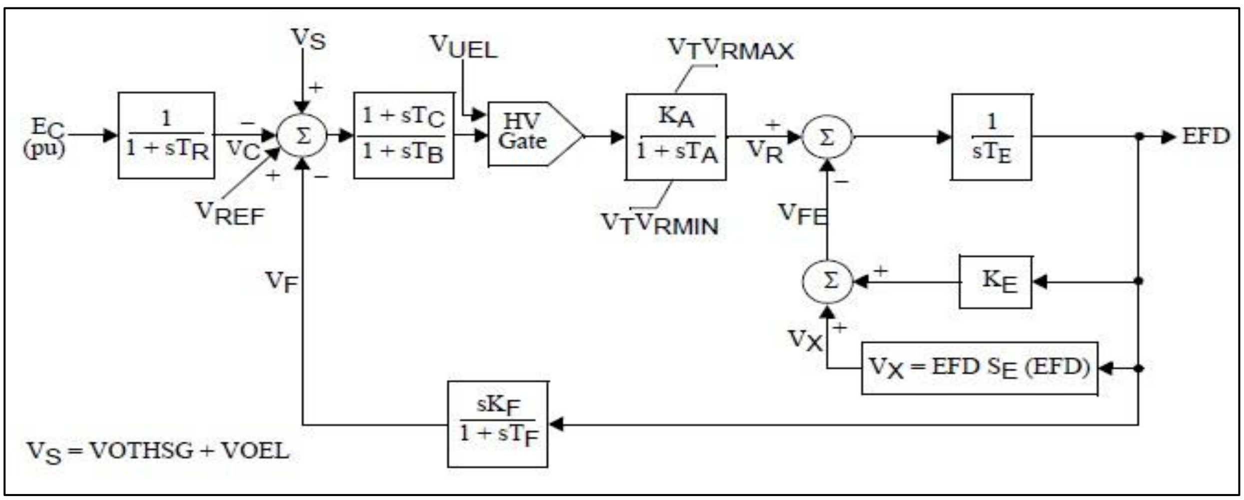
Category	Parameter Description	Data
Static Exciter		
ST6B	TR regulator input filter time constant (sec)	
	KPA (pu) (> 0) voltage regulator proportional gain	
	KIA (pu) voltage regulator integral gain	
	KDA (pu) voltage regulator derivative gain	
	TDA voltage regulator derivative channel time constant (sec)	
	VAMAX (pu) regulator output maximum limit	
	VAMIN (pu) regulator output minimum limit	
	KFF (pu) pre-control gain of the inner loop field regulator	
	KM (pu) forward gain of the inner loop field regulator	
	KCI (pu) exciter output current limit adjustment gain	
	KLR (pu) exciter output current limiter gain	
	ILR (pu) exciter current limit reference	
	VRMAX (pu) voltage regulator output maximum limit	
	VRMIN (pu) voltage regulator output minimum limit	
	KG (pu) feedback gain of the inner loop field voltage regulator	
	TG (> 0) feedback time constant of the inner loop field voltage regulator (sec)	
ST7B	TR regulator input filter time constant (sec)	
	TG lead time constant of voltage input (sec)	
	TF lag time constant of voltage input (sec)	
	Vmax (pu) voltage reference maximum limit	
	Vmin (pu) voltage reference minimum limit	
	KPA (pu) (>0) voltage regulator gain	
	VRMAX (pu) voltage regulator output maximum limit	
	VRMIN (pu) voltage regulator output minimum limit	
	KH (pu) feedback gain	
	KL (pu) feedback gain	
	TC lead time constant of voltage regulator (sec)	
	TB lag time constant of voltage regulator (sec)	
	KIA (pu) (>0) gain of the first order feedback block	
	TIA (>0) time constant of the first order feedback block (sec)	

(i) DC Exciters Generic model:

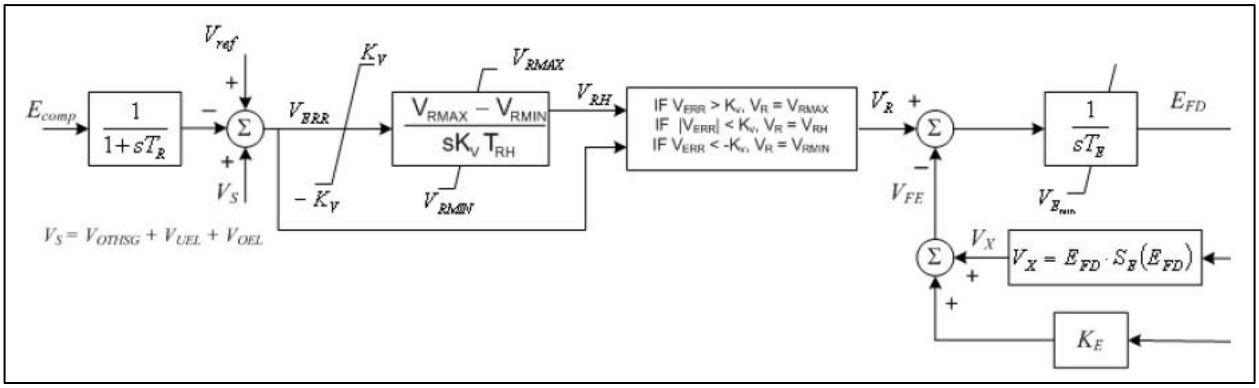
- **Type DC1A: 1992 IEEE type DC1A excitation system model**



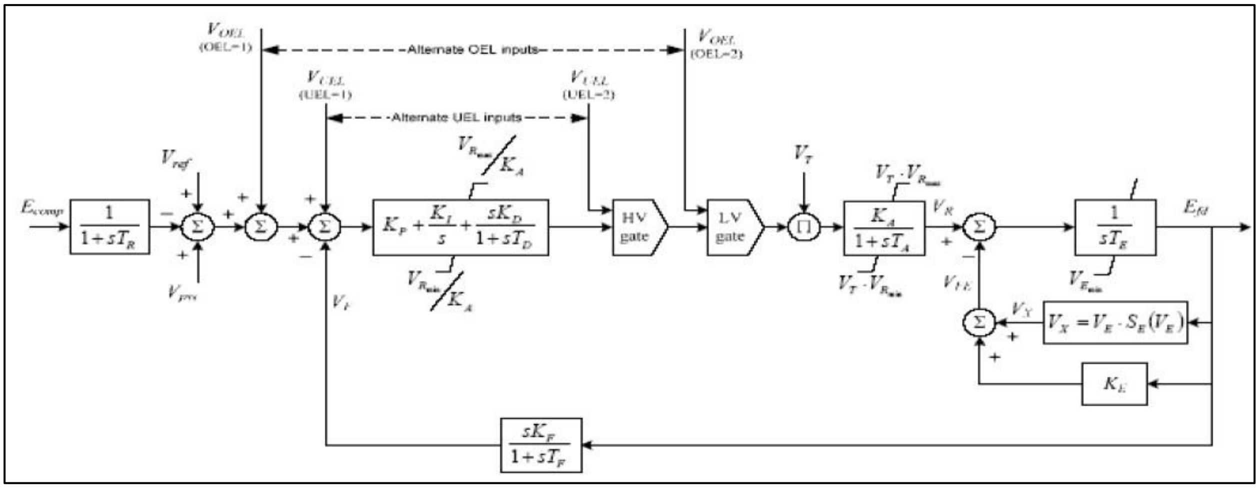
- **Type DC2A: 1992 IEEE type DC2A excitation system model**



➢ **Type DC3A: IEEE 421.5 2005 DC3A excitation system**

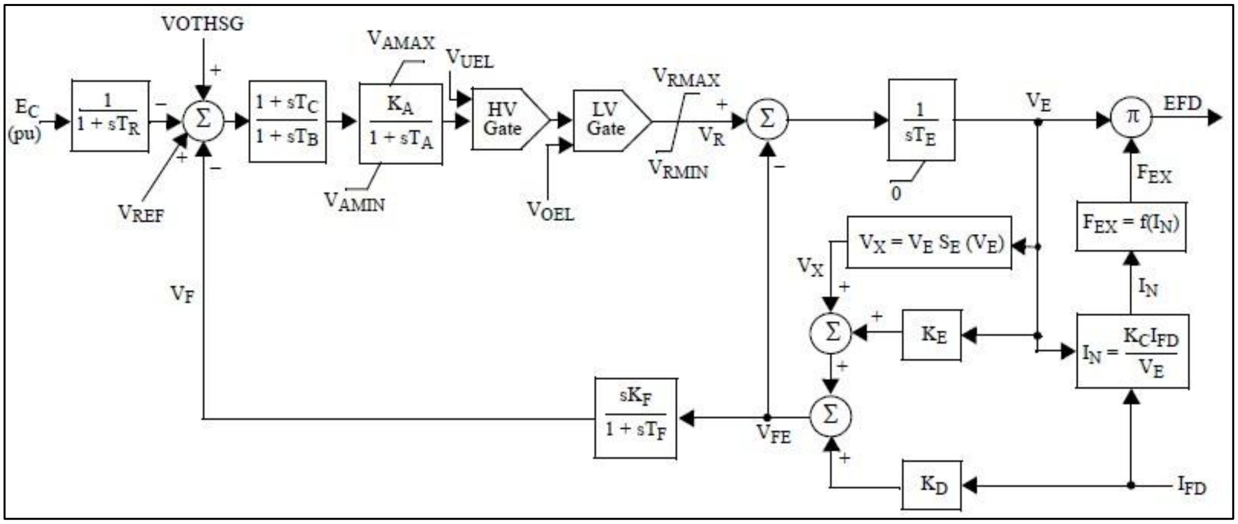


➢ **Type DC4B: IEEE 421.5 2005 DC4B excitation system**



(ii) AC Exciters Generic Models:

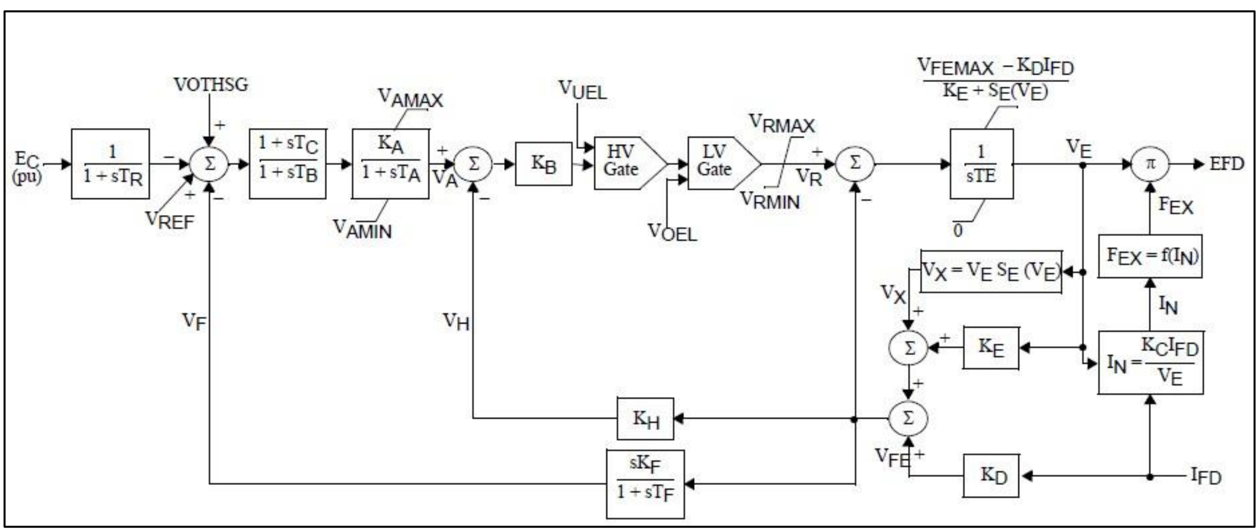
- **Type AC1A: 1992 IEEE type AC1A excitation system model**



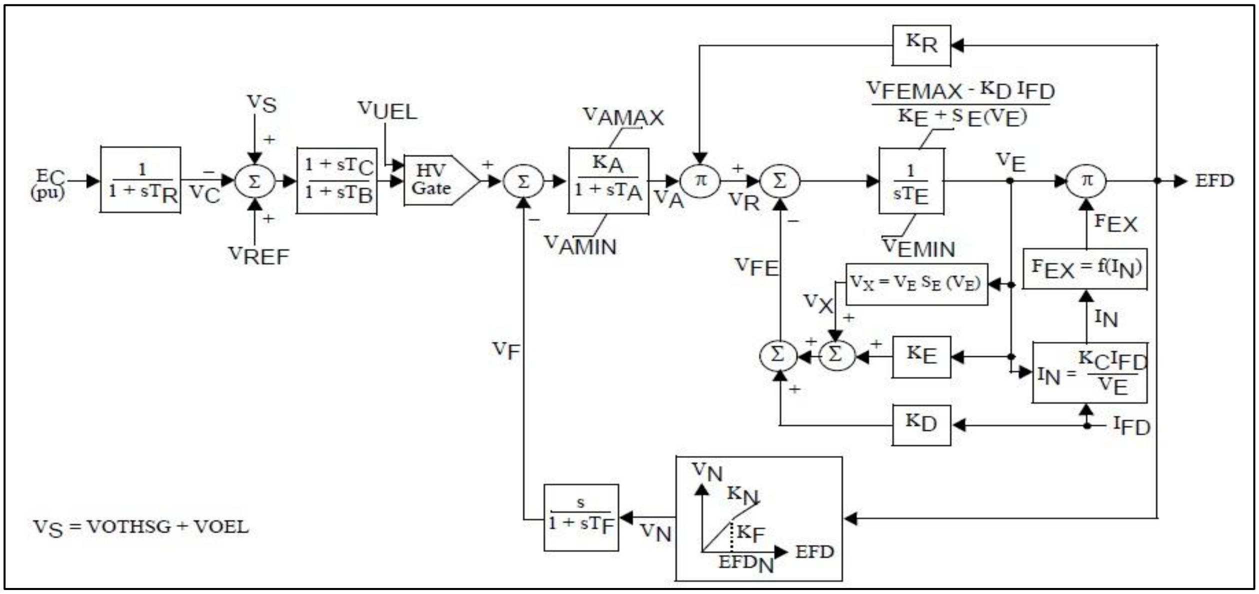
If $I_N \le 0$	$F_{EX} = 1$
If $I_N \le 0.433$	$F_{EX} = 1 - 0.577\ I_N$
If $0.433 < I_N < 0.75$	$F_{EX} = \sqrt{0.75 - I_N^2}$
If $I_N \ge 0.75$	$F_{EX} = 1.732(1 - I_N)$
If $I_N > 1$	$F_{EX} = 0$

$I_N \rightarrow$ (above) $\rightarrow F_{EX}$

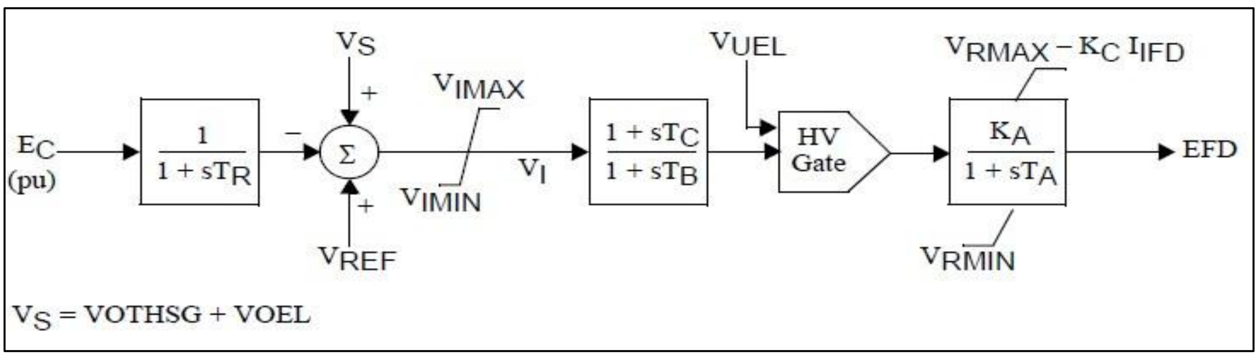
- **Type AC2A: 1992 IEEE type AC2A excitation system model**



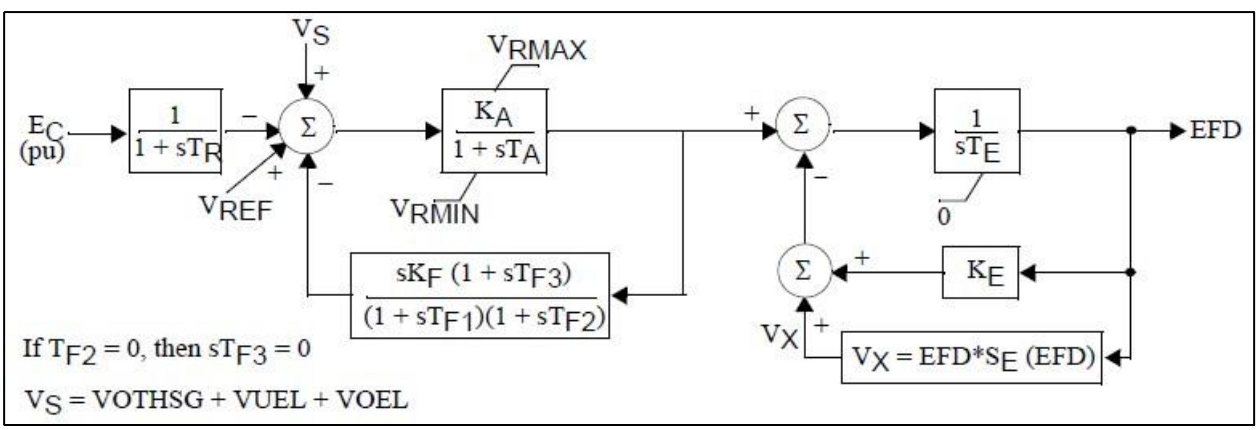
- **Type AC3A: 1992 IEEE type AC3A excitation system model**



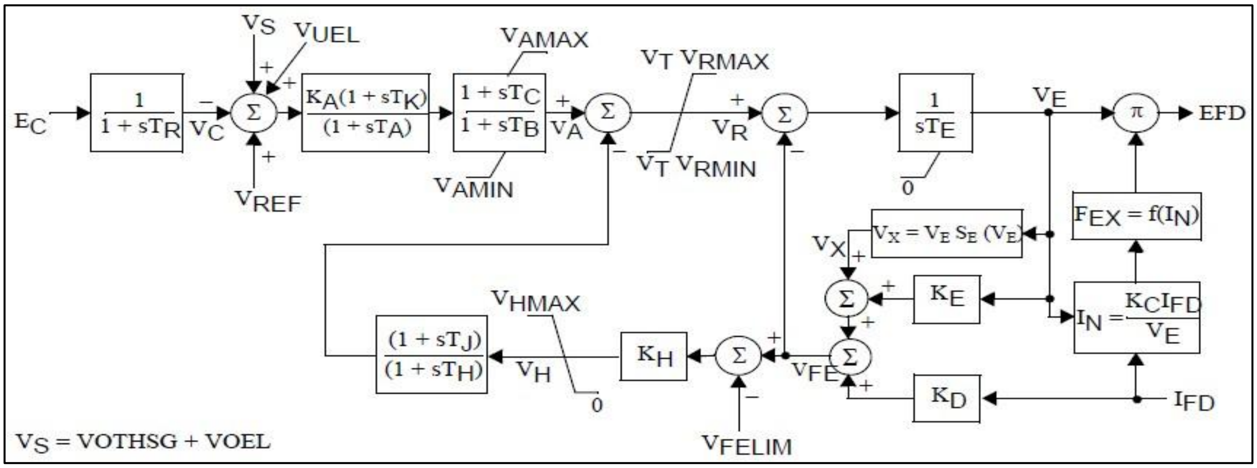
- **Type AC4A: 1992 IEEE type AC4A excitation system model**



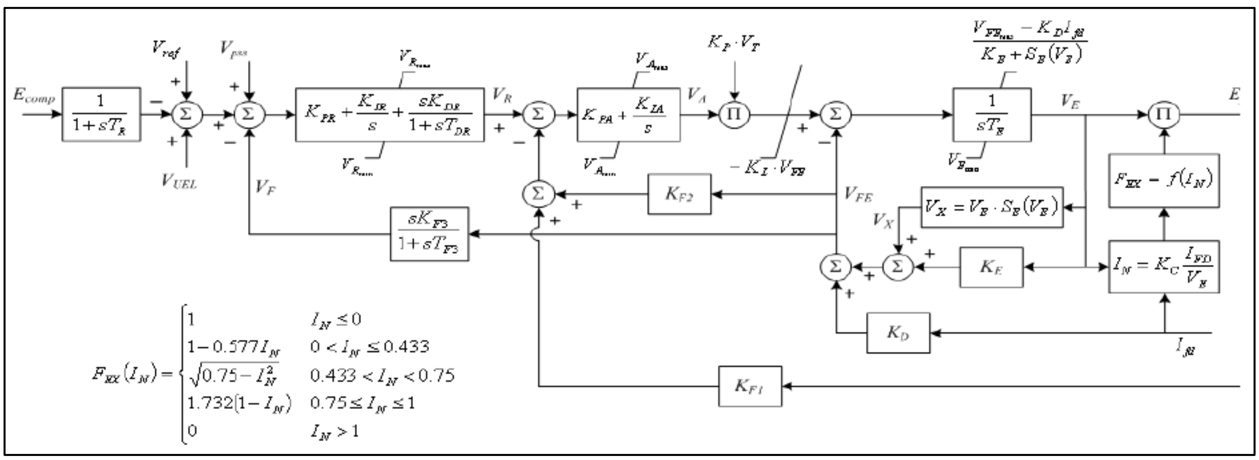
- **Type AC5A: 1992 IEEE type AC5A excitation system model**



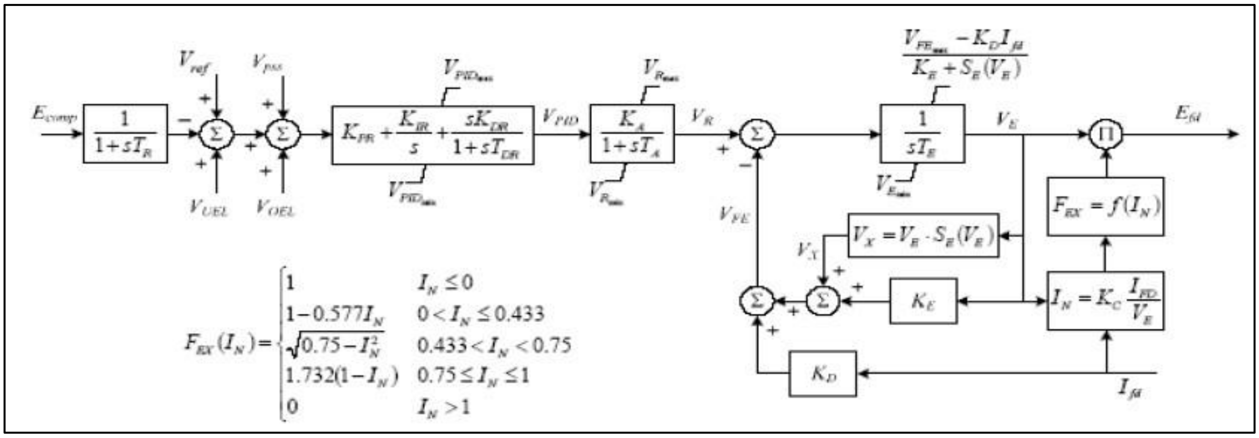
- **Type AC6A: IEEE 421.5 excitation system model**



