

Turbine Controls Seminar

TURBINE CONTROLS BASICS

Pero Skoric - 2018

BASIC DEFINITIONS (1)

TURBINE

Any of various types of machine in which the kinetic energy of a moving fluid is converted into mechanical energy by causing a bladed rotor to rotate. The moving fluid may be water, steam, air, or combustion products of a fuel. (<http://www.thefreedictionary.com/turbine>)

TURBINE CONTROLS

Turbine operating speed is held constant by ensuring that the power generated matches the driven machine load. Balance of power and load is maintained by turbine control system. Turbine control system is often called governor.

*Note a difference in terminology: In the turbine definition there is **energy** while in the turbine controls it is **power/load** instead.*

*Power = energy/**time***

(as soon time is involved it is dynamic process!)

BASIC DEFINITIONS (2)

- The core of any turbine controls is a closed loop with speed (RPM) as the main control process variable. This loop is called **SPEED CONTROL**.
- There are some other controls involved often:
 - *Steam Turbines* - Inlet Pressure Control, Exhaust Pressure Control,
 - *Gas Turbines* – Exhaust Temperature Control, Firing Temperature Control,
 - *Hydro Turbines* – Water Level Control ,

However, they should be seen as additions to the speed control loop.

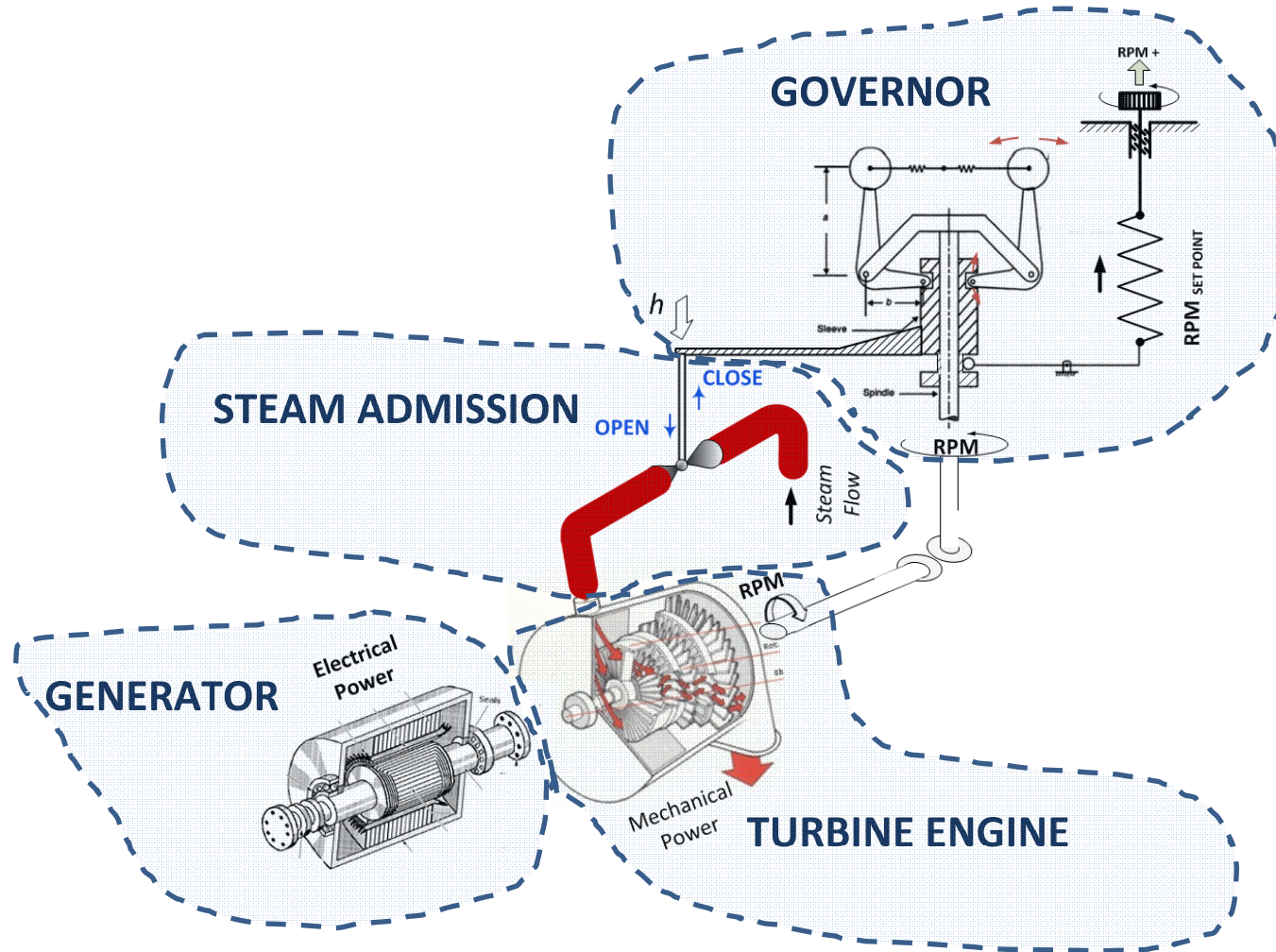
SPEED CONTROL (1)