- **Type AC7B: IEEE 421.5 2005 AC7B excitation system**

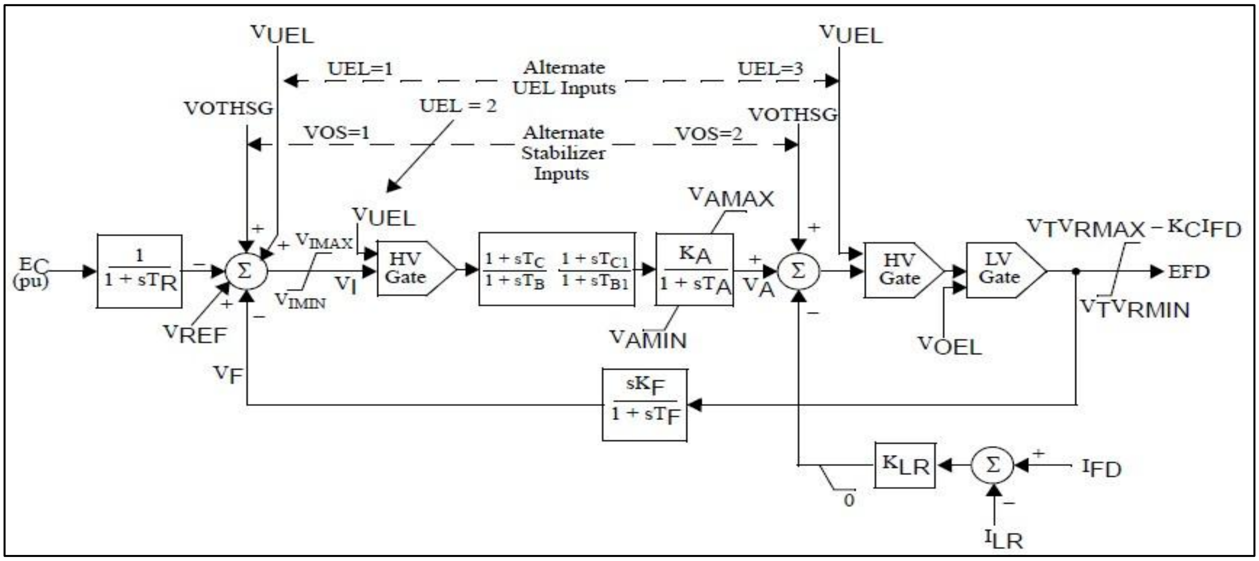


- **Type AC8B: IEEE 421.5 2005 AC8B excitation system**

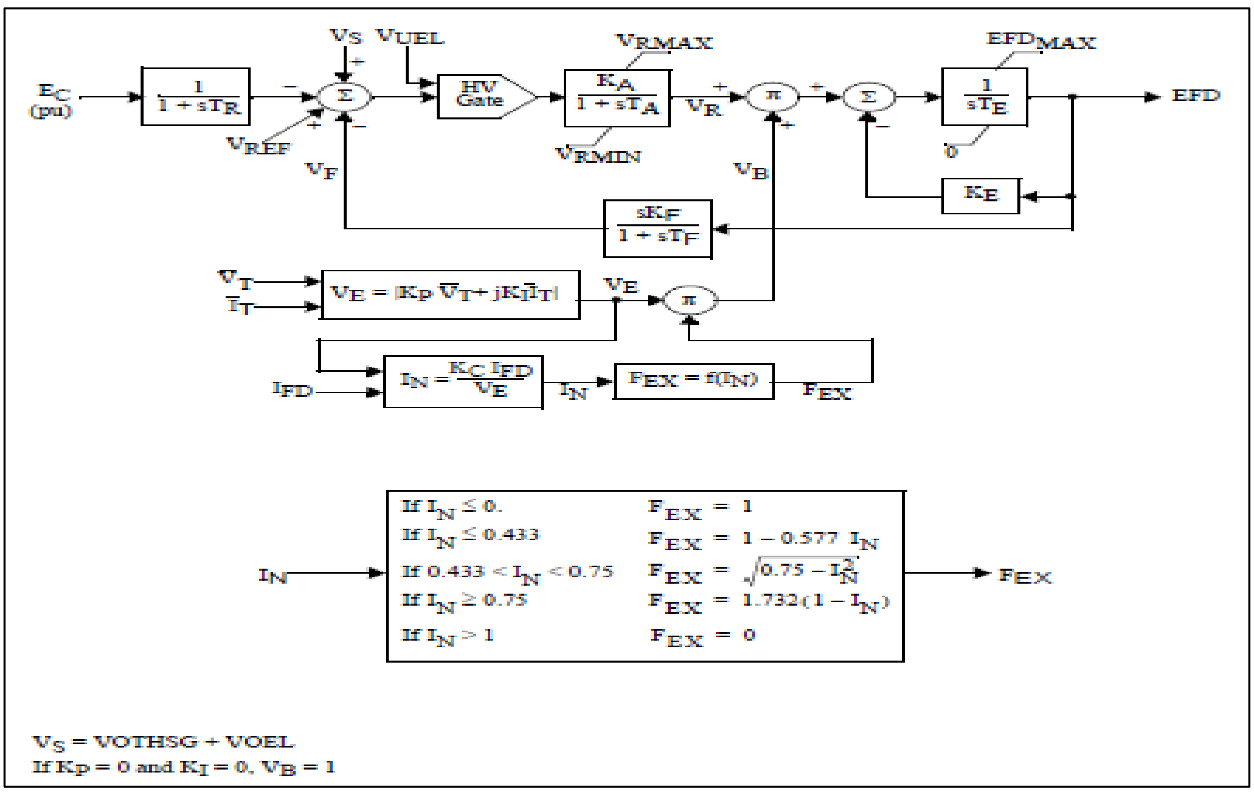


(iii) Commonly Used Static Exciters Generic Models block diagrams:

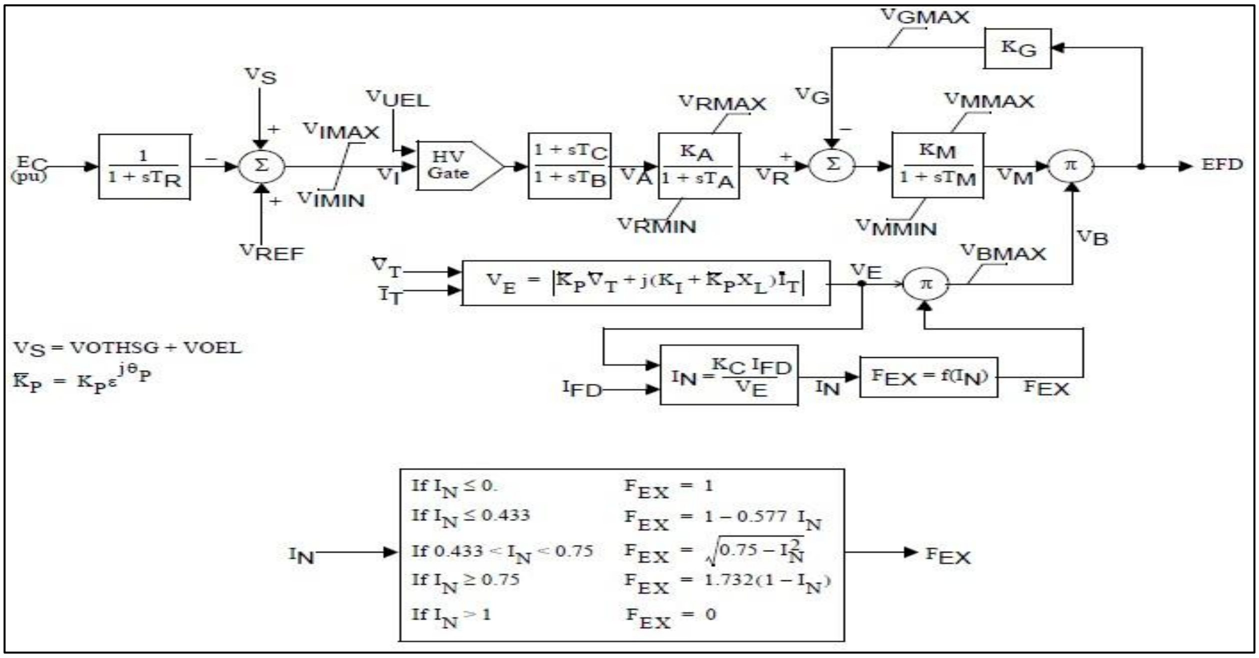
- **Type ST1A: 1992 IEEE type ST1A excitation system model**



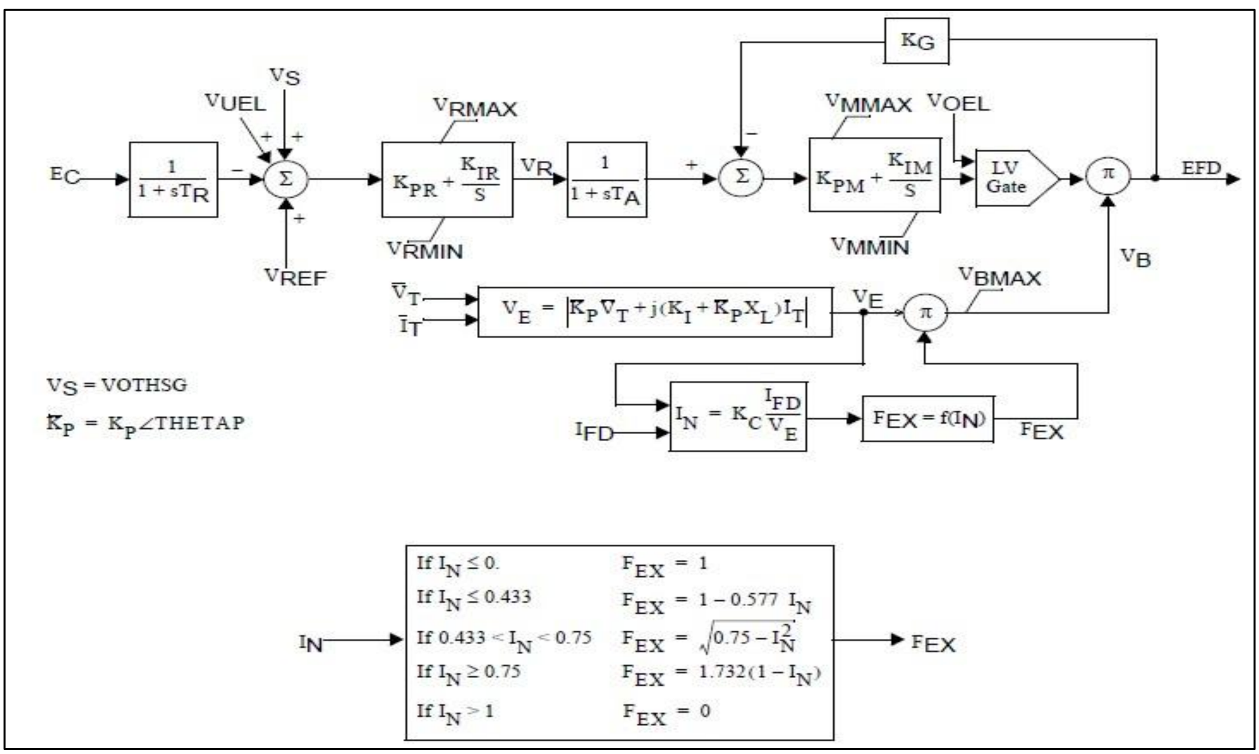
- **Type ST2A: 1992 IEEE type ST2A excitation system model**



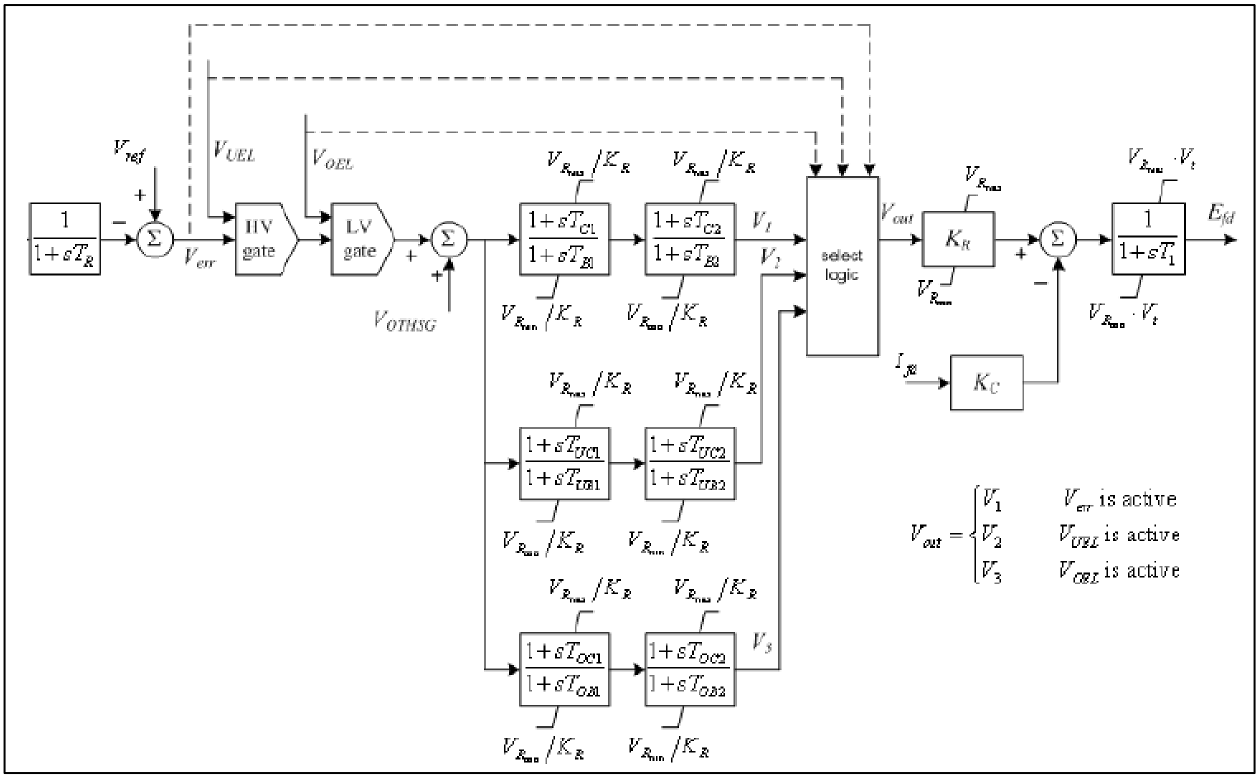
➢ **Type ST3A: 1992 IEEE type ST3A excitation system model**



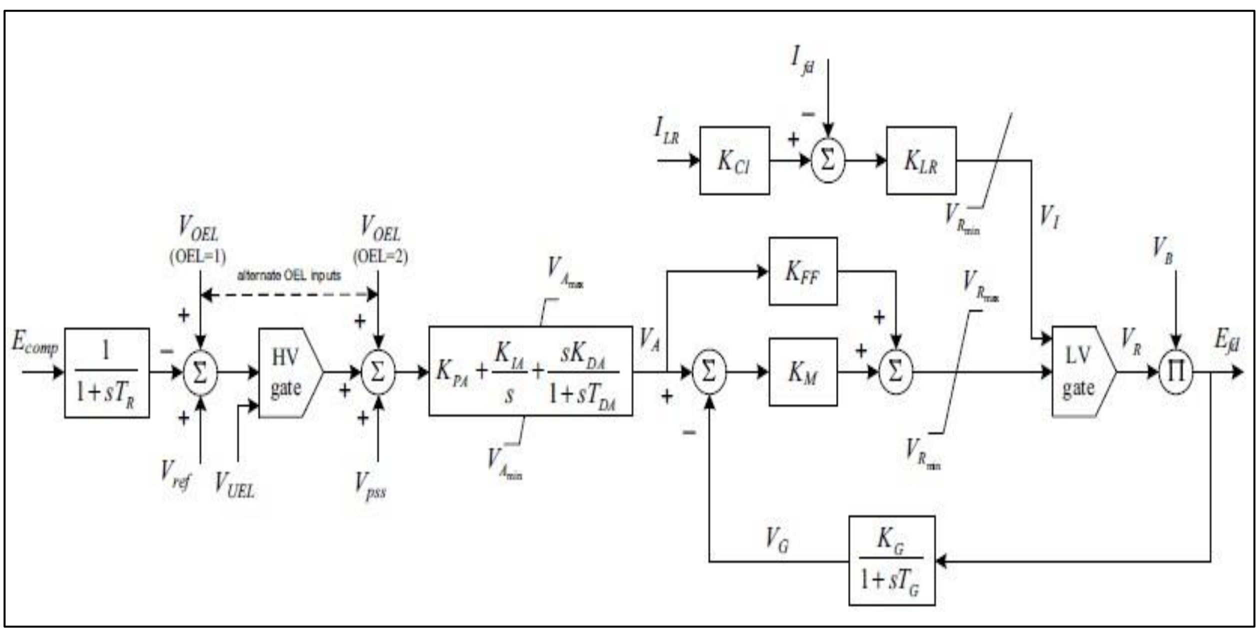
➢ **Type ST4B: IEEE type ST4B potential or compounded source-controlled rectifier exciter**



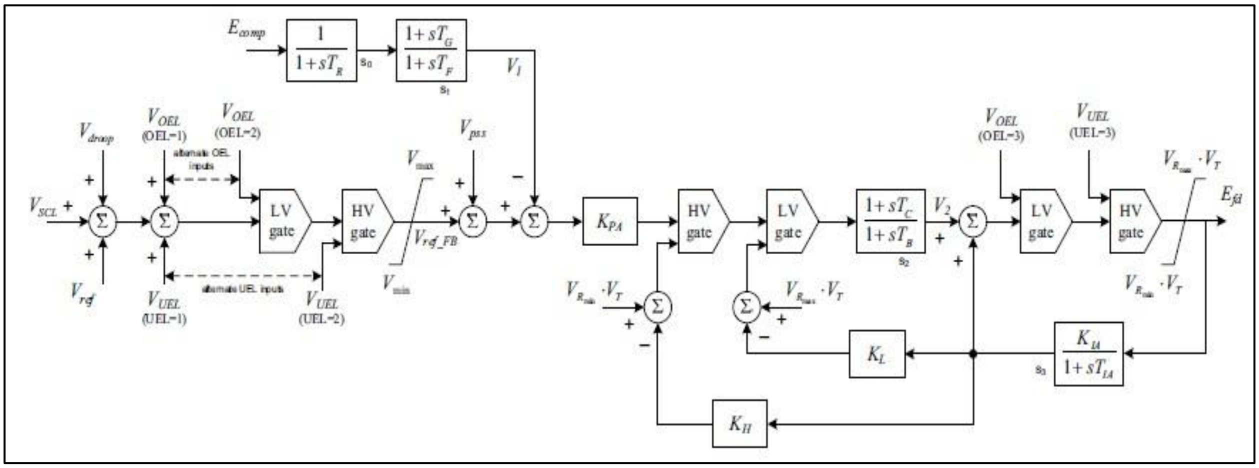
- **Type ST5B: IEEE 421.5 2005 ST5B excitation system**



- **Type ST6B: IEEE 421.5 2005 ST6B excitation system**



➢ **Type ST7B: IEEE 421.5 2005 ST7B excitation system**



Source-PSSE Model Library

4. Power system stabilizer:

The function of the PSS is to add to the unit's characteristic electromechanical oscillations. This is achieved by modulating excitation to develop a component in electrical torque in phase with rotor speed deviations.

The most important aspect when considering a PSS model is the number of inputs. The following table shows the type of models separated based on the inputs:

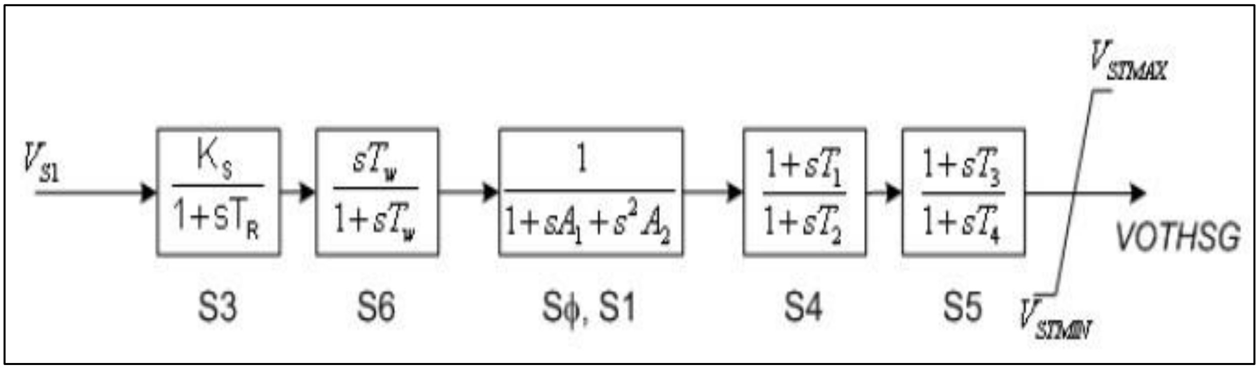
Type	Inputs	Remarks
PSS1A	Single input	Two lead-lags Input can either be speed, frequency or power
PSS2B	Dual input	Integral of accelerating power type stabiliser Speed and Power Most common type Supersedes PSS2A (three versus two lead lags)
PSS3B	Dual input	Power and rotor angular frequency deviation Stabilising signal is a vector sum of processed signals Not very common

Category	Parameter Description	Data
Stabilizer Models		
PSS1A	A1, Filter coefficient	
	A2, Filter coefficient	
	TR, transducer time constant	
	0	
	0	
	0	
	T1, 1st Lead-Lag Derivative Time Constant	
	T2, 1st Lead-Lag Delay Time Constant	
	T3, 2nd Lead-Lag Derivative Time Constant	
	T4, 2nd Lead-Lag Delay Time Constant	
	Tw, Washout Time Constant	
	Tw, Washout Time Constant	
	Ks, input channel gain	
	VSTMAX, Controller maximum output	
	VSTMAX, Controller minimum output	
	0	
	0	
PSS2B	TW1, 1st Washout 1th Time Constant	
	TW2, 1st Washout 2th Time Constant	
	T6, 1st Signal Transducer Time Constant	
	TW3, 2nd Washout 1th Time Constant	
	TW4, 2nd Washout 2th Time Constant	
	T7, 2nd Signal Transducer Time Constant	
	KS2, 2nd Signal Transducer Factor	
	KS3, Washouts Coupling Factor	
	T8, Ramp Tracking Filter Deriv. Time Constant	
	T9, Ramp Tracking Filter Delay Time Constant	
	KS1, PSS Gain	
	T1, 1st Lead-Lag Derivative Time Constant	
	T2, 1st Lead-Lag Delay Time Constant	
	T3, 2nd Lead-Lag Derivative Time Constant	
	T4, 2nd Lead-Lag Delay Time Constant	
	T10, 3rd Lead-Lag Derivative Time Constant	
	T11, 3rd Lead-Lag Delay Time Constant	
	VS1MAX, Input 1 Maximum limit	
	VS1MIN, Input 1 Minimum limit	
	VS2MAX, Input 2 Maximum limit	
	VS2MIN, Input 2 Minimum limit	
	VSTMAX, Controller Maximum Output	
	VSTMIN, Controller Minimum Output	

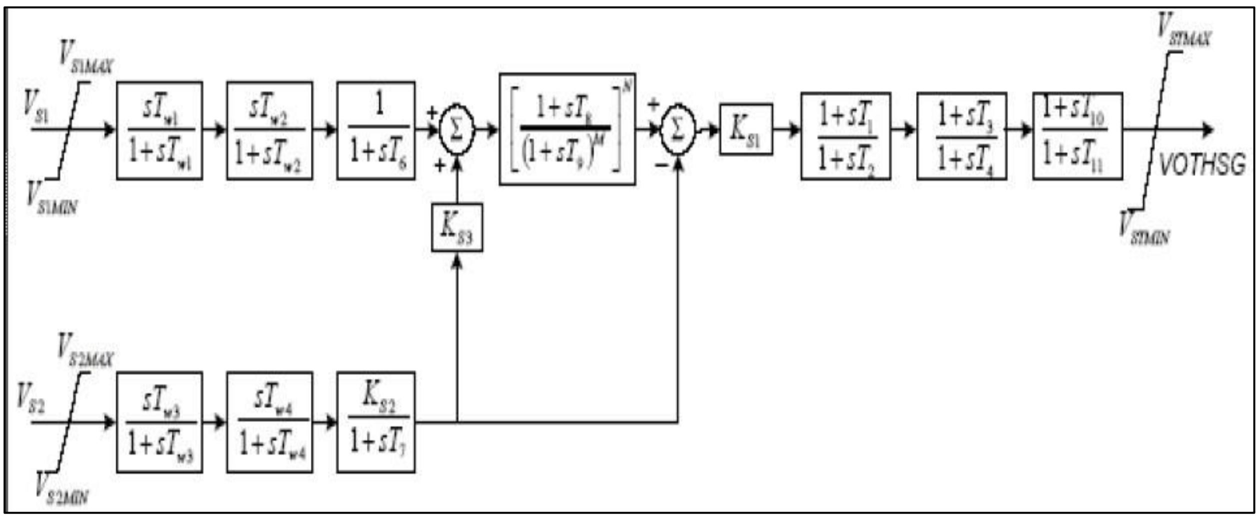
Category	Parameter Description	Data
Stabilizer Models		
	KS1 (pu) (≠0), input channel #1 gain	
	T1 input channel #1 transducer time constant (sec)	
	Tw1 input channel #1 washout time constant (sec)	
	KS2 (pu) (□0), input channel #2 gain	
	T2 input channel #2 transducer time constant (sec)	
	Tw2 input channel #2 washout time constant (sec)	
	Tw3 (0), main washout time constant (sec)	
PSS3B	A1, Filter coefficient	
	A2, Filter coefficient	
	A3, Filter coefficient	
	A4, Filter coefficient	
	A5, Filter coefficient	
	A6, Filter coefficient	
	A7, Filter coefficient	
	A8, Filter coefficient	
	VSTMAX, Controller maximum output	
	VSTMAX, Controller minimum output	

Commonly Used Power System Stabilizer generic models block diagrams:

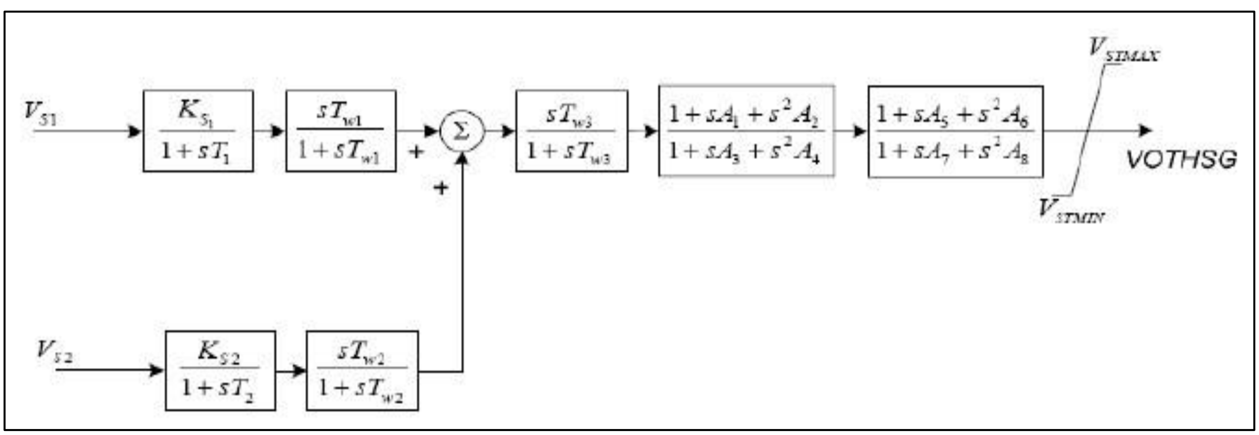
- **PSS1A: IEEE Std. 421.5-2005 PSS1A Single-Input Stabilizer model**



- **PSS2B: IEEE 421.5 2005 PSS2B IEEE dual-input stabilizer model**



- **PSS3B: IEEE Std. 421.5 2005 PSS3B IEEE dual-input stabilizer model**



Source-PSSE Model Library

5. Generic models for turbine-governor:

The following table is a list for common generic models of hydro turbines:

Type	Name	Remarks
HYGOV	Hydro-turbine Governor	Simple hydro model with unrestricted head race and tail race, no surge tank
HYGOVDU	Hydro turbine-governor model with speed dead band	Added asymmetrical deal band
HYGOVM	Hydro-Turbine Governor	Includes detailed representation of surge chamber
WEHGOV	Woodward Electric Hydro Governor Model	Woodward hydro governor with non-linear model for penstock dynamics
HYGOVT	Hydro Turbine-Governor traveling wave model	Travelling-wave solution applied to penstock and tunnel
PIDGOV	Hydro Turbine Governor	Straight forward penstock configuration with PID governor
HYGOVR1	Fourth order lead-lag hydro-turbine	for a unit with digital controls, allows a nonlinear relationship between the gate
TURCZT	Czech hydro or steam turbine governor model	General-purpose hydro and thermal turbine- governor model. Penstock dynamic is not included in the model
TWDM1T	Tail water depression hydro governor model 1	same basic permanent and transient droop elements as the HYGOV model, but it adds a representation for a tail water depression protection system
TWDM2T	Tail water depression hydro governor model 2	Same as TWDM1T and uses a governor proportional-integral-derivative (PID)
WPIDHY	Woodward PID hydro governor model	includes governor controls representing a Woodward PID hydro governor. The model includes a nonlinear gate/power relationship and a linearized
WSHYDD	WECC double derivative hydro governor model	Double-derivative hydro turbine-governor mode. Includes two dead band, also includes a nonlinear gate/power relationship and a linearized turbine/ penstock model
WSHYGP	WECC GP hydro governor plus turbine model	WECC GP hydro turbine-governor model with a PID controller, penstock dynamics are similar to those of the WECC WSHYDD

Source: PSSE Model Library, for models other than the above list refer to

https://w3.usa.siemens.com/smartgrid/us/en/transmission-grid/products/grid-analysis-tools/transmission-system- planning/transmission-system-planning-tab/pages/user-support.aspx

Category	Parameter Description	Data
TURBINE GOVERNOR model		
HYGOV	R, permanent droop	
	r, temporary droop	
	Tr (>0) governor time constant	
	Tf (>0) filter time constant	
	Tg (>0) servo time constant	
	+ VELM, gate velocity limit	
	GMAX, maximum gate limit	
	GMIN, minimum gate limit	
	TW (>0) water time constant	
	At, turbine gain	
	Dturb, turbine damping	
	qNL, no power flow	
HYGOVDU	R, permanent droop	
	r, temporary droop	
	Tr (>0) governor time constant	
	Tf (>0) filter time constant	
	Tg (>0) servo time constant	
	+ VELM, gate velocity limit	
	GMAX, maximum gate limit	
	GMIN, minimum gate limit	
	TW (>0) water time constant	
	At, turbine gain	
	Dturb, turbine damping	
	qNL, no power flow	
	DBH (pu), droop for over-speed, (> 0)	
	DBL (pu), droop for under-speed, (< 0)	
	TRate (MW), turbine rating, if zero, then MBASE used	

Category	Parameter Description	Data
	TURBINE GOVERNOR model	
	Prated, rated turbine power (MW	
	Qrated, rated turbine flow (cfs or cms)	
	Hrated, rated turbine head (ft or m)	
	Grated, gate position at rated conditions (pu)	
	QNL, no power flow (pu of Qrated)	
	R, permanent droop (pu)	
	r, temporary droop (pu)	
	Tr, governor time constant (> 0) (sec)	
	Tf, filter time constant (> 0) (sec)	
	Tg, servo time constant (> 0) (sec)	
	MXGTOR, maximum gate opening rate (pu/sec)	
	MXGTCR, maximum gate closing rate (< 0) (pu/sec)	
	MXBGOR, maximum buffered gate opening rate (pu/sec)	
	MXBGCR, maximum buffered gate closing rate (< 0) (pu/sec)	
	BUFLIM, buffer upper limit (pu)	
	GMAX, maximum gate limit (pu)	
	GMIN, minimum gate limit (pu)	
HYGOVM	RVLVCR, relief valve closing rate (< 0) (pu/sec) or MXJDOR, maximum jet deflector opening rate (pu/sec)	
	RVLMAX, maximum relief valve limit (pu) or MXJDCR, maximum jet deflector closing rate (< 0) (pu/sec)	
	HLAKE, lake head (ft or m)	
	HTAIL, tail head (ft or m)	
	PENL/A, summation of penstock, scroll case and draft tube lengths/ cross sections (> 0) (1/ft or 1/m)	
	PENLOS, penstock head loss coefficient (ft/cfs2 or m/cms2)	
	TUNL/A, summation of tunnel lengths/cross sections (>0) (1/ft or 1/m)	
	TUNLOS, tunnel head loss coefficient (ft/cfs^2 or m/cms^2)	
	SCHARE, surge chamber effective cross section (>0) (ft^2 or m^2)	
	SCHMAX, maximum water level in surge chamber (ft or m)	
	SCHMIN, minimum water level in surge chamber (ft or m)	
	SCHLOS, surge chamber orifice head loss coefficient (ft/cfs^2 or m/cms^2)	
	DAMP1, turbine damping under RPM1	
	RPM1, over speed (pu)	
	DAMP2, turbine damping above RPM2	
	RPM2, over speed (pu)	

Category	Parameter Description	Data
TURBINE GOVERNOR model		
WEHGOV	R-PERM-GATE (Feedback settings)	
	R-PERM-PE (Feedback settings)	
	TPE (sec), Power time constant	
	Kp, Proportional gain	
	KI, Integral gain	
	KD, Derivative gain	
	TD (sec), Derivative time constant	
	TP (sec), Gate servo time constant	
	TDV (sec), Time constant	
	Tg (sec), Gate servo time constant	
	GTMXOP (>0), Max gate opening velocity	
	GTMXCL (<0), Max gate closing velocity	
	GMAX, Maximum governor output	
	GMIN, Minimum governor output	
	DTURB, Turbine damping factor	
	TW (sec), Water inertia time constant	
	Speed Dead Band (DBAND)	
	DPV, Governor limit factor	
	DICN, Gate limiter modifier	
	GATE 1	
	GATE 2	
	GATE 3	
	GATE 4	
	GATE 5	
	FLOW G1	
	FLOW G2	
	FLOW G3	
	FLOW G4	
	FLOW G5	
	FLOW P1	
	FLOW P2	
	FLOW P3	
	FLOW P4	
	FLOW P5	
	FLOW P6	
	FLOW P7	
	FLOW P8	
	FLOW P9	
	FLOW P10	
	PMECH1	

Category	Parameter Description	Data
TURBINE GOVERNOR model		
WEHGOV	PMECH2	
	PMECH3	
	PMECH4	
	PMECH5	
	PMECH6	
	PMECH7	
	PMECH8	
	PMECH9	
	PMECH10	
HYGOVT	Prated, rated turbine power (MW)	
	Qrated, rated turbine flow (cfs or cms)	
	Hrated, rated turbine head (ft or m)	
	Grated, gate position at rated conditions (pu)	
	QNL, no power flow (pu of Qrated)	
	R, permanent droop	
	r, temporary droop (pu)	
	Tr, governor time constant (> 0) (sec)	
	Tf, filter time constant (> 0) (sec)	
	Tg, servo time constant (> 0) (sec)	
	MXGTOR, maximum gate opening rate (pu/sec)	
	MXGTCR, maximum gate closing rate (< 0) (pu/sec)	
	MXBGOR, maximum buffered gate opening rate (pu/sec)	
	MXBGCR, maximum buffered gate closing rate (< 0) (pu/sec)	
	BUFLIM, buffer upper limit (pu)	
	GMAX, maximum gate limit (pu)	
	GMIN, minimum gate limit (pu)	
	RVLVCR, relief valve closing rate (< 0) (pu/sec) or MXJDOR, maximum jet deflector opening rate (pu/sec)	
	RVLMAX, maximum relief valve limit (pu) or MXJDCR, maximum jet deflector closing rate (< 0) (pu/sec)	
	HLAKE, lake head (ft or m)	
	HTAIL, tail head (ft or m)	
	PENLGTH, penstock length (ft or m)	
	PENLOS, penstock head loss coefficient (ft/cfs2 or m/cms2)	
	TUNLGTH, tunnel length (ft or m)	
	TUNLOS, tunnel head loss coefficient (ft/cfs2 or m/cms2)	
	SCHARE, surge chamber effective cross section (>0) (ft2 or m2)	
	SCHMAX, maximum water level in surge chamber (ft or m)	
	SCHMIN, minimum water level in surge chamber (ft or m)	
	SCHLOS, surge chamber orifice head loss coefficient (ft/cfs2 or m/cms2)	
	DAMP1, turbine damping under RPM1	
	RPM1, overspeed (pu)	

Category	Parameter Description	Data
TURBINE GOVERNOR model		
HYGOVT	DAMP2, turbine damping above RPM2	
	RPM2, overspeed (pu)	
	PENSPD, penstock wave velocity (>0) (ft/sec or m/sec)	
	PENARE, penstock cross section (>0) (ft2 or m2)	
	TUNSPD, tunnel wave velocity (>0) (ft/sec or m/sec)	
	TUNARE, tunnel cross section (>0) (ft2 or m2)	
PIDGOV	Rperm, permanent drop, pu	
	Treg (sec), speed detector time constant	
	Kp, proportional gain, pu/sec	
	Ki, reset gain, pu/sec	
	Kd, derivative gain, pu	
	Ta (sec) > 0, controller time constant	
	Tb (sec) > 0, gate servo time constant	
	Dturb, turbine damping factor, pu	
	G0, gate opening at speed no load, pu	
	G1, intermediate gate opening, pu	
	P1, power at gate opening G1, pu	
	G2, intermediate gate opening, pu	
	P2, power at gate opening G2, pu	
	P3, power at full opened gate, pu	
	Gmax, maximum gate opening, pu	
	Gmin, minimum gate opening, pu	
	Atw > 0, factor multiplying Tw, pu	
	Tw (sec) > 0, water inertia time constant	
	Velmax, minimum gate opening velocity, pu/sec	
	Velmin < 0, minimum gate closing velocity, pu/sec	
HYGOVR1	db1, Intentional dead band width, Hz	
	Err, deadband hysteresis (p.u.)	
	Td (sec), Input filter time constant, s	
	T1 (sec), Lead time constant 1, s	
	T2 (sec) q, Lag time constant 1, s	
	T3 (sec), Lead time constant 2, s	
	T4 (sec), Lag time constant 2, s	
	T5 (sec), Lead time constant 3, s	
	T6 (sec), Lag time constant 3, s	
	T7 (sec), Lead time constant 4, s	
	T8 (sec), Lag time constant 4, s	
	KP, proportional gain	
	R, Steady-state droop, p.u.	
	Tt, Power feedback time constant, s	

Category	Parameter Description	Data
TURBINE GOVERNOR model		
HYGOVR1	KG, Gate servo gain, p.u.	
	TP (sec), Gate servo time constant, s	
	VELOPEN, Maximum gate opening velocity, p.u./s	
	VELCLOSE, Maximum gate closing velocity, p.u./s (<0)	
	PMAX, Maximum gate opening, p.u. of mwcap	
	PMIN, Minimum gate opening, p.u. of mwcap	
	db2, Unintentional deadband, MW	
	TW (>0) water time constant	
	At, turbine gain	
	Dturb, turbine damping	
	qNL, no power flow	
	Trate (Turbine MW rating)	
TURCZT	fDEAD (pu), Frequency Dead Band	
	fMIN (pu), Frequency Minimum Deviation	
	fMAX (pu), Frequency Maximum Deviation	
	KKOR (pu), Frequency Gain	
	KM > 0 (pu), Power Measurement Gain	
	KP (pu), Regulator Proportional Gain	
	SDEAD (pu), Speed Dead Band	
	KSTAT (pu), Speed Gain	
	KHP (pu), High Pressure Constant	
	TC (sec), Measuring transducer time constant	
	T 1 (sec), Regulator Integrator Time Constant	
	TEHP (sec), Hydro Converter Time Constant	
	TV > 0 (sec), Regulation Valve Time Constant	
	THP (sec), High Pressure Time Constant	
	TR (sec), Reheater time constant	
	TW (sec), Water Time Constant	
	NTMAX (pu), Power Regulator-Integrator Maximum Limiter	
	NTMIN (pu), Power Regulator-Integrator Minimum Limiter	
	GMAX (pu), Valve Maximum Open	
	GMIN (pu), Valve Minimum Open	
	VMIN (pu/sec), Valve Maximum Speed Close	
	VMAX (pu/sec), Valve Maximum Speed Open	
TWDM1T	R, permanent droop	
	r, temporary droop	
	Tr, governor time constant (>0)	
	Tf, filter time constant (>0)	
	Tg, servo time constant (>0)	
	VELMX, open gate velocity limit (pu/sec)	

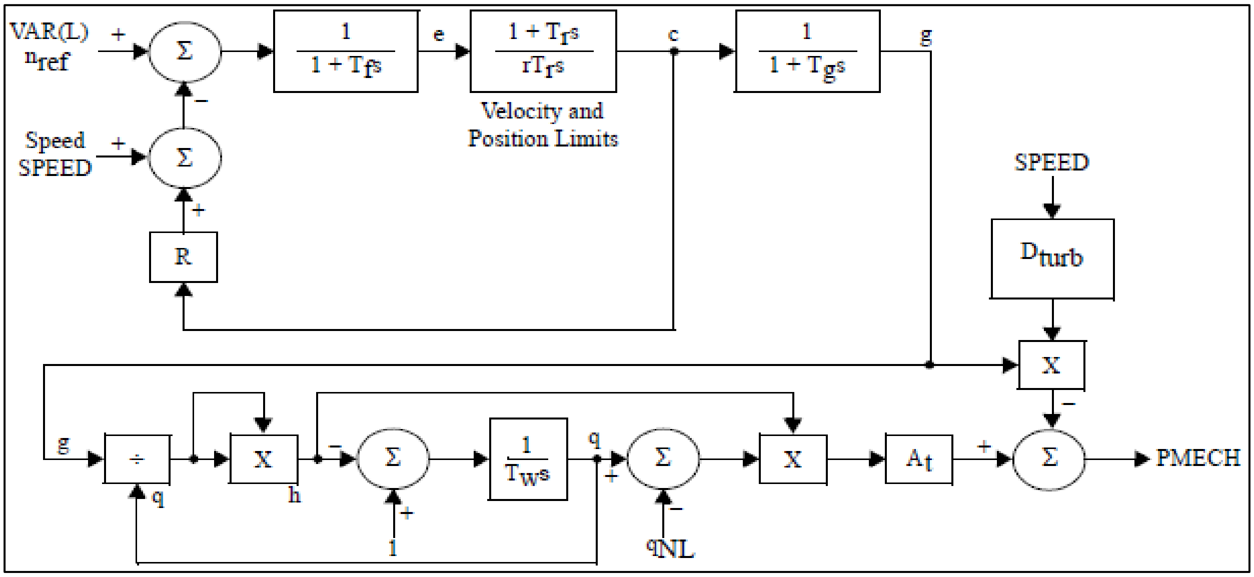
Category	Parameter Description	Data
TURBINE GOVERNOR model		
TWDM1	VELMN, close gate velocity limit (pu/sec) (<0)	
	GMAX, maximum gate limit	
	GMIN, minimum gate limit	
	TW, water time constant (sec) (>0)	
	At, turbine gain	
	Dturb, turbine damping	
	qNL, no power flow	
	F1, frequency deviation (pu)	
	TF1, time delay (sec)	
	F2, frequency deviation (pu)	
	sF2, frequency (pu/sec)	
	TF2, time delay (sec)	
	GMXRT, rate with which GMAX changes when TWD is tripped (pu/sec)	
	NREF, setpoint frequency deviation (pu)	
	Tft, frequency filter time constant (>0	
TWDM2	TREG (sec), governor time constant (s)	
	Reg, permanent droop (p.u. on generator MVA rating)	
	KP, controller proportional gain (p.u.)	
	KI, controller integral gain (p.u./s)	
	KD, controller derivative gain (p.u.-s)	
	TA (sec) (> 0), controller time constant (s)	
	TB (sec) (> 0), controller time constant (s)	
	VELMX (pu/sec), open gate velocity limit (p.u./s)	
	VELMN (pu/sec) (> 0), close gate velocity limit (p.u./s)	
	GATMX (pu), maximum gate limit (p.u.)	
	GATMN (pu), minimum gate limit (p.u.)	
	TW (sec) (> 0), water time constant (s)	
	At, turbine gain	
	qNL, flow rate at no load (p.u.)	
	Dturb, turbine damping factor	
	F1, frequency deviation (pu)	
	TF1, time delay (sec)	
	F2, frequency deviation (pu)	
	sF2, frequency (pu/sec)	
	TF2, time delay (sec)	
	PREF, power reference (pu)	
	Tft, frequency filter time constant (sec) (>0)	

Category	Parameter Description	Data
TURBINE GOVERNOR model		
WPIDHY	TREG (sec), governor time constant (s)	
	REG1, permanent droop (p.u. on generator MVA base)	
	KP, controller proportional gain (p.u.)	
	KI, controller integral gain (p.u./s)	
	KD, controller derivative gain (p.u./s)	
	TA (>0) (sec), controller time constant (s)	
	TB (>0) (sec), controller time constant (s)	
	VELMX (>0), open gate velocity limit (p.u./s)	
	VELMN (<0), close gate velocity limit (p.u./s)	
	GATMX, maximum gate limit (p.u.)	
	GATMN, minimum gate limit (p.u.)	
	TW (>0) (sec), water time constant (s)	
	PMAX, maximum gate position (p.u.)	
	PMIN, minimum gate position (p.u.)	
	D	
	G0, gate position at no load (p.u.)	
	G1, first gate intermediate position (p.u.)	
	P1, power at gate position G1 (p.u. on generator MVA rating)	
	G2, second gate intermediate position (p.u.)	
	P2, power at gate position G2 (p.u. on generator MVA rating)	
	P3, power at fully open gate (p.u. on generator MVA rating)	
WSHYDD	db1, deadband width (p.u.)	
	Err, deadband hysteresis (p.u.)	
	Td (sec), input filter time constant (s)	
	K1, derivative gain (p.u.)	
	Tf (sec), derivative time constant (s)	
	KD, double derivative gain (p.u.)	
	KP, integral gain (p.u.)	
	R, droop (p.u. on Trate)	
	Tt, power feedback time constant (s)	
	KG, gate servo gain (p.u.)	
	TP (sec), gate servo time constant (s)	
	VELOPEN (>0), maximum gate opening rate (p.u./s)	
	VELCLOSE (>0), maximum gate closing rate (p.u./s)	
	PMAX, maximum gate opening (p.u.)	
	PMIN, minimum gate opening (p.u.)	
	db2, deadband (p.u.)	
	GV1, coordinate of power-gate look-up table (p.u. gate)	
	PGV1, coordinate of power-gate look-up table (p.u. power)	
	GV2, coordinate of power-gate look-up table (p.u. gate)	

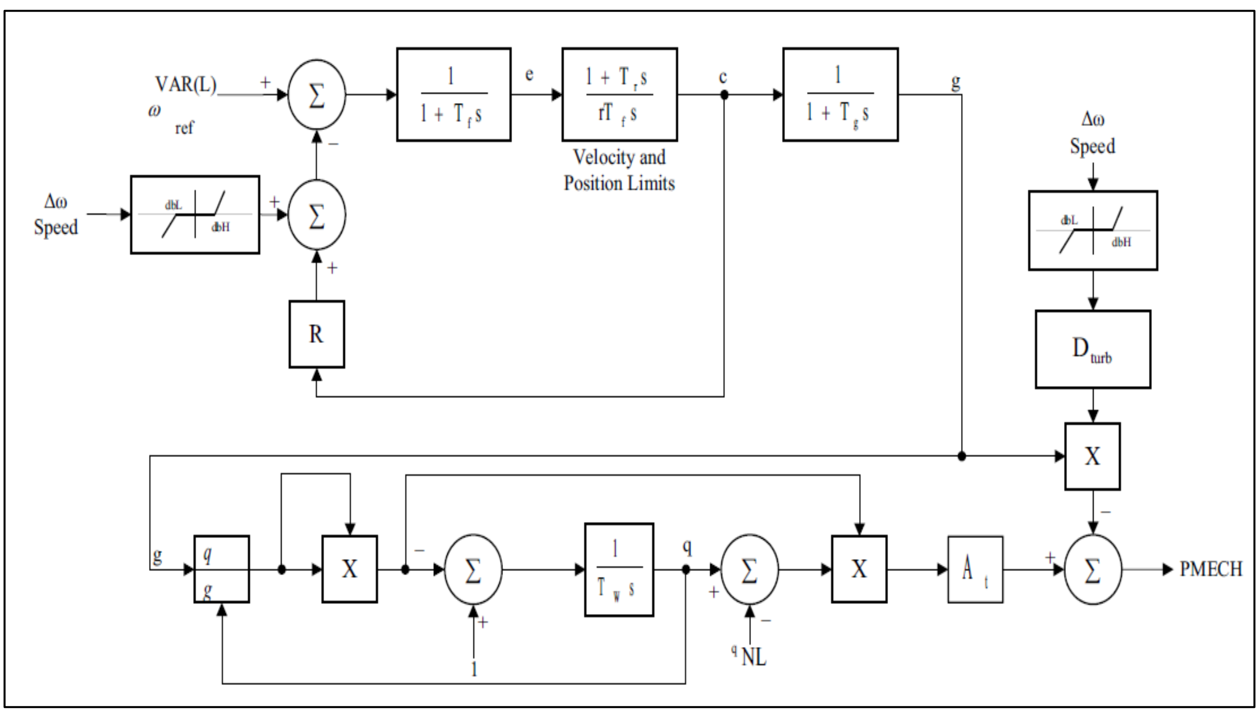
Category	Parameter Description	Data
TURBINE GOVERNOR model		
WSHYDD	PGV2, coordinate of power-gate look-up table (p.u. power)	
	GV3, coordinate of power-gate look-up table (p.u. gate)	
	PGV3, coordinate of power-gate look-up table (p.u. power)	
	GV4, coordinate of power-gate look-up table (p.u. gate)	
	PGV4, coordinate of power-gate look-up table (p.u. power)	
	GV5, coordinate of power-gate look-up table (p.u. gate)	
	PGV5, coordinate of power-gate look-up table (p.u. power)	
	Aturb, turbine lead time constant multiplier	
	Bturb (> 0), turbine lag time constant multiplier	
	Tturb (> 0) (sec), turbine time constant (s)	
	Trate, turbine rating (MW)	
WSHYGP	db1, deadband width (p.u.)	
	Err, deadband hysteresis (p.u.)	
	Td (sec), input filter time constant (s)	
	K1, derivative gain (p.u.)	
	Tf (sec), derivative time constant (s)	
	KD, double derivative gain (p.u.)	
	KP, integral gain (p.u.)	
	R, droop (p.u. on Trate)	
	Tt, power feedback time constant (s)	
	KG, gate servo gain (p.u.)	
	TP (sec), gate servo time constant (s)	
	VELOPEN (>0), maximum gate opening rate (p.u./s)	
	VELCLOSE (>0), maximum gate closing rate (p.u./s)	
	PMAX, maximum gate opening (p.u.)	
	PMIN, minimum gate opening (p.u.)	
	db2, deadband (p.u.)	
	GV1, coordinate of power-gate look-up table (p.u. gate)	
	PGV1, coordinate of power-gate look-up table (p.u. power)	
	GV2, coordinate of power-gate look-up table (p.u. gate)	
	PGV2, coordinate of power-gate look-up table (p.u. power)	
	GV3, coordinate of power-gate look-up table (p.u. gate)	
	PGV3, coordinate of power-gate look-up table (p.u. power)	
	GV4, coordinate of power-gate look-up table (p.u. gate)	
	PGV4, coordinate of power-gate look-up table (p.u. power)	
	GV5, coordinate of power-gate look-up table (p.u. gate)	
	PGV5, coordinate of power-gate look-up table (p.u. power)	
	Aturb, turbine lead time constant multiplier	
	Bturb (> 0), turbine lag time constant multiplier	
	Tturb (> 0) (sec), turbine time constant (s)	
	Trate, turbine rating (MW)	

Commonly Used Hydro Turbine Generic Models Block Diagrams:

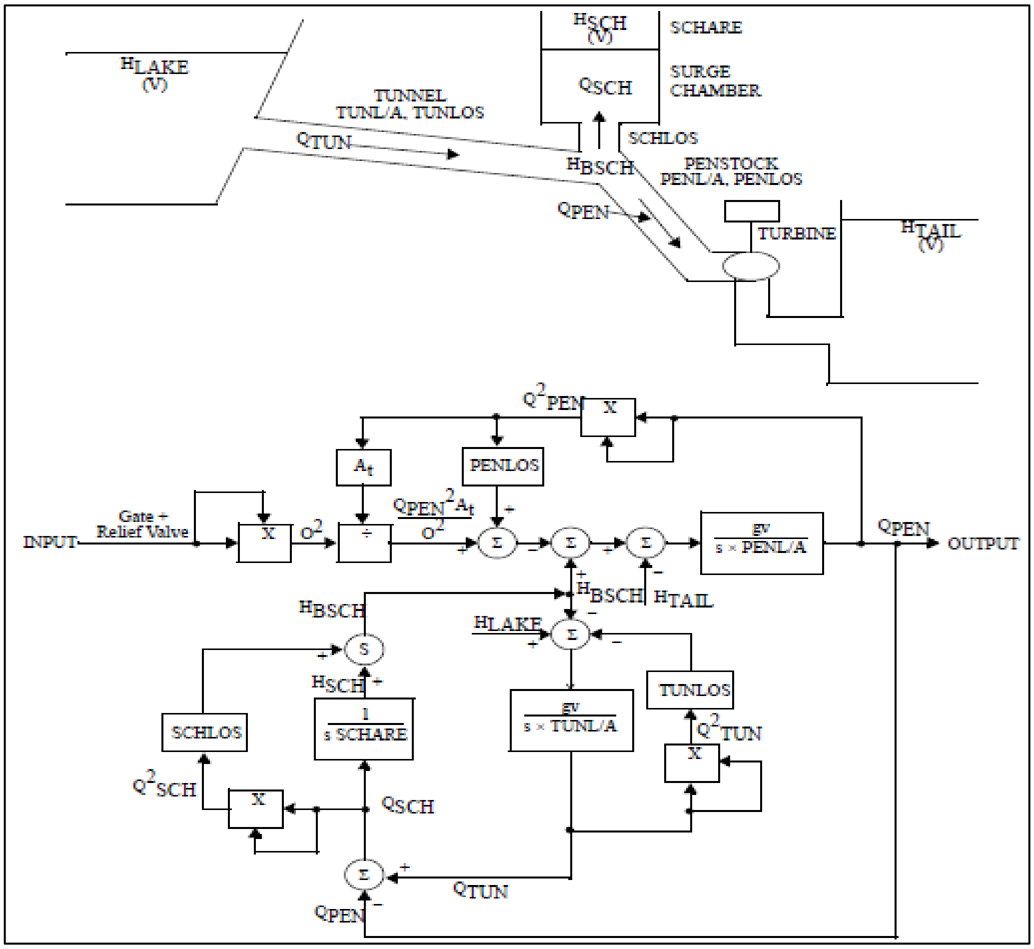
- **HYGOV: Hydro Turbine-Governor**



- **HYGOVDU: Hydro Turbine-Governor**

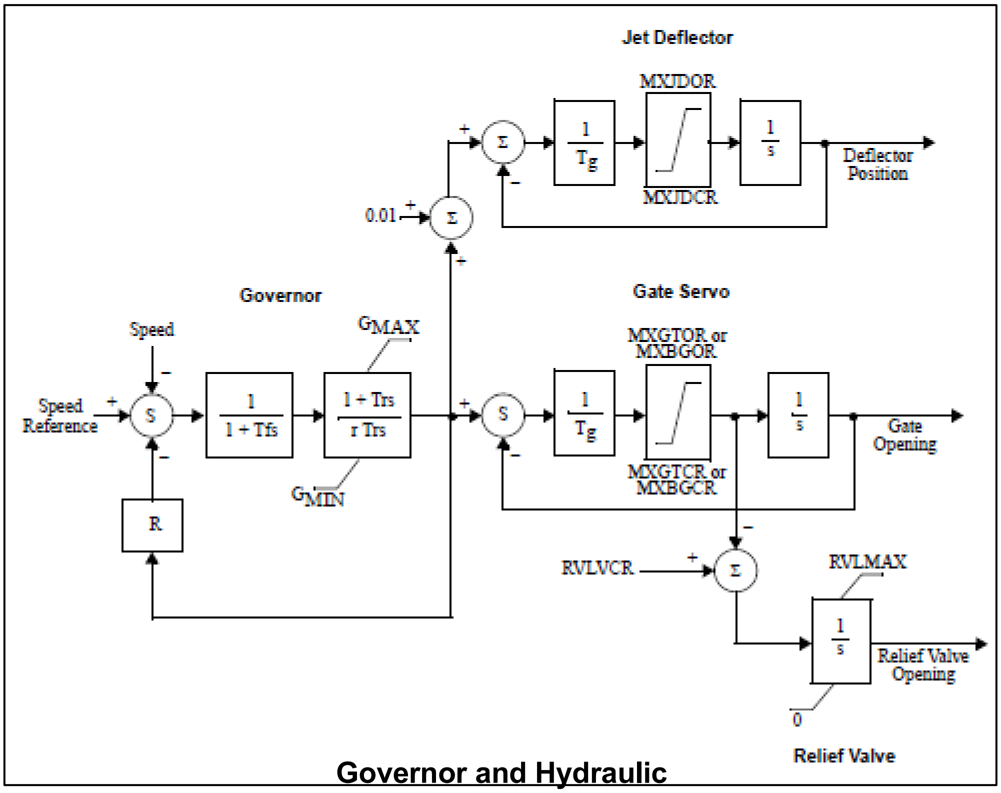


- **HYGOVM: Hydro Turbine-Governor Lumped Parameter Model**

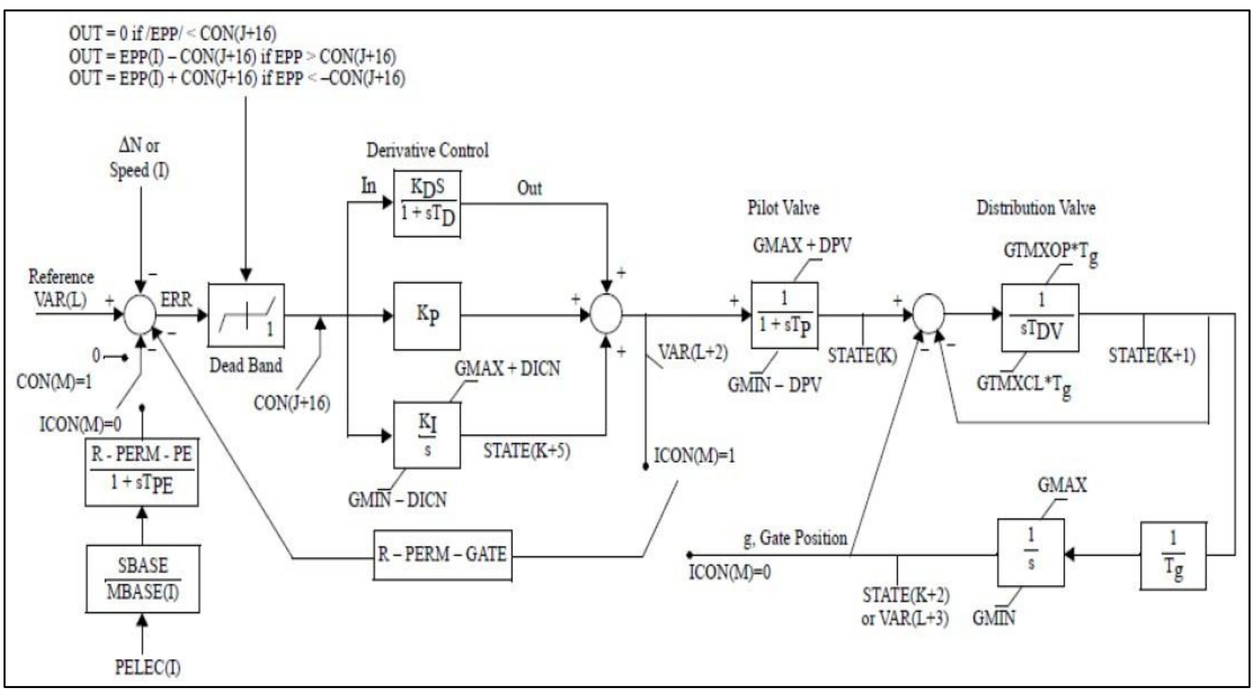


gv	Gravitational acceleration	At	Turbine flow gain
TUNL/A	Summation of length/cross section of tunnel	O	Gate + relief valve opening
SCHARE	Surge chamber cross section	HSCH	Water level in surge chamber
PENLOS	Penstock head loss coefficient	QPEN	Penstock flow
TUNLOS	Tunnel head loss coefficient	QTUN	Tunnel flow
FSCH	Surge chamber orifice head loss coefficient	QSCH	Surge chamber flow
PENL/A	Summation of length/cross section of penstock, scroll case and draft tube		

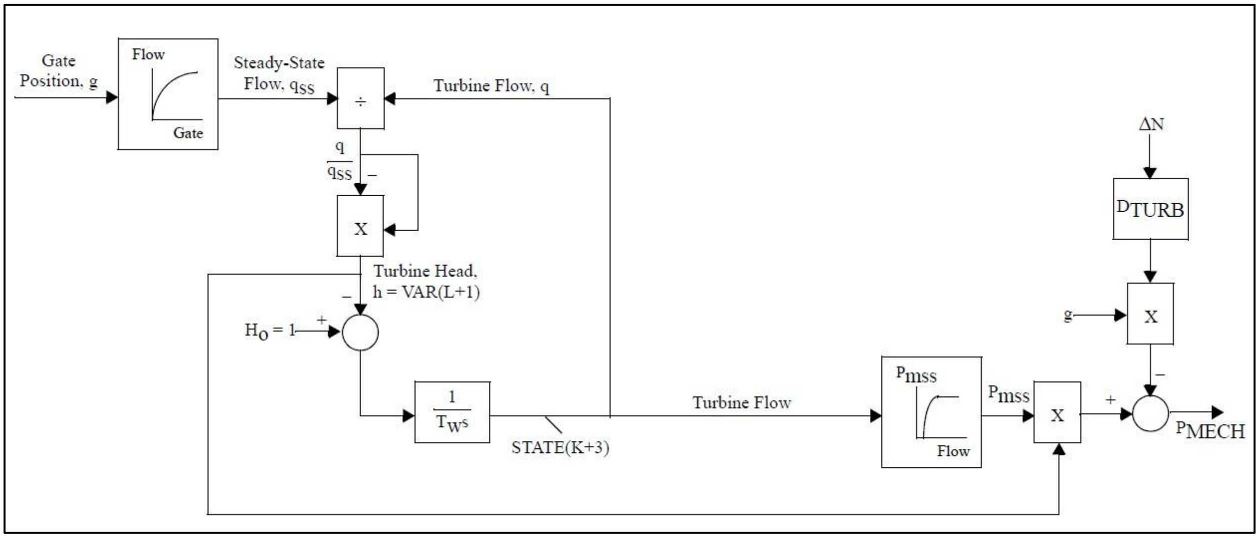
- **WEHGOV: Woodward Electric Hydro Governor Model**



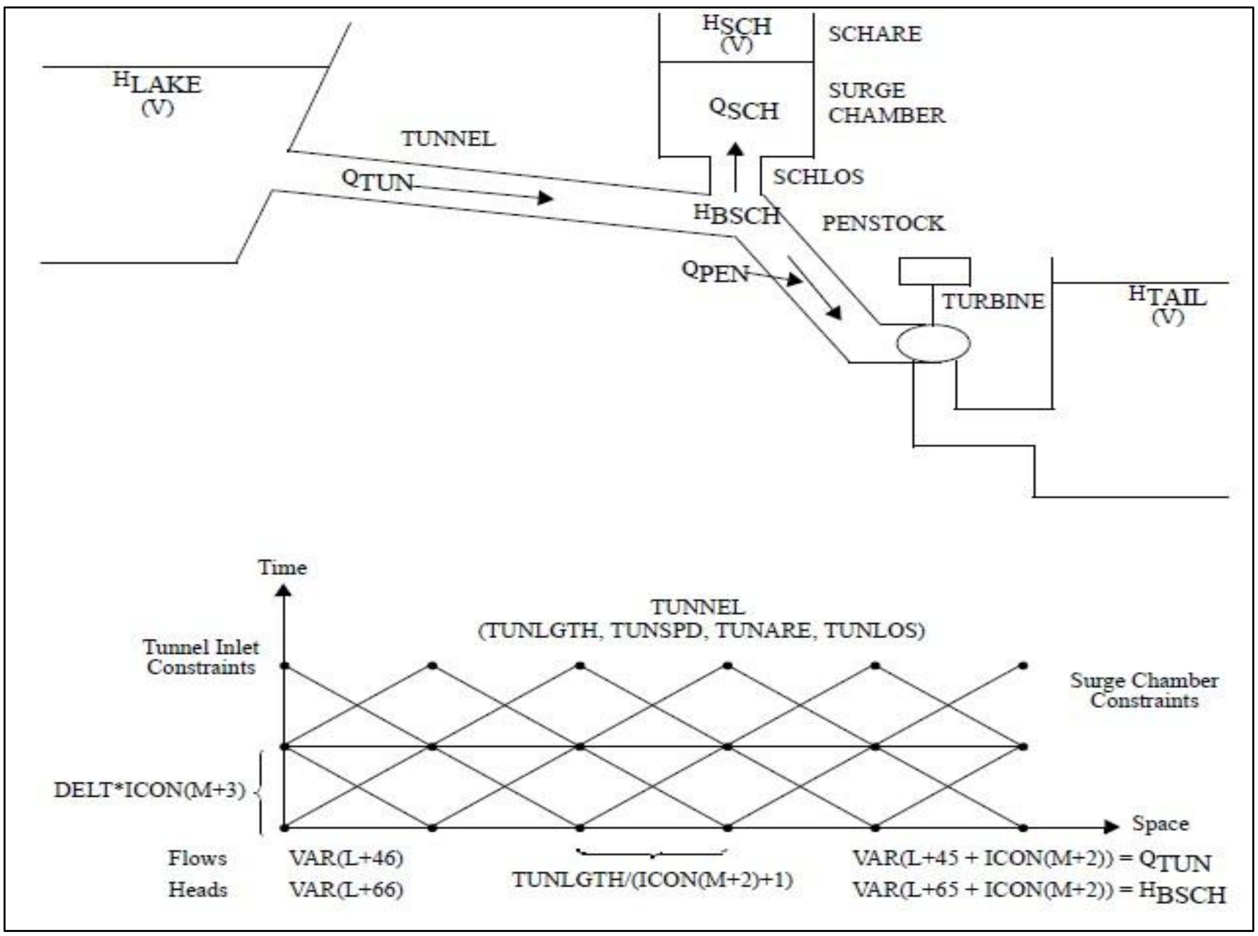
Governor and Hydraulic Actuators

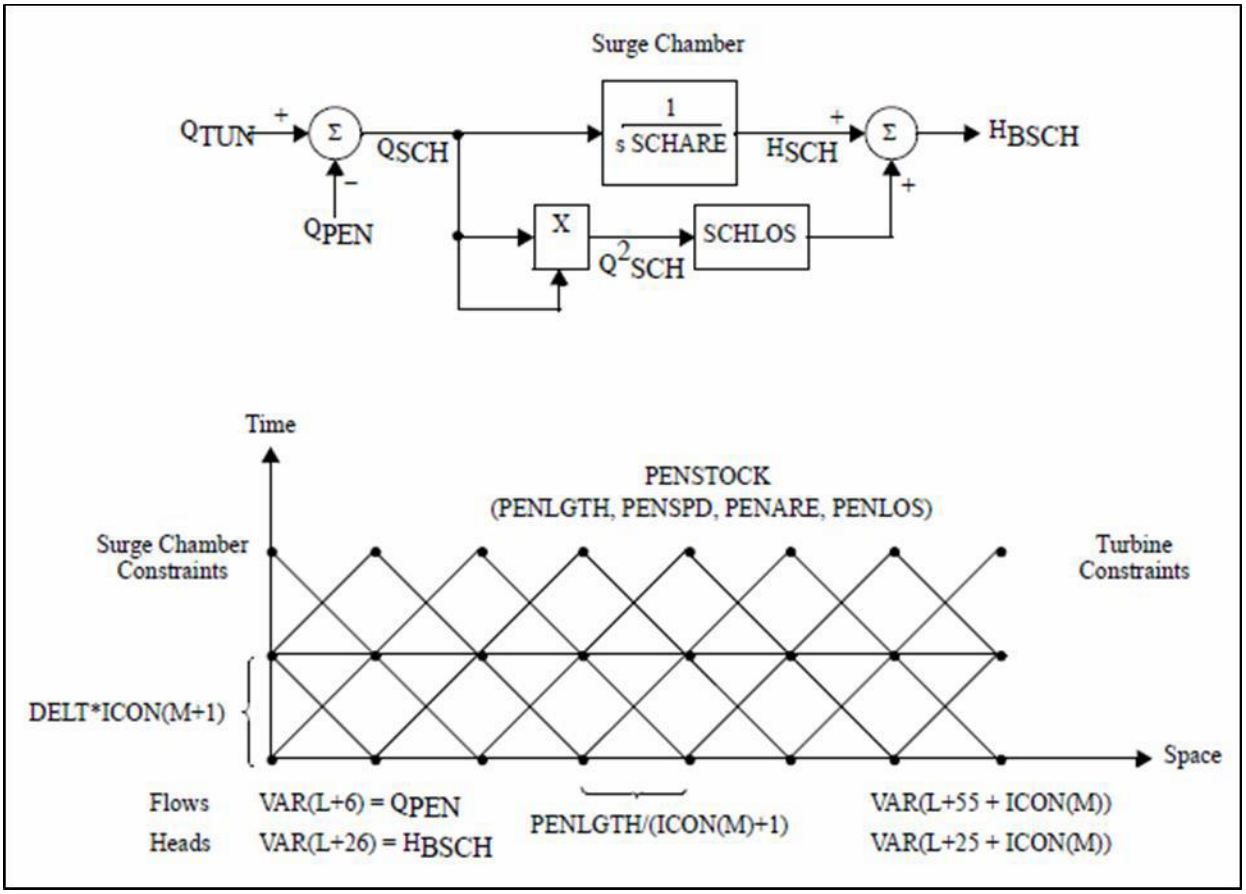


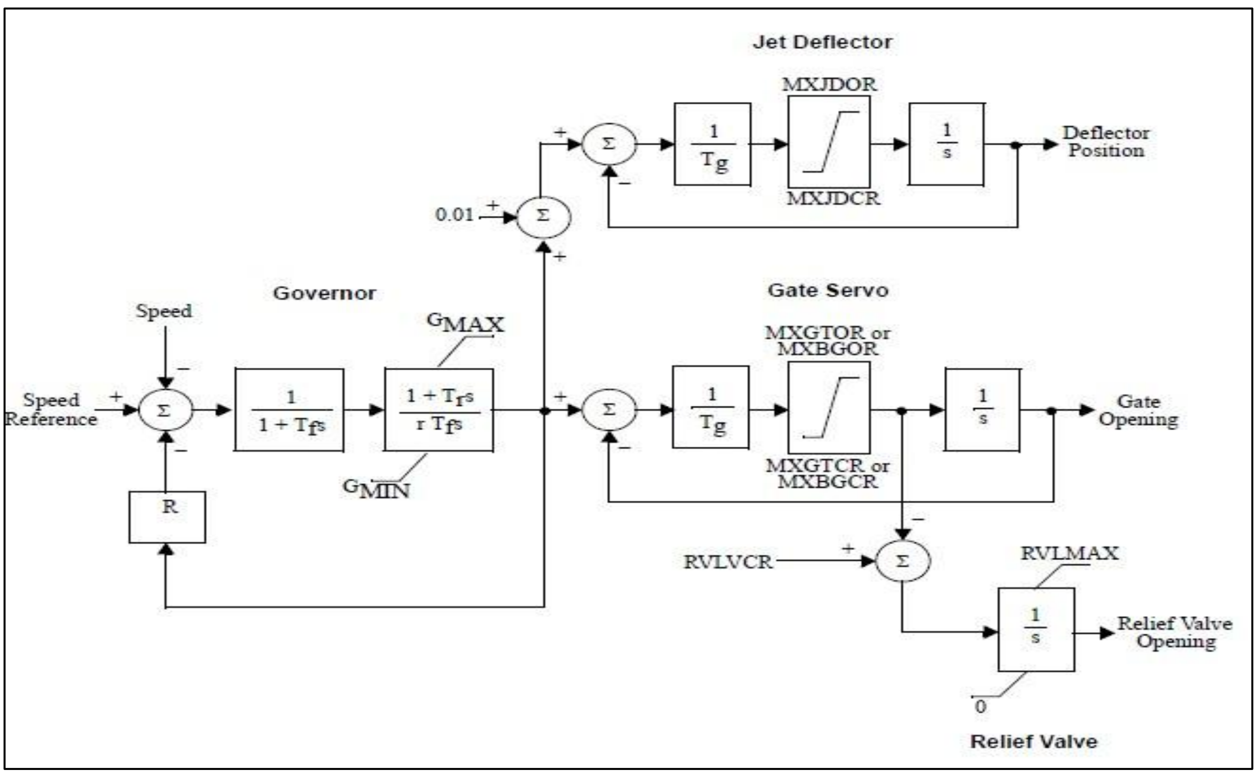
Turbine Dynamics



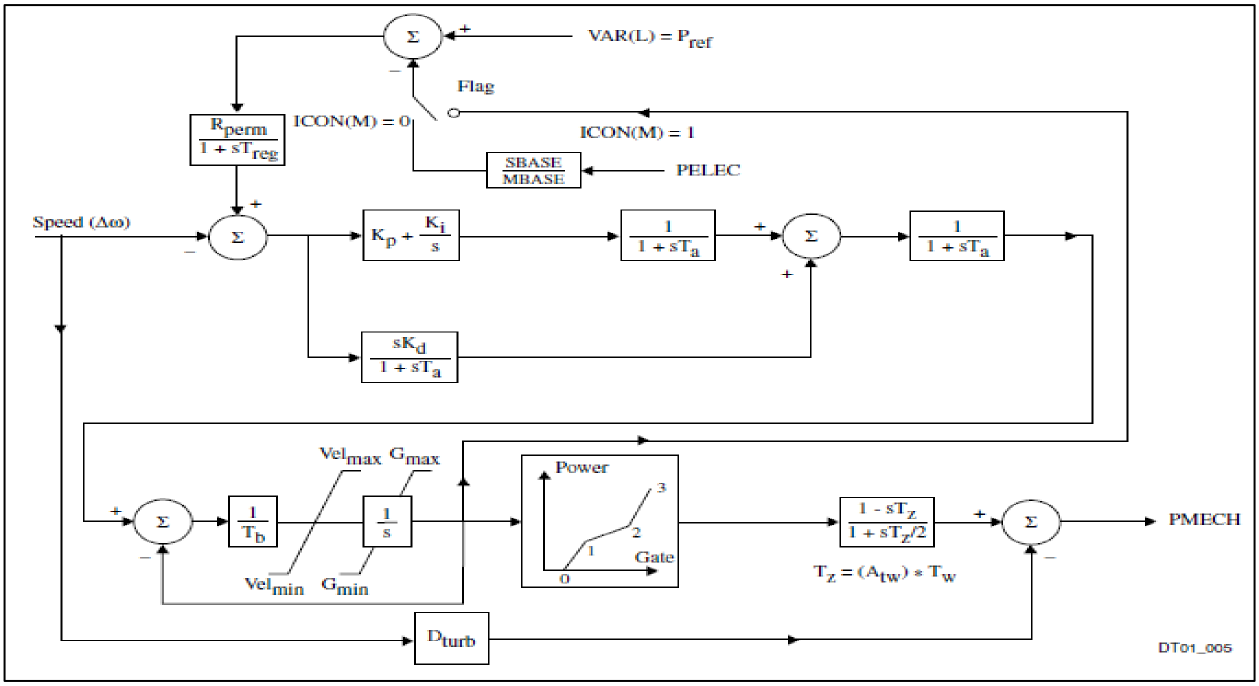
- **HYGOVT: Hydro Turbine-Governor Traveling Wave Model**



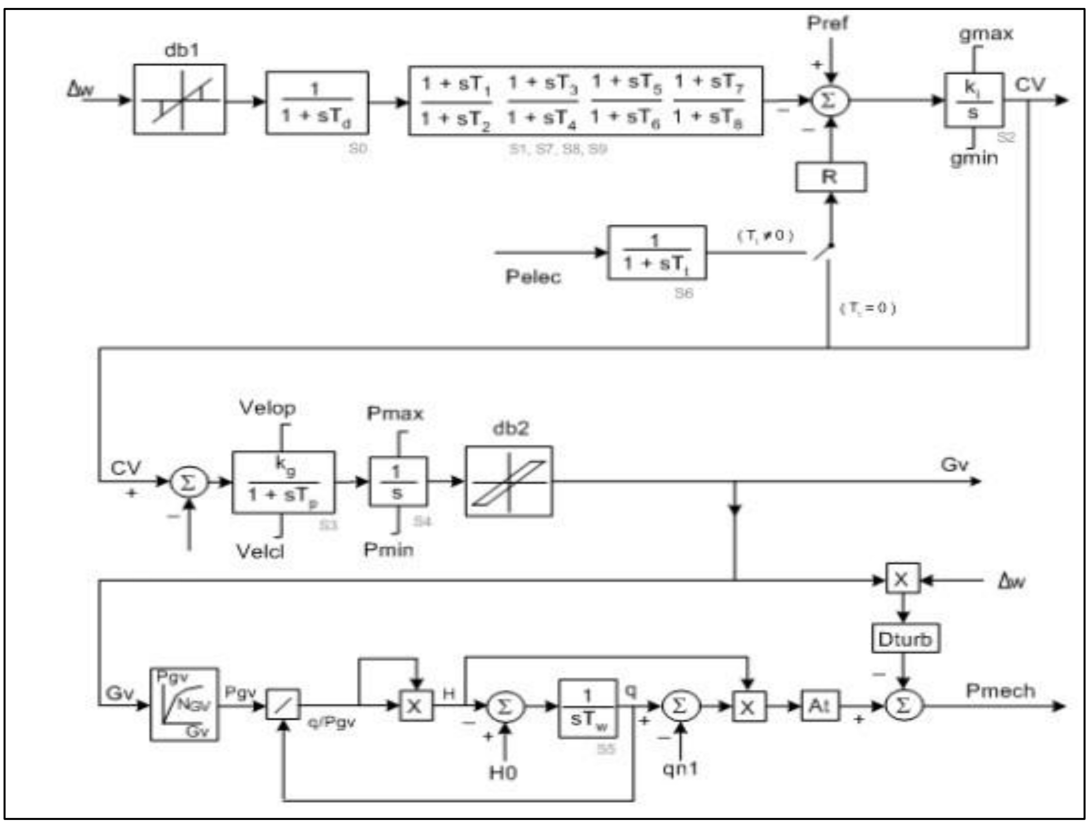

Surge Chamber
QTUN
QSCH
QPEN
1
s SCHARE
HSCH
HBSCH
X
Q2SCH
SCHLOS
Time
PENSTOCK
(PENLGTH, PENSPD, PENARE, PENLOS)
Surge Chamber Constraints
Turbine Constraints
DELT*ICON(M+1)
Space
Flows VAR(L+6) = QPEN
Heads VAR(L+26) = HBSCH
PENLGTH/(ICON(M)+1)
VAR(L+55 + ICON(M))
VAR(L+25 + ICON(M))


Jet Deflector
MXJDOR
MXJDCR
1
Tg
1
s
Deflector Position
0.01
Governor
Speed
Speed Reference
1
1 + Tfs
1 + Trs
r Tfs
GMAX
GMIN
R
Gate Servo
MXGTOR or MXBGOR
MXGTCR or MXBGCR
Gate Opening
RVLVCR
RVLMAX
Relief Valve Opening
0
Relief Valve

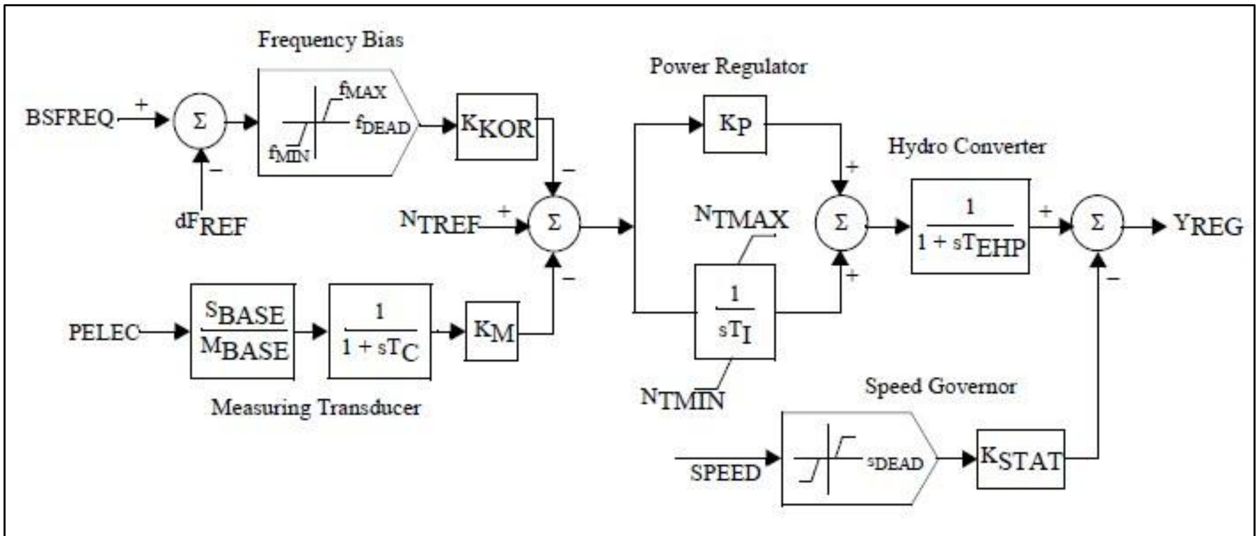
- **PIDGOV: Hydro Turbine-Governor**



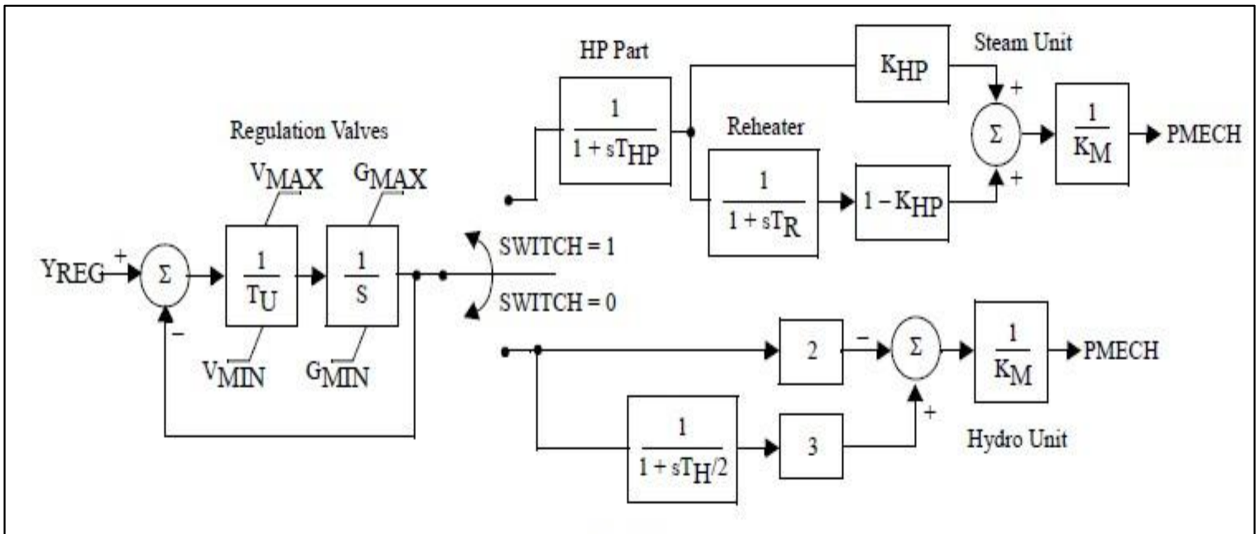
- **HYGOVR1: Fourth order lead-lag hydro-turbine**



- **TURCZT: Czech Hydro and Steam Governor**

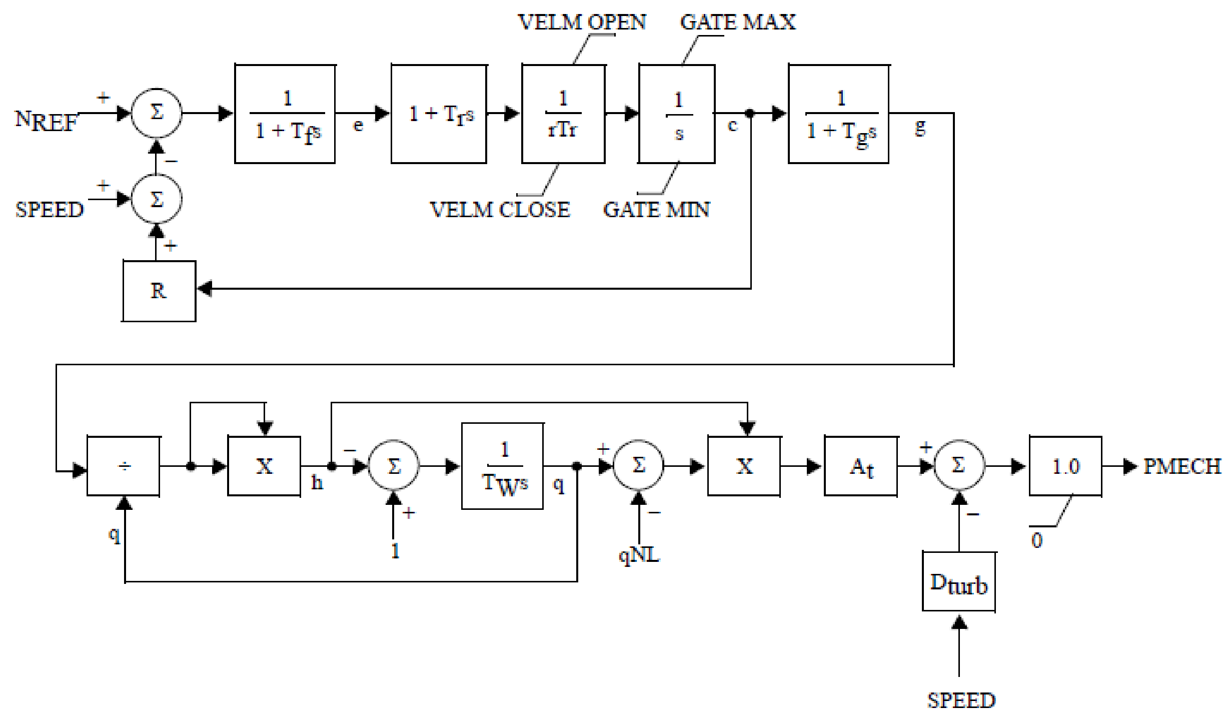


Governor

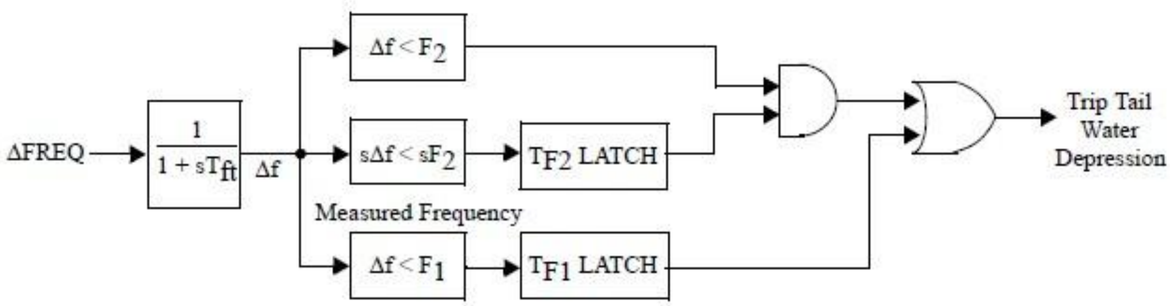


Turbine

- **TWDM1T: Tail Water Depression Hydro Governor Model 1**

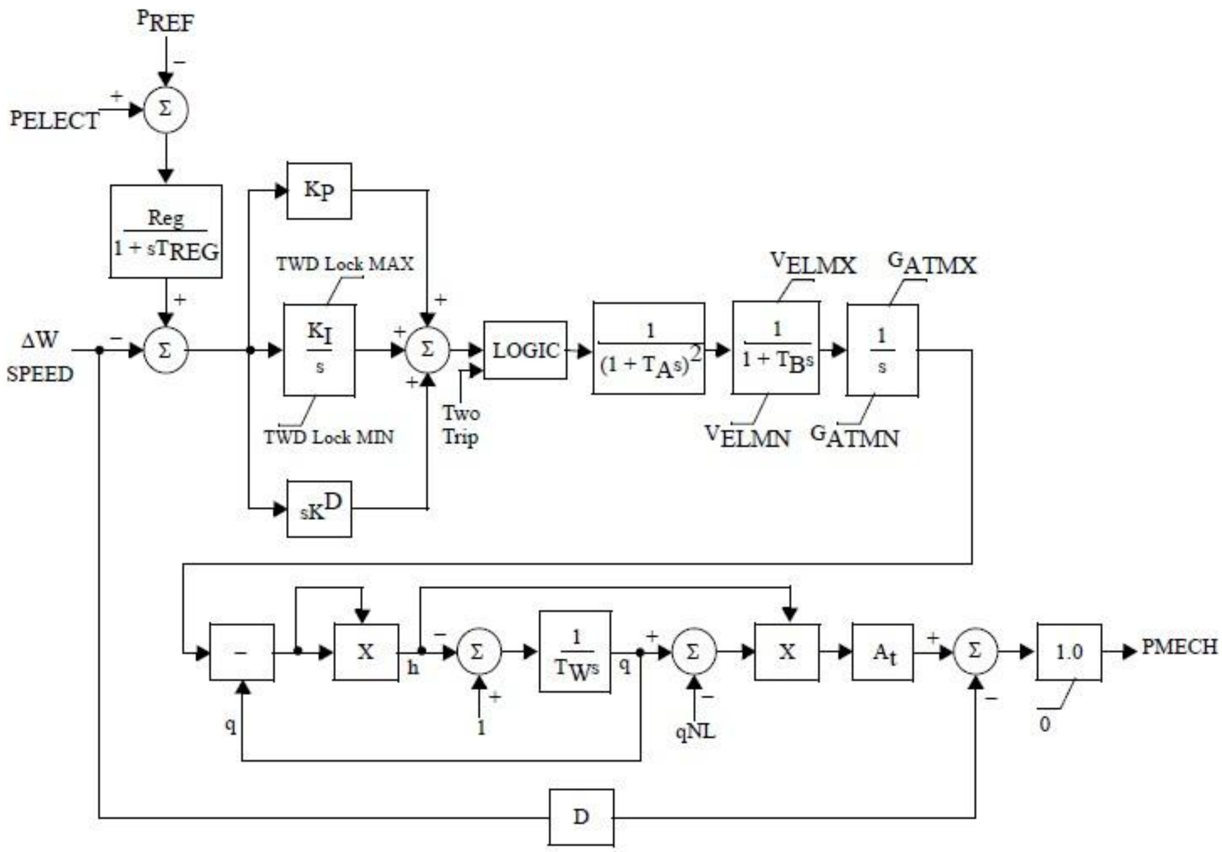


Tail Water Depression Model 1

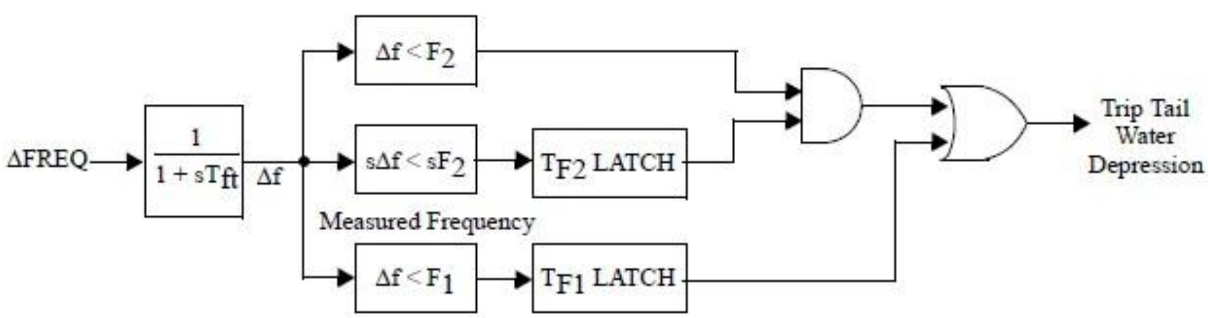


Tail Water Depression Trip Model

➢ TWDM2T: Tail Water Depression Hydro Governor Model 2

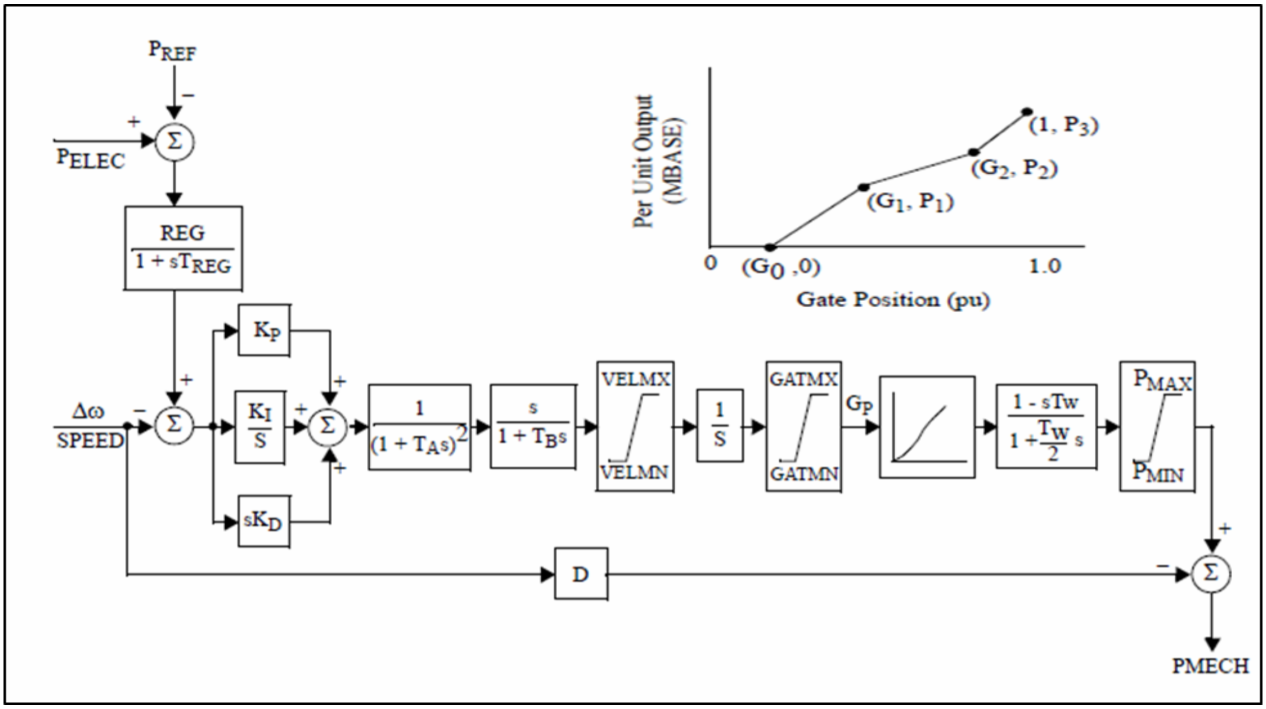


Tail Water Depression Model 2

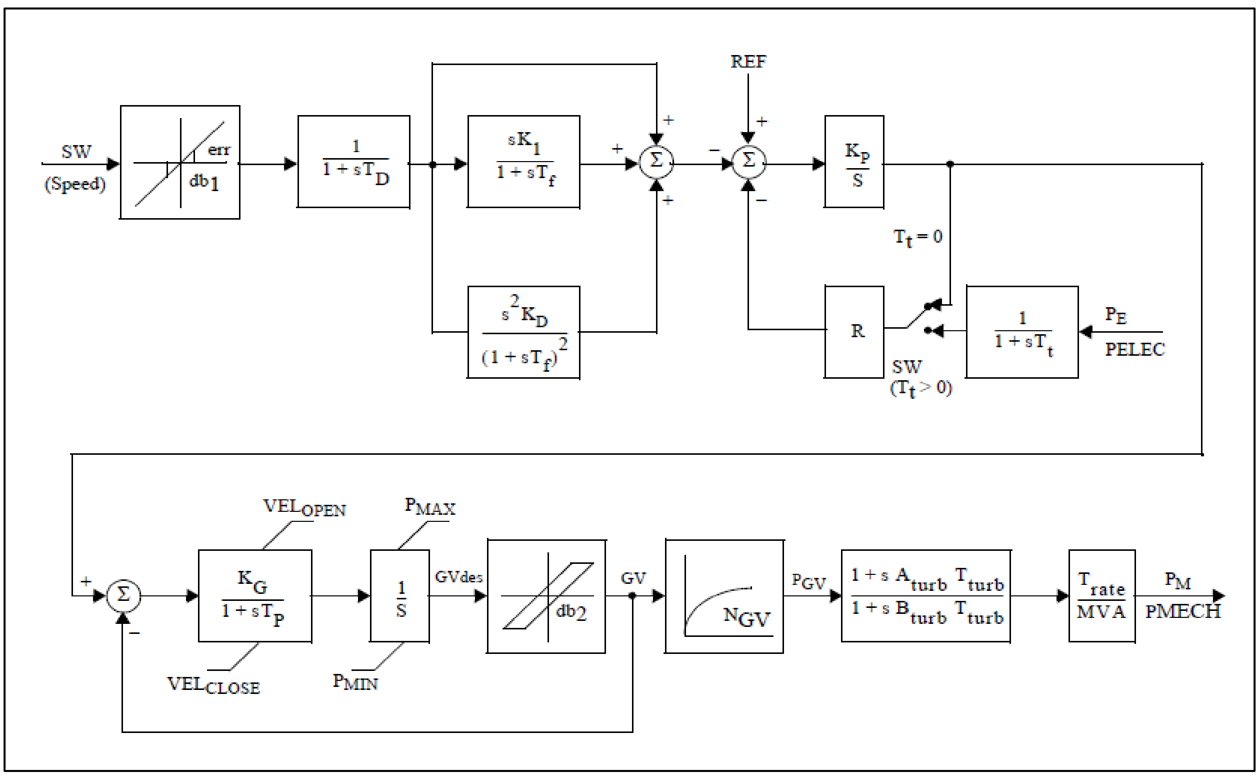


Tail Water Depression Trip Model

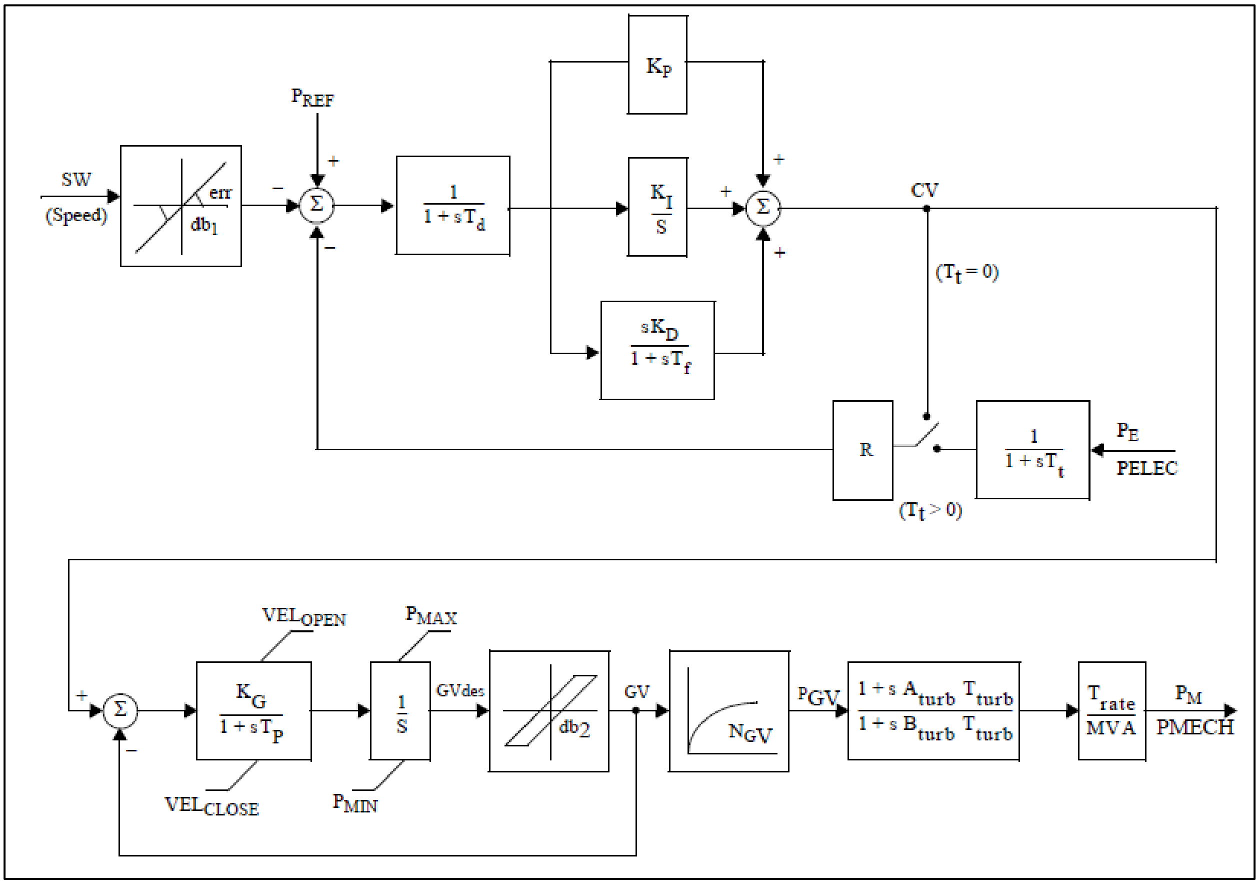
➢ **WPIDHY: Woodward PID Hydro Governor**



➢ **WSHYDD: WECC Double-Derivative Hydro Governor**

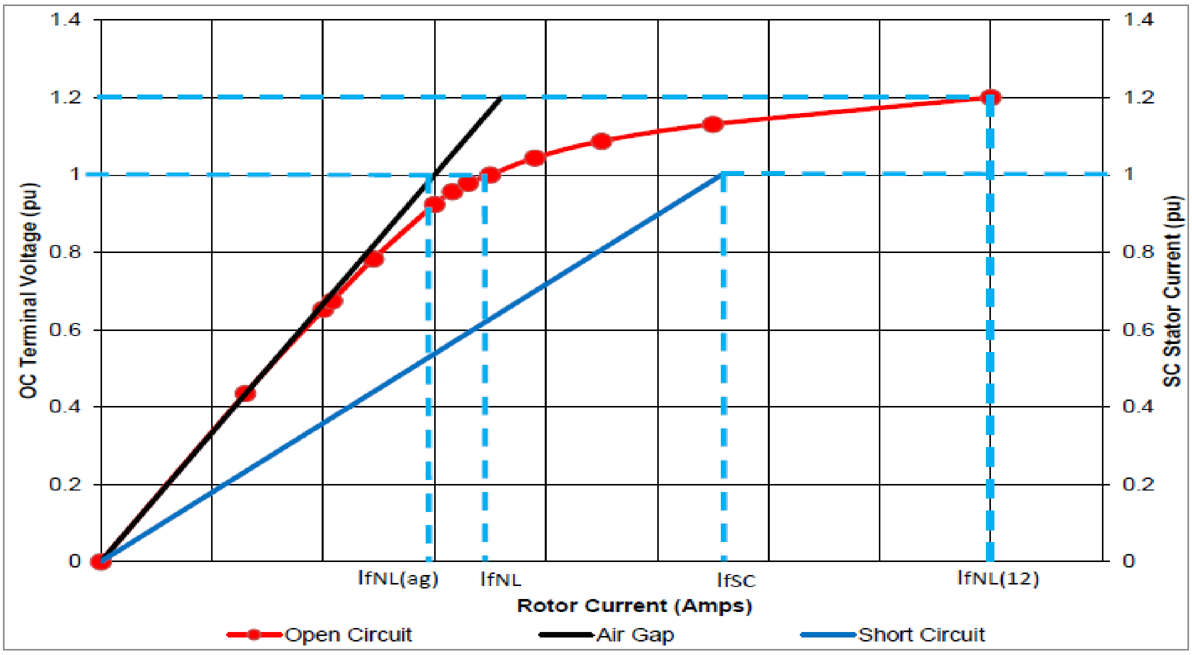


- **WSHYGP: WECC GP Hydro Governor Plus Turbine**



Source-PSSE Model Library

Calculation of saturation parameters:

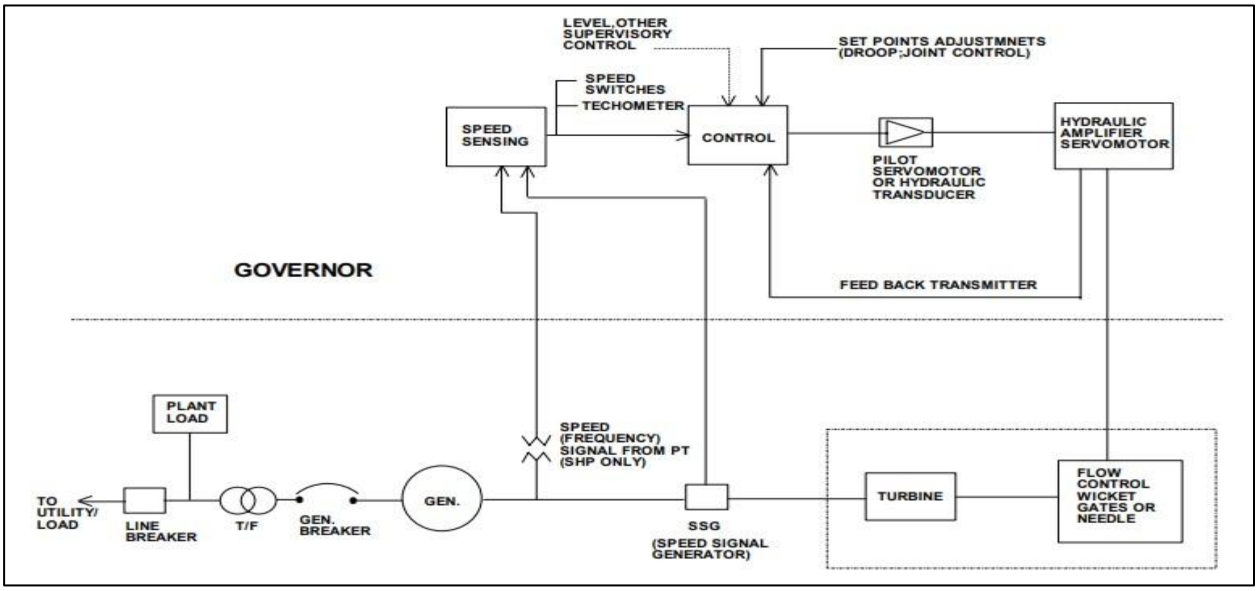


Open and short circuit characteristics

The saturation can be calculated using the following calculation:

$$S(1.0) = \frac{IfNL - IfNL(AG)}{IfNL(AG)}$$

$$S(1.2) = \frac{IfNL(12) - 1.2 \times IfNL(AG)}{1.2 \times IfNL(AG)}$$



Governing system - Block Diagram (Typical) as per IEEE std. -75

- **Models for Adjustable Speed Pumped Storage Hydro Plants:**

a) Adjustable Speed Pumped Storage Hydro Turbine Employing a Doubly Fed Induction Machine

Category	Parameter Description	Data
Adjustable Speed Pumped Storage Hydro Turbine Employing a Doubly Fed Induction Machine-Generation Mode-Single Unit and Penstock		
	T_{Iqcmd} , converter time constant for Eqcmd (sec)	
	T_{Ipcmd} , converter time constant for Ipcmd (sec)	
	VLVPL1, LVPL low voltage point (pu)	
	VLVPL2, LVPL higher voltage point (pu)	
	GLVPL, LVPL gain (pu)	
	VHVRCR, higher voltage to define reactive current limit (pu)	
	CURHVRCR, Max. reactive current at VHVRCR (pu)	
	RIp_LVPL, rate of LVACR active current change (pu/sec)	
	T_LVPL, voltage sensor time constant (sec)	
	Khv, overvoltage compensation gain (pu)	
	Iqrmax, reactive current increasing rate limit (pu/sec)	
	Iqrmin, reactive current decreasing rate limit (pu/sec)	
	H, turbine inertia constant (sec)	
	R, frequency control droop (pu)	
	Tv, remote voltage measurement time constant (sec)	
	TE, internal voltage Eq filtering time constant (sec)	
	Tp, power measurement time constant (sec)	
	Tbf, bus frequency measurement time constant (sec)	
	Tn, lead time constant of bus frequency lead-lag (sec)	
PSHGN1	Tnp, lag time constant of bus frequency lead-lag (sec)	
	Tff, filter time constant of frequency control (sec)	
	Tr, 1/Tr is the integral gain in the frequency controller (pu)	
	Tpo, time constant of power order controller (sec)	
	Kpv, proportional gain in voltage regulator(pu)	
	Kiv, integrator gain in voltage regulator (pu)	
	rr, 1/rr is the proportional gain in the frequency controller (pu)	
	Kptrq, proportional gain in power regulator (pu)	
	Kitrq, integrator gain in power regulator (pu)	
	SPmax, maximum limit for shaft speed deviation (pu)	
	SPMin, minimum limit for shaft speed deviation (pu)	
	Pmax, maximum limit for power command (pu)	
	Pmin, minimum limit for power command (pu)	
	IPmax, maximum limit for real current command (pu)	
	IPmin, minimum limit for real current command (pu)	
	dPmax, maximum rate of change for real current command change (pu)	
	dPMin, minimum rate of change for real current command change (pu)	
	Eqmax, maximum limit for internal voltage Eq command (pu)	
	Eqmin, minimum limit for internal voltage Eq command (pu)	

	fdbd, deadband for frequency regulator (pu)	
	h0, steady state head (pu)	
	Rgate, gate control droop (pu)	
	Dturb, turbine damping factor (pu)	
	Trate, turbine rating (pu on MBASE)	
	Kg1, gain of gate reference control (pu)	
	Tg1, time constant of gate reference control (sec)	
	Kigov, integrator gain in governor PID regulator (pu)	
	Kpgov, proportional gain in governor PID regulator (pu)	
	Kdgov, differential gain in governor PID regulator (pu)	
	Tdgov, differential time constant in governor PID regulator (sec)	
	Kp1, gain of pilot and distribution valves (pu)	
	Tp1, time constant of pilot and distribution valves (sec)	
	qnl, no load power flow (pu)	
	At, turbine gain (pu)	
	Gmax1, maximum limit for gate position (pu)	
	Gmin1, minimum limit for gate position (pu)	
	Gmax2, maximum limit for governor integrator (pu)	
	Gmin2, minimum limit for governor integrator (pu)	
	Vop1, maximum limit for pilot valve (pu)	
	Vol1, minimum limit for pilot valve (pu)	
	Tw, water starting time constant (sec)	

Category	**Parameter Description**	**Data**
Adjustable Speed Pumped Storage Hydro Turbine Employing a Doubly Fed Induction Machine-Generation Mode-Up to Four Units with a Common Penstock		
PSHGN4	T_{Iqcmd} , converter time constant for Eqcmd (sec)	
	T_{Ipcmd} , converter time constant for Ipcmd (sec)	
	VLVPL1, LVPL low voltage point (pu)	
	VLVPL2, LVPL higher voltage point (pu)	
	GLVPL, LVPL gain (pu)	
	VHVRCR, higher voltage to define reactive current limit (pu)	
	CURHVRCR, Max. reactive current at VHVRCR (pu)	
	RIp_LVPL, rate of LVACR active current change (pu/sec)	
	T_LVPL, voltage sensor time constant (sec)	
	Khv, overvoltage compensation gain (pu)	
	Iqrmax, reactive current increasing rate limit (pu/sec)	
	Iqrmin, reactive current decreasing rate limit (pu/sec)	
	H, turbine inertia constant (sec)	
	R, frequency control droop (pu)	
	Tv, remote voltage measurement time constant (sec)	
	TE, internal voltage Eq filtering time constant (sec)	
	Tp, power measurement time constant (sec)	
	Tbf, bus frequency measurement time constant (sec)	
	Tn, lead time constant of bus frequency lead-lag (sec)	
	Tnp, lag time constant of bus frequency lead-lag (sec)	

Tff, filter time constant of frequency control (sec)	
Tr, 1/Tr is the integral gain in the frequency controller (pu)	
Tpo, time constant of power order controller (sec)	
Kpv, proportional gain in voltage regulator(pu)	
Kiv, integrator gain in voltage regulator (pu)	
rr, 1/rr is the proportional gain in the frequency controller (pu)	
Kptrq, proportional gain in power regulator (pu)	
Kitrq, integrator gain in power regulator (pu)	
SPmax, maximum limit for shaft speed deviation (pu)	
SPMin, minimum limit for shaft speed deviation (pu)	
Pmax, maximum limit for power command (pu)	
Pmin, minimum limit for power command (pu)	
IPmax, maximum limit for real current command (pu)	
IPmin, minimum limit for real current command (pu)	
dPmax, maximum rate of change for real current command change (pu)	
dPMin, minimum rate of change for real current command change (pu)	
Eqmax, maximum limit for internal voltage Eq command (pu)	
Eqmin, minimum limit for internal voltage Eq command (pu)	
fdbd, deadband for frequency regulator (pu)	
h0, steady state head (pu)	
Rgate, gate control droop (pu)	
Dturb, turbine damping factor (pu)	
Trate, turbine rating (pu on MBASE)	
Kg1, gain of gate reference control (pu)	
Tg1, time constant of gate reference control (sec)	
Kigov, integrator gain in governor PID regulator (pu)	
Kpgov, proportional gain in governor PID regulator (pu)	
Kdgov, differential gain in governor PID regulator (pu)	
Tdgov, differential time constant in governor PID regulator (sec)	
Kp1, gain of pilot and distribution valves (pu)	
Tp1, time constant of pilot and distribution valves (sec)	
qnl, no load power flow (pu)	
At, turbine gain (pu)	
Gmax1, maximum limit for gate position (pu)	
Gmin1, minimum limit for gate position (pu)	
Gmax2, maximum limit for governor integrator (pu)	
Gmin2, minimum limit for governor integrator (pu)	
Vop1, maximum limit for pilot valve (pu)	
Vol1, minimum limit for pilot valve (pu)	
Tw11, water time constant for unit 1 (sec)	
Tw12, water time constant for common tunnel of units 1 and 2 (sec)	
Tw13, water time constant for common tunnel of units 1 and 3 (sec)	
Tw14, water time constant for common tunnel of units 1 and 4 (sec)	
Tw21, water time constant for common tunnel of units 2 and 1 (sec)	
Tw22, water time constant for unit 2 (sec)	

	Tw23, water time constant for common tunnel of units 2 and 3 (sec)	
	Tw24, water time constant for common tunnel of units 2 and 4 (sec)	
	Tw31, water time constant for common tunnel of units 3 and 1 (sec)	
	Tw32, water time constant for common tunnel of units 3 and 2 (sec)	
	Tw33, water time constant for unit 3 (sec)	
	Tw34, water time constant for common tunnel of units 3 and 4 (sec)	
	Tw41, water time constant for common tunnel of units 4 and 1 (sec)	
	Tw42, water time constant for common tunnel of units 4 and 2 (sec)	
	Tw43 water time constant for common tunnel of units 4 and 3 (sec)	
	Tw44, water time constant for unit 4 (sec)	

Category	**Parameter Description**	**Data**
Adjustable Speed Pumped Storage Hydro Turbine Employing a Doubly Fed Induction Machine-Generation mode- Up to Four Units with a Common Penstock with Individual Optimizers		
PSHGM4	T_{Iqcmd} , converter time constant for Eqcmd (sec)	
	T_{Ipcmd} , converter time constant for Ipcmd (sec)	
	VLVPL1, LVPL low voltage point (pu)	
	VLVPL2, LVPL higher voltage point (pu)	
	GLVPL, LVPL gain (pu)	
	VHVRCR, higher voltage to define reactive current limit (pu)	
	CURHVRCR, Max. reactive current at VHVRCR (pu)	
	RIp_LVPL, rate of LVACR active current change (pu/sec)	
	T_LVPL, voltage sensor time constant (sec)	
	Khv, overvoltage compensation gain (pu)	
	Iqrmax, reactive current increasing rate limit (pu/sec)	
	Iqrmin, reactive current decreasing rate limit (pu/sec)	
	H, turbine inertia constant (sec)	
	R, frequency control droop (pu)	
	Tv, remote voltage measurement time constant (sec)	
	TE, internal voltage Eq filtering time constant (sec)	
	Tp, power measurement time constant (sec)	
	Tbf, bus frequency measurement time constant (sec)	
	Tn, lead time constant of bus frequency lead-lag (sec)	
	Tnp, lag time constant of bus frequency lead-lag (sec)	
	Tff, filter time constant of frequency control (sec)	
	Tr, 1/Tr is the integral gain in the frequency controller (pu)	
	Tpo, time constant of power order controller (sec)	
	Kpv, proportional gain in voltage regulator(pu)	
	Kiv, integrator gain in voltage regulator (pu)	
	rr, 1/rr is the proportional gain in the frequency controller (pu)	
	Kptrq, proportional gain in power regulator (pu)	
	Kitrq, integrator gain in power regulator (pu)	
	SPmax, maximum limit for shaft speed deviation (pu)	
	SPMin, minimum limit for shaft speed deviation (pu)	
	Pmax, maximum limit for power command (pu)	
	Pmin, minimum limit for power command (pu)	

	IPmax, maximum limit for real current command (pu)	
	IPmin, minimum limit for real current command (pu)	
	dPmax, maximum rate of change for real current command change (pu)	
	dPMin, minimum rate of change for real current command change (pu)	
	Eqmax, maximum limit for internal voltage Eq command (pu)	
	Eqmin, minimum limit for internal voltage Eq command (pu)	
	fdbd, deadband for frequency regulator (pu)	
	h0, steady state head (pu)	
	Rgate, gate control droop (pu)	
	Dturb, turbine damping factor (pu)	
	Trate, turbine rating (pu on MBASE)	
	Kg1, gain of gate reference control (pu)	
	Tg1, time constant of gate reference control (sec)	
	Kigov, integrator gain in governor PID regulator (pu)	
	Kpgov, proportional gain in governor PID regulator (pu)	
	Kdgov, differential gain in governor PID regulator (pu)	
	Tdgov, differential time constant in governor PID regulator (sec)	
	Kp1, gain of pilot and distribution valves (pu)	
	Tp1, time constant of pilot and distribution valves (sec)	
	qnl, no load power flow (pu)	
	At, turbine gain (pu)	
	Gmax1, maximum limit for gate position (pu)	
	Gmin1, minimum limit for gate position (pu)	
	Gmax2, maximum limit for governor integrator (pu)	
	Gmin2, minimum limit for governor integrator (pu)	
	Vop1, maximum limit for pilot valve (pu)	
	Vol1, minimum limit for pilot valve (pu)	
	Tw11, water time constant for unit 1 (sec)	
	Tw12, water time constant for common tunnel of units 1 and 2 (sec)	
	Tw13, water time constant for common tunnel of units 1 and 3 (sec)	
	Tw14, water time constant for common tunnel of units 1 and 4 (sec)	
	Tw21, water time constant for common tunnel of units 2 and 1 (sec)	
	Tw22, water time constant for unit 2 (sec)	
	Tw23, water time constant for common tunnel of units 2 and 3 (sec)	
	Tw24, water time constant for common tunnel of units 2 and 4 (sec)	
	Tw31, water time constant for common tunnel of units 3 and 1 (sec)	
	Tw32, water time constant for common tunnel of units 3 and 2 (sec)	
	Tw33, water time constant for unit 3 (sec)	
	Tw34, water time constant for common tunnel of units 3 and 4 (sec)	
	Tw41, water time constant for common tunnel of units 4 and 1 (sec)	
	Tw42, water time constant for common tunnel of units 4 and 2 (sec)	
	Tw43 water time constant for common tunnel of units 4 and 3 (sec)	
	Tw44, water time constant for unit 4 (sec)	

Category	Parameter Description	Data
Adjustable Speed Pumped Storage Hydro Turbine Employing a Doubly Fed Induction Machine-Pump mode- Single Unit and Penstock		
	TIQCmd, converter time constant for IQcmd (sec)	
	TIpCmd, converter time constant for IPcmd (sec)	
	VLVPL, LVPL low voltage point (pu)	
	LVPL, LVPL high voltage point (pu)	
	LVPL gain (pu)	
	HVRCR, high voltage reactive current limit (pu)	
	CURHVRCR, Max. reactive current at HVRCR (pu)	
	RIp_LVPL, rate of LVACR active current change (pu/sec)	
	T_LVPL, voltage sensor time constant (sec)	
	Khv, overvoltage compensation gain (pu)	
	Iqrmax, reactive power increasing rate limit (pu/sec)	
	Iqrmin, reactive power decreasing rate limit (pu/sec)	
	H, turbine inertia constant (sec)	
	R, frequency control droop (pu)	
	Tv, remote voltage sampling time constant (sec)	
	TE, internal voltage filtering time constant (sec)	
	Tp, power sampling time constant (sec)	
	Tbf, bus frequency sampling time constant (sec)	
	Tn, lead time constant of bus frequency lead-lag control (sec)	
	Tnp, lag time constant of bus frequency lead-lag control (sec)	
	Tff, filter time constant of frequency control (sec)	
PSHPM1	Tr, frequency P-I controller time constant (sec)	
	Tpo, time constant of power order filter (sec)	
	Kpv, proportional gain in voltage regulator(pu)	
	Kiv, integrator gain in voltage regulator (pu)	
	rr, 1/rr is a proportional gain in frequency regulator (pu)	
	Kp2, proportional gain in power regulator(pu)	
	Ki2, integrator gain in power regulator (pu)	
	Kpsp, proportional gain in speed regulator (pu)	
	Kisp, integrator gain in speed regulator (pu)	
	SPmax, max limit for shaft speed deviation (pu)	
	SPMin, min limit for shaft speed deviation (pu)	
	Pmax, max limit for power command (pu)	
	PMin, min limit for power command (pu)	
	IPmax, max limit for real current command (pu)	
	IPMin, min limit for real current command (pu)	
	dPmax, max limit for real current command change (pu)	
	dPMin, min limit for real current command change (pu)	
	Eqmax, max limit for Internal voltage command (pu)	
	EqMin, min limit for Internal voltage command (pu)	
	fdbd, deadband for frequency regulator (pu)	
	H0, steady state head (pu)	
	Dturb, turbine damping factor (pu)	

	Trate, turbine rating (pu on MBASE)	
	Kg1, gain of gate reference (pu)	
	Tg1, time constant on gate reference (sec)	
	Kp1, gain on pilot and distribution valves (pu)	
	Tp1, time constant of pilot and distribution valves (sec)	
	Qnl, no load power flow (pu)	
	Gmax1, max limit for gate position (pu)	
	Gmin1, min limit for gate position (pu)	
	Vop1, max limit for pilot valve (pu)	
	Vol1, min limit for pilot valve (pu)	
	A0, Flow-Head curve parameter: H = A0 + B0*q + C0*q**2	
	B0, Flow-Head curve parameter: H = A0 + B0*q + C0*q**2	
	C0, Flow-Head curve parameter: H = A0 + B0*q + C0*q**2	
	Tw, water starting time constant (sec)	

Category	**Parameter Description**	**Data**
Adjustable Speed Pumped Storage Hydro Turbine Employing a Doubly Fed Induction Machine-Pump mode- Up to Four Units with a Common Penstock.		
PSHPM4	TIQCmd, converter time constant for IQcmd (sec)	
	TIpCmd, converter time constant for IPcmd (sec)	
	VLVPL, LVPL low voltage point (pu)	
	LVPL, LVPL high voltage point (pu)	
	LVPL gain (pu)	
	HVRCR, high voltage reactive current limit (pu)	
	CURHVRCR, Max. reactive current at HVRCR (pu)	
	RIp_LVPL, rate of LVACR active current change (pu/sec)	
	T_LVPL, voltage sensor time constant (sec)	
	Khv, overvoltage compensation gain (pu)	
	Iqrmax, reactive power increasing rate limit (pu/sec)	
	Iqrmin, reactive power decreasing rate limit (pu/sec)	
	H, turbine inertia constant (sec)	
	R, frequency control droop (pu)	
	Tv, remote voltage sampling time constant (sec)	
	TE, internal voltage filtering time constant (sec)	
	Tp, power sampling time constant (sec)	
	Tbf, bus frequency sampling time constant (sec)	
	Tn, lead time constant of bus frequency lead-lag control (sec)	
	Tnp, lag time constant of bus frequency lead-lag control (sec)	
	Tff, filter time constant of frequency control (sec)	
	Tr, frequency P-I controller time constant (sec)	
	Tpo, time constant of power order filter (sec)	
	Kpv, proportional gain in voltage regulator(pu)	
	Kiv, integrator gain in voltage regulator (pu)	
	rr, 1/rr is a proportional gain in frequency regulator (pu)	
	Kp2, proportional gain in power regulator(pu)	
	Ki2, integrator gain in power regulator (pu)	

	Kpsp, proportional gain in speed regulator (pu)	
	Kisp, integrator gain in speed regulator (pu)	
	SPmax, max limit for shaft speed deviation (pu)	
	SPMin, min limit for shaft speed deviation (pu)	
	Pmax, max limit for power command (pu)	
	PMin, min limit for power command (pu)	
	IPmax, max limit for real current command (pu)	
	IPMin, min limit for real current command (pu)	
	dPmax, max limit for real current command change (pu)	
	dPMin, min limit for real current command change (pu)	
	Eqmax, max limit for Internal voltage command (pu)	
	EqMin, min limit for Internal voltage command (pu)	
	fdbd, deadband for frequency regulator (pu)	
	H0, steady state head (pu)	
	Dturb, turbine damping factor (pu)	
	Trate, turbine rating (pu on MBASE)	
	Kg1, gain of gate reference (pu)	
	Tg1, time constant on gate reference (sec)	
	Kp1, gain on pilot and distribution valves (pu)	
	Tp1, time constant of pilot and distribution valves (sec)	
	Qnl, no load power flow (pu)	
	Gmax1, max limit for gate position (pu)	
	Gmin1, min limit for gate position (pu)	
	Vop1, max limit for pilot valve (pu)	
	Vol1, min limit for pilot valve (pu)	
	A0, Flow-Head curve parameter: H = A0 + B0*q + C0*q**2	
	B0, Flow-Head curve parameter: H = A0 + B0*q + C0*q**2	
	C0, Flow-Head curve parameter: H = A0 + B0*q + C0*q**2	
	Tw11, water time constant for unit 1 (sec)	
	Tw12, water time constant for common tunnel of units 1 and 2 (sec)	
	Tw13, water time constant for common tunnel of units 1 and 3 (sec)	
	Tw14, water time constant for common tunnel of units 1 and 4 (sec)	
	Tw21, water time constant for common tunnel of units 2 and 1 (sec)	
	Tw22, water time constant for unit 2 (sec)	
	Tw23, water time constant for common tunnel of units 2 and 3 (sec)	
	Tw24, water time constant for common tunnel of units 2 and 4 (sec)	
	Tw31, water time constant for common tunnel of units 3 and 1 (sec)	
	Tw32, water time constant for common tunnel of units 3 and 2 (sec)	
	Tw33, water time constant for unit 3 (sec)	
	Tw34, water time constant for common tunnel of units 3 and 4 (sec)	
	Tw41, water time constant for common tunnel of units 4 and 1 (sec)	
	Tw42, water time constant for common tunnel of units 4 and 2 (sec)	
	Tw43 water time constant for common tunnel of units 4 and 3 (sec)	
	Tw44, water time constant for unit 4 (sec)	

b) Ternary Pumped Storage Hydro

Category	Parameter Description	Data
Ternary Pumped Storage Hydro Unit, One Units with a Common Penstock.		
	H0_t, Turbine Steady State Head (pu)	
	rgate_t, Turbine Gate Control Droop (pu)	
	Dturb_t, Turbine Damping Factor (pu)	
	Trate_t, Turbine Rating (MW)	
	rpe_t, Turbine Gain on Power Filter (pu)	
	Tpe_t, Turbine Time Constant on Power filter (sec)	
	Kigov_t, Turbine Integrator Gain in Governor PID Regulator (pu)	
	Kpgov_t, Turbine Proportional Gain in Governor PID Regulator (pu)	
	Kdgov_t, Turbine Differential Gain in Governor PID Regulator (pu)	
	Tdgov_t, Turbine Differential Time Constant in Governor PID Regulator (sec)	
	Kp_t, Turbine Gain on Pilot and Distribution Valves (pu)	
	Tp_t, Turbine Time Constant on Pilot and Distribution Valves (sec)	
	qnl_t, Turbine No Power Flow (pu)	
	At_t, Turbine Gain (pu)	
	Gmax1_t, Turbine Max Limit for Gate Position (pu)	
	GMin1_t, Turbine Min Limit for Gate Position (pu)	
	Gmax2_t, Turbine Max Limit for Governor Integrator (pu)	
	GMin2_t, Turbine Min Limit for Governor Integrator (pu)	
	Vop_t, Turbine Max Limit for Pilot Valve (pu)	
	Vol_t, Turbine Min Limit for Pilot Valve (pu)	
PSHTNY	DB_spd1_t, Turbine Speed Deadband Lower Limit	
	DB_spd2_t, Turbine Speed Deadband Upper Limit	
	Gate1_t, Turbine Gate Point 1 on Gate-Power Curve (pu)	
	Pg1_t, Turbine Power Point 1 on Gate-Power Curve (pu)	
	Gate2_t, Turbine Gate Point 2 on Gate-Power Curve (pu)	
	Pg2_t, Turbine Power Point 2 on Gate-Power Curve (pu)	
	Gate3_t, Turbine Gate Point 3 on Gate-Power Curve (pu)	
	Pg3_t, Turbine Power Point 3 on Gate-Power Curve (pu)	
	Gate4_t, Turbine Gate Point 4 on Gate-Power Curve (pu)	
	Pg4_t, Turbine Power Point 4 on Gate-Power Curve (pu)	
	Gate5_t, Turbine Gate Point 5 on gate-Power Curve (pu)	
	Pg5_t, Turbine Power Point 5 on Gate-Power Curve (pu)	
	Dturb_p, Pump Damping Factor (pu)	
	Trate_p, Pump Rating (MW)	
	Kp_p, Pump Gain on Pilot and Distribution Valves (pu)	
	Tp_p, Pump Time Constant on Pilot and Distribution Valves(sec)	
	qnl_p, Pump No Power Flow (pu)	
	At_p, Pump Gain (pu)	
	Gmax1_p, Pump Max Limit for Gate Position (pu)	
	GMin1_p, Pump Min Limit for Gate Position (pu)	
	Vop_p, Pump Max Limit for Pilot Valve (pu)	
	Vol_p, Pump Min Limit for Pilot Valve (pu)	

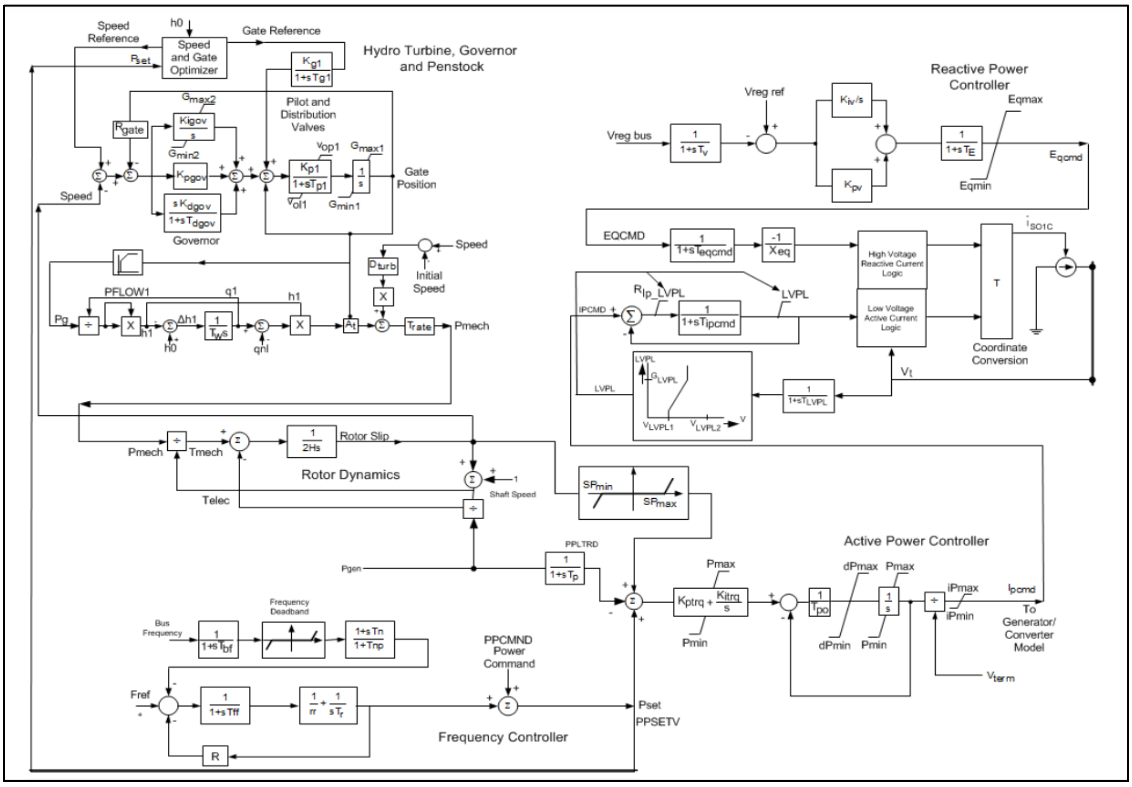
	A0, Pump Flow-Head Curve Parameter H = A0 + B0*q + C0*q**2	
	B0, Pump Flow-Head Curve Parameter H = A0 + B0*q + C0*q**2	
	C0, Pump Flow-Head Curve Parameter H = A0 + B0*q + C0*q**2	
	Gate1_p, Pump Gate Point 1 on Gate-Power Curve (pu)	
	Pg1_p, Pump Power Point 1 on Gate-Power Curve (pu)	
	Gate2_p, Pump Gate Point 2 on Gate-Power Curve (pu)	
	Pg2_p, Pump Power Point 2 on Gate-Power Curve (pu)	
	Gate3_p, Pump Gate Point 3 on Gate-Power Curve (pu)	
	Pg3_p, Pump Power Point 3 on Gate-Power Curve (pu)	
	Gate4_p, Pump Gate Point 4 on Gate-Power Curve (pu)	
	Pg4_p, Pump Power Point 4 on Gate-Power Curve (pu)	
	Gate5_p, Pump Gate Point 5 on Gate-Power Curve (pu)	
	Pg5_p, Pump Power Point 5 on Gate-Power Curve (pu)	
	Twtt1, Water Starting Time Constant for Turbine at Rated Flow (sec)	
	Twpp1, Water Starting Time Constant for Pump at Rated Flow (sec)	
	Kd, Dispatch Ratio between Turbine and Pump	

Category	Parameter Description	Data
Ternary Pumped Storage Hydro Unit, Two Units with a Common Penstock.		
	H0_t, Turbine Steady State Head (pu)	
	rgate_t, Turbine Gate Control Droop (pu)	
	Dturb_t, Turbine Damping Factor (pu)	
	Trate_t, Turbine Rating (MW)	
	rpe_t, Turbine Gain on Power Filter (pu)	
	Tpe_t, Turbine Time Constant on Power filter (sec)	
	Kigov_t, Turbine Integrator Gain in Governor PID Regulator (pu)	
	Kpgov_t, Turbine Proportional Gain in Governor PID Regulator (pu)	
	Kdgov_t, Turbine Differential Gain in Governor PID Regulator (pu)	
	Tdgov_t, Turbine Differential Time Constant in Governor PID Regulator (sec)	
	Kp_t, Turbine Gain on Pilot and Distribution Valves (pu)	
	Tp_t, Turbine Time Constant on Pilot and Distribution Valves (sec)	
	qnl_t, Turbine No Power Flow (pu)	
PSHTN2	At_t, Turbine Gain (pu)	
	Gmax1_t, Turbine Max Limit for Gate Position (pu)	
	GMin1_t, Turbine Min Limit for Gate Position (pu)	
	Gmax2_t, Turbine Max Limit for Governor Integrator (pu)	
	GMin2_t, Turbine Min Limit for Governor Integrator (pu)	
	Vop_t, Turbine Max Limit for Pilot Valve (pu)	
	Vol_t, Turbine Min Limit for Pilot Valve (pu)	
	DB_spd1_t, Turbine Speed Deadband Lower Limit	
	DB_spd2_t, Turbine Speed Deadband Upper Limit	
	Gate1_t, Turbine Gate Point 1 on Gate-Power Curve (pu)	
	Pg1_t, Turbine Power Point 1 on Gate-Power Curve (pu)	
	Gate2_t, Turbine Gate Point 2 on Gate-Power Curve (pu)	
	Pg2_t, Turbine Power Point 2 on Gate-Power Curve (pu)	
	Gate3_t, Turbine Gate Point 3 on Gate-Power Curve (pu)	

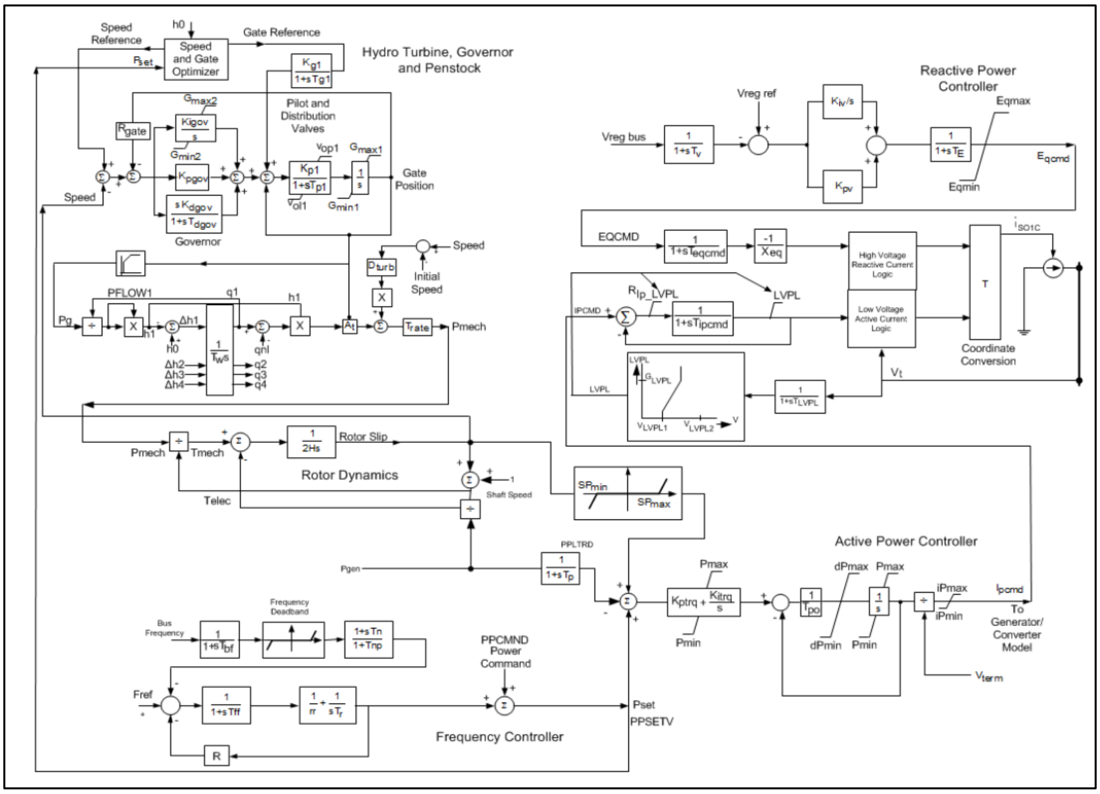
	Pg3_t, Turbine Power Point 3 on Gate-Power Curve (pu)	
	Gate4_t, Turbine Gate Point 4 on Gate-Power Curve (pu)	
	Pg4_t, Turbine Power Point 4 on Gate-Power Curve (pu)	
	Gate5_t, Turbine Gate Point 5 on gate-Power Curve (pu)	
	Pg5_t, Turbine Power Point 5 on Gate-Power Curve (pu)	
	Dturb_p, Pump Damping Factor (pu)	
	Trate_p, Pump Rating (MW)	
	Kp_p, Pump Gain on Pilot and Distribution Valves (pu)	
	Tp_p, Pump Time Constant on Pilot and Distribution Valves(sec)	
	qnl_p, Pump No Power Flow (pu)	
	At_p, Pump Gain (pu)	
	Gmax1_p, Pump Max Limit for Gate Position (pu)	
	GMin1_p, Pump Min Limit for Gate Position (pu)	
	Vop_p, Pump Max Limit for Pilot Valve (pu)	
	Vol_p, Pump Min Limit for Pilot Valve (pu)	
	A0, Pump Flow-Head Curve Parameter H = A0 + B0*q + C0*q**2	
	B0, Pump Flow-Head Curve Parameter H = A0 + B0*q + C0*q**2	
	C0, Pump Flow-Head Curve Parameter H = A0 + B0*q + C0*q**2	
	Gate1_p, Pump Gate Point 1 on Gate-Power Curve (pu)	
	Pg1_p, Pump Power Point 1 on Gate-Power Curve (pu)	
	Gate2_p, Pump Gate Point 2 on Gate-Power Curve (pu)	
	Pg2_p, Pump Power Point 2 on Gate-Power Curve (pu)	
	Gate3_p, Pump Gate Point 3 on Gate-Power Curve (pu)	
	Pg3_p, Pump Power Point 3 on Gate-Power Curve (pu)	
	Gate4_p, Pump Gate Point 4 on Gate-Power Curve (pu)	
	Pg4_p, Pump Power Point 4 on Gate-Power Curve (pu)	
	Gate5_p, Pump Gate Point 5 on Gate-Power Curve (pu)	
	Pg5_p, Pump Power Point 5 on Gate-Power Curve (pu)	
	Tw11, Water Starting Time Constant for Unit 1Turbine (sec)	
	Tw12, Common Tunnel Water time constant for Unit 1 turbine and pump(sec)	
	Tw13, Common Tunnel Water time constant for Unit 1 turbine and Unit 2 turbine (sec)	
	Tw14, Common Tunnel Water time constant for Unit 1 turbine and Unit 2 pump (sec)	
	Tw21, Common Tunnel Water time constant for Unit 1 pump and Unit 1 turbine (sec)	
	Tw22, Water Starting Time Constant for Unit 1Pump (sec)	
	Tw23, Common Tunnel Water time constant for Unit 1 pump and Unit 2 turbine (sec)	
	Tw24, Common Tunnel Water time constant for Unit 1 pump and Unit 2 pump (sec)	
	Tw31, Common Tunnel Water time constant for Unit 2 turbine and Unit 1 turbine (sec)	
	Tw32, Common Tunnel Water time constant for Unit 2 turbine and Unit 1 pump (sec)	
	Tw33, Water Starting Time Constant for Unit 2 Turbine (sec)	
	Tw34, Common Tunnel Water time constant for Unit 2 turbine and Unit 2 pump (sec)	
	Tw41, Common Tunnel Water time constant for Unit 2 pump and Unit 1 turbine (sec)	
	Tw42, Common Tunnel Water time constant for Unit 2 pump and Unit 1 pump (sec)	
	Tw43, Common Tunnel Water time constant for Unit 2 pump and Unit 2 turbine (sec)	
	Tw44, Water Starting Time Constant for Unit 2 Pump (sec)	
	Kd, Dispatch Ratio between Turbine and Pump	

Block Diagrams

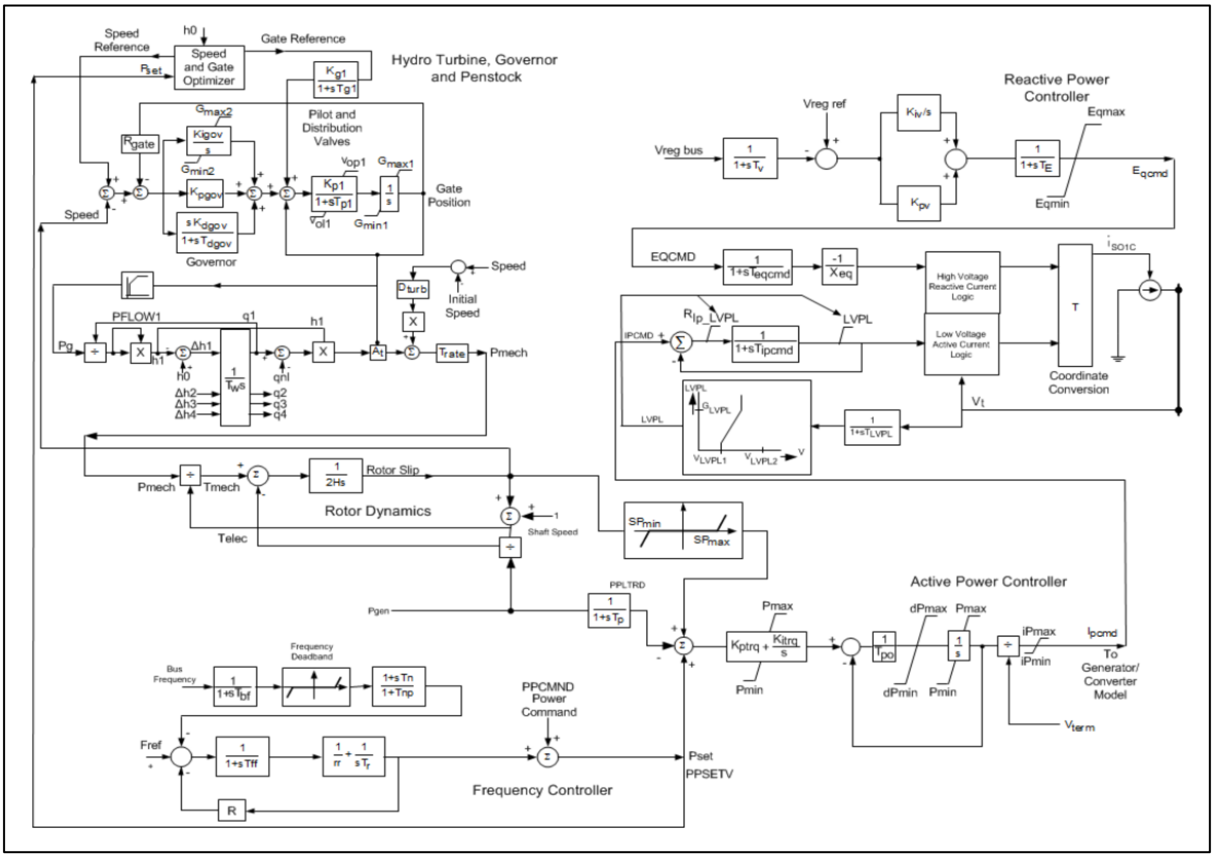
1. PSHGN1:



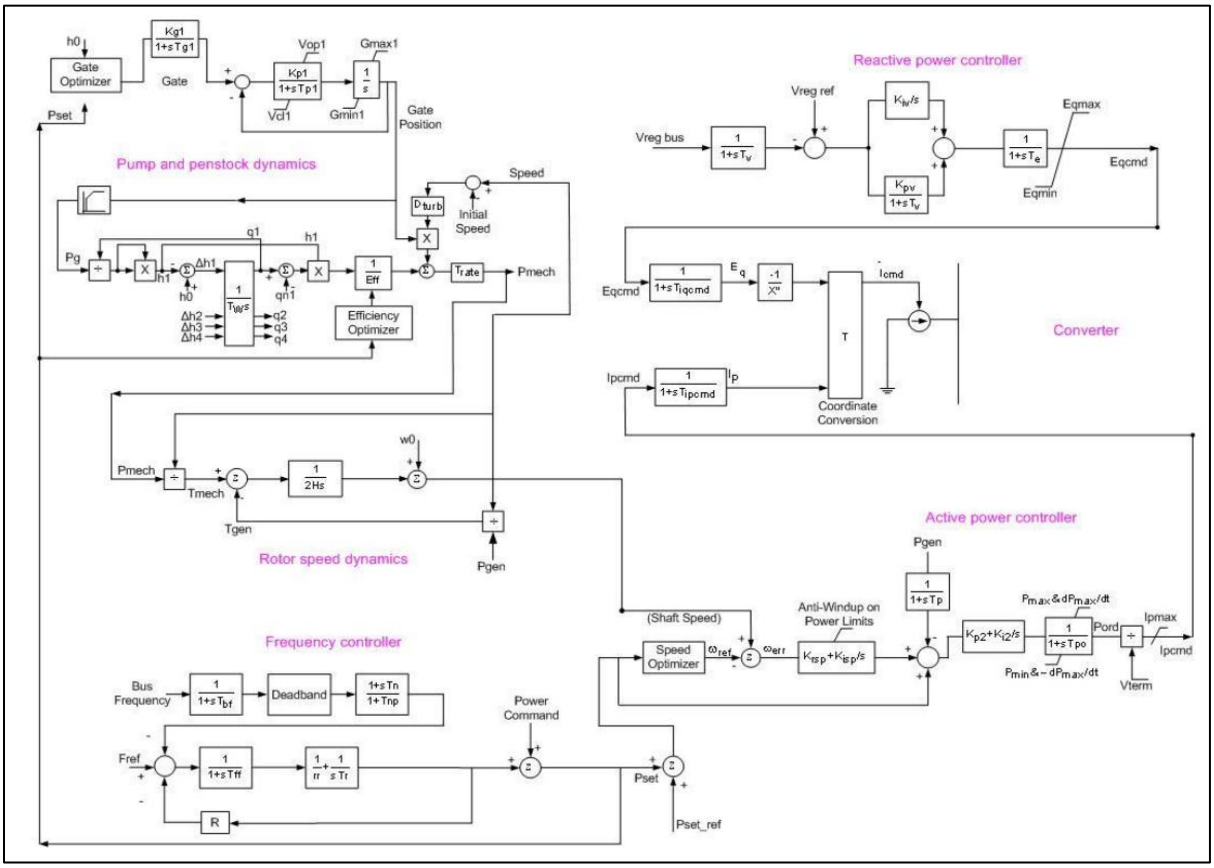
2. PSHGN4:



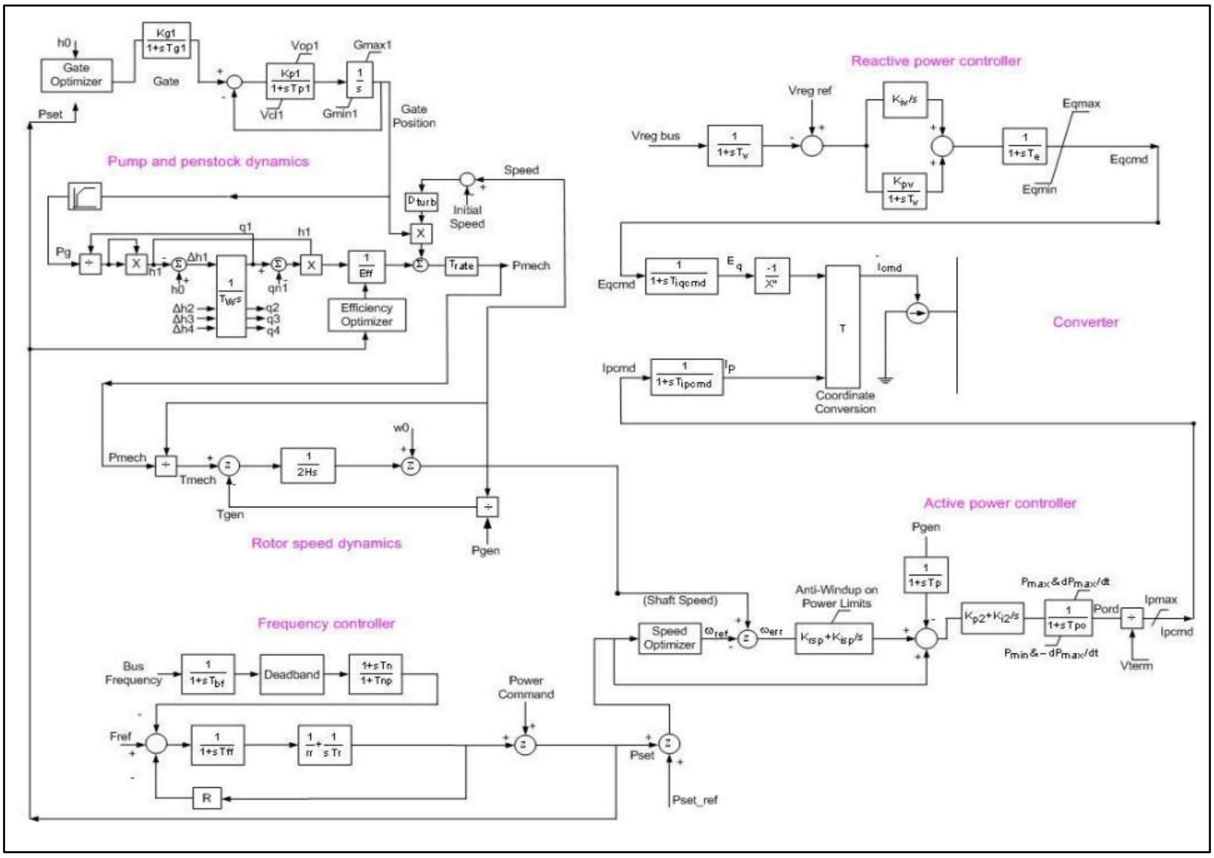
3. PSHGM4:



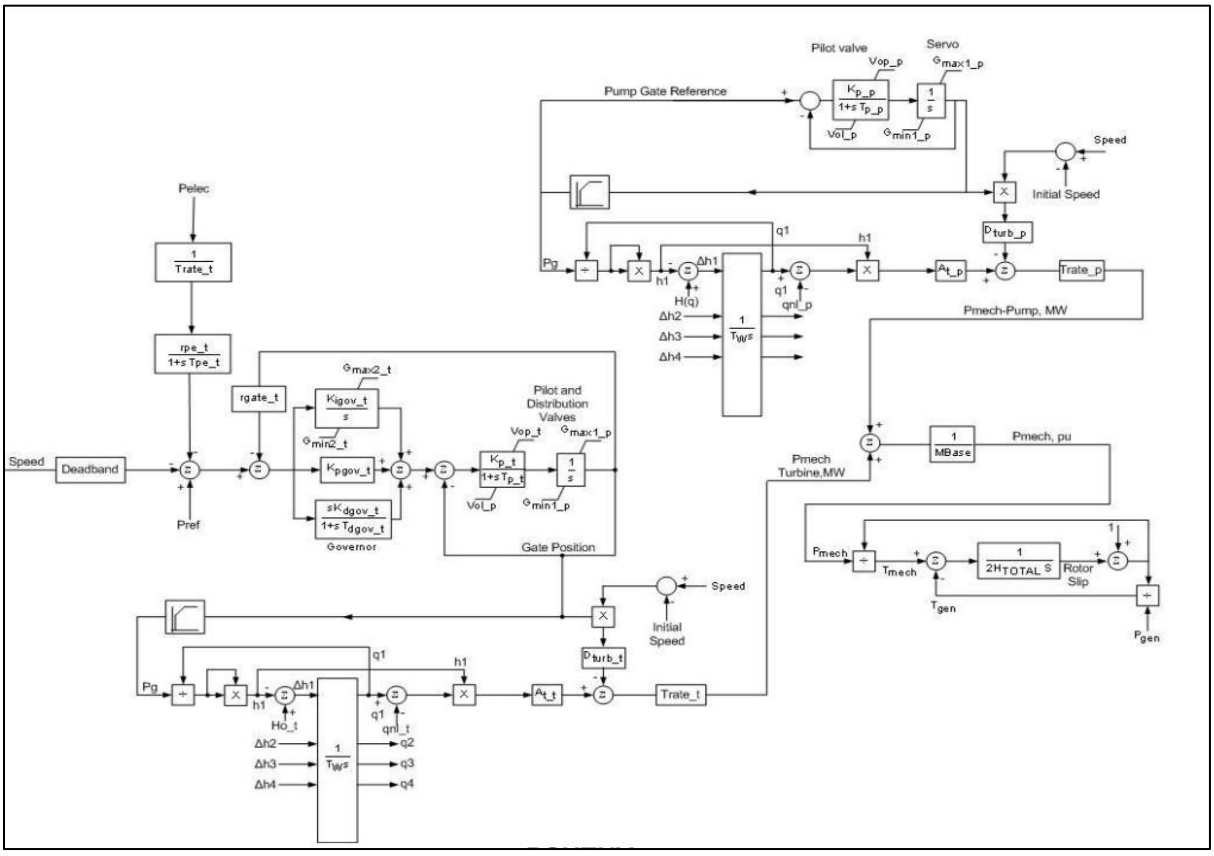
4. PSHPM1:



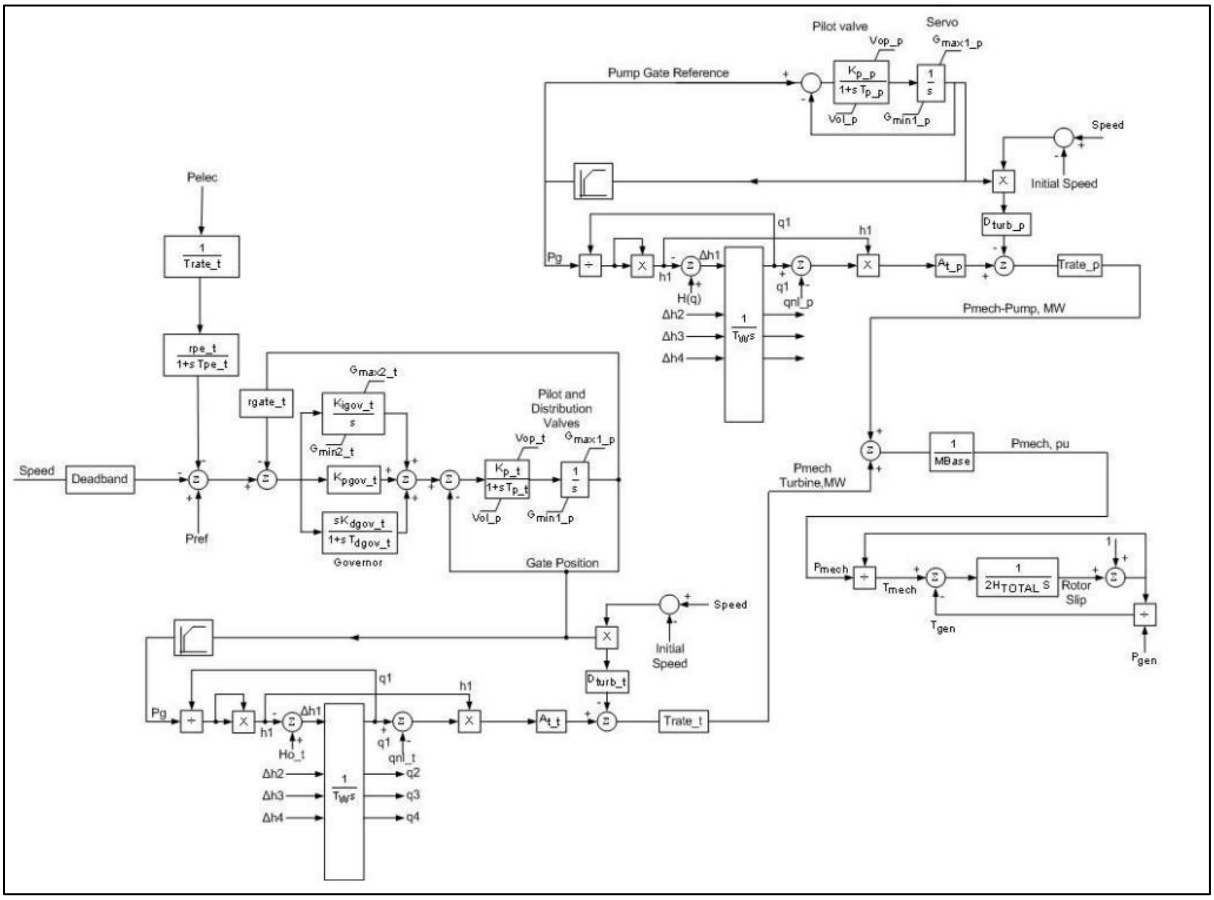
5. PSHPM4:



6. PSHTNY:



7. PSHTN2


Pilot valve
Servo
Vop_p
Gmax1_p
Pump Gate Reference
Kp_p
1+s Tp_p
1
s
Vol_p
Gmin1_p
Speed
Initial Speed
Pelec
1
Trate_t
q1
h1
Dturb_p
Pg
Δh1
h1
H(q)
q1
qnl_p
At_p
Trate_p
Δh2
Δh3
Δh4
1
TWs
Pmech-Pump, MW
rpe_t
1+s Tpe_t
Gmax2_t
rgate_t
Kigov_t
s
Pilot and Distribution Valves
Vop_t
Gmax1_p
Gmin2_t
1
MBase
Pmech, pu
Speed
Deadband
Kpgov_t
Kp_t
1+sTp_t
Pmech Turbine,MW
Vol_p
Gmin1_p
sKdgov_t
1+s Tdgov_t
Pref
Governor
Gate Position
Pmech
Tmech
1
2HTOTAL S
Rotor Slip
Tgen
Pgen
Speed
Initial Speed
Dturb_t
q1
h1
Pg
Δh1
h1
Ho_t
q1
qnl_t
At_t
Trate_t
Δh2
Δh3
Δh4
q2
q3
q4

Guidelines for Model Compatibility and Support for Conventional generating (Thermal, Gas & Hydro) plants, Bulk Consumers or Load Serving Entities and Combined (Load and Captive) Generation Complex

1. Model Compatibility and Support Guidelines

i. Both RMS and EMT models for conventional generating stations and Bulk Consumers / Load Serving Entities and Combined (Load + Captive) Generation Complex shall be submitted. The model shall include auxiliary models such as excitation system model, turbine governor model, AVR and PSS model etc.

ii. The models shall be compatible with the power system software simulation products as specified by Grid-India below: -

a) RMS models shall be compatible with **PSS/E version 36** and above.

Provided that the concerned RLDC may accept the model compatible with version 34 also under special circumstances. The decision in this regard will be at the discretion of the concerned RLDC only.

The RMS models are required to be **generic** [1]models and shall not contain any encrypted or compiled parts, as the system operator must be able to maintain the same without the restrictions of software updates etc.

If there is significant difference in the actual performance of the element vis-à-vis the response of the generic model, then **user defined model (UDM)** shall also be submitted in addition to the generic RMS models.

In case of submission of User Defined Models (UDMs), the submission of the **source code and compiling procedure** along with the model is mandatory.

Further, a comparison report highlighting the difference between the simulation response obtained from the generic model and UDM shall be submitted.

a) EMT models shall be compatible with PSCAD version **5.0** and above with the following –

i. Intel 15 Update 5 and newer (32-bit) and Visual Studio 2015 and newer
ii. Intel 15 Update 5 and newer (64-bit) and Visual Studio 2015 and newer
iii. Model works across a range of time steps and does not require a specific time step

These models must not be dependent on a specific Intel Visual FORTRAN version and should not have dependencies on additional external commercial software.

iii. The simulation models (applicable for generic and UDMs) shall:

a) Be submitted in the form of generating units/load connected to the representation of the Grid (Thevenin-equivalent) SMIB (Single Machine Infinite Bus) model.

b) Be supported by model descriptions that, as a minimum, shall include Laplace domain transfer functions (for RMS models), and function descriptions of the arithmetical, logical and sequence-controlled modules used in the simulation model.

c) Include descriptions of the individual model components and related parameters including saturation, non-linearity, dead band, time delays and constraint functions (non-wind-up/anti wind-up) etc.

d) Include descriptions of the set-up of the simulation model as well as any limitations to the application hereof. There shall be no initialization errors for the dynamic models. The warning messages shall be reviewed and resolution or explanation shall be provided.

e) Work for a range of dynamic simulation solution parameters rather than for specific settings only.

iv) Any model validity limitations due to system impedance or strength or any other reason shall be clearly defined.

v) Models shall not show any characteristics that are not present in the actual HVDC response.

vi) **Model user guide** including model setup procedure, RMS & EMT software version, compiler, visual studio version etc. shall be submitted along with the model.

vii) Model limitations, maximum solution time step etc. to be included in user guide

viii) EMT model shall not contain any dependent libraries. The submitted workspace file (.pswx) must not load any PSCAD library (.pslx) files apart from the PSCAD master library. The model shall be capable of running with no extra steps aside from clicking “Run” option in PSCAD.