Analysis and Synthesis

- Speed Control Loop is analyzed here through an example of steam turbo-generator (steam turbine driving electric generator). The same analysis is easily applicable to any other driving machine as, gas turbine, hydro turbine, diesel engines, etc. as well as to any other driven machine as, compressor, pump, etc.
- Turbo-generator is “split” into two parts:
 - **Turbine engine**
It is an energy conversion process. From steam at the control valve to electrical power at the generator.
 - **Turbine rotor**
It is a process of balance that happens at the unit rotor. Electrical power generated is balanced against electrical load with rotor inertia accumulating the difference.

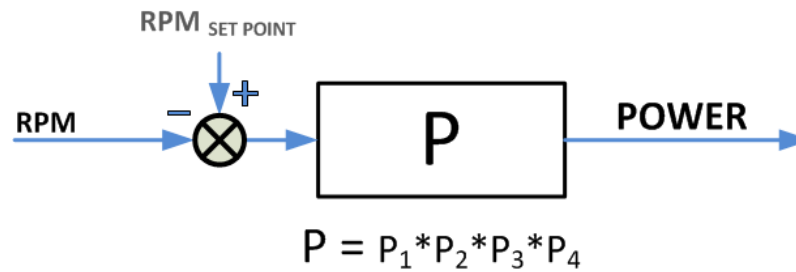
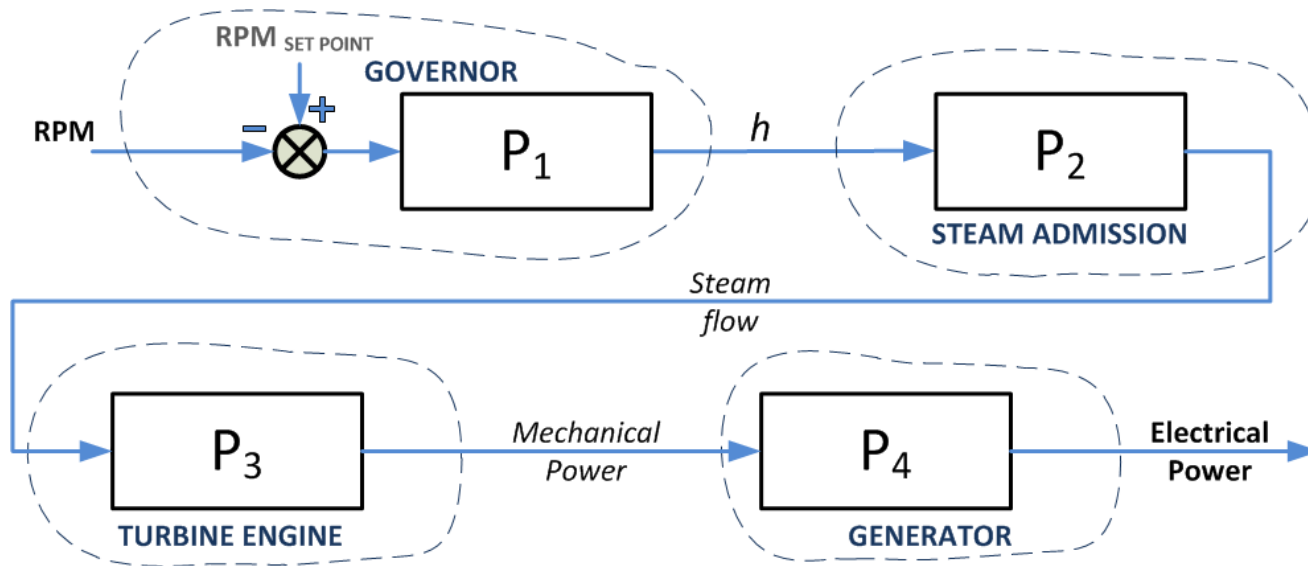
SPEED CONTROL (2)

Turbine Engine Analysis (1)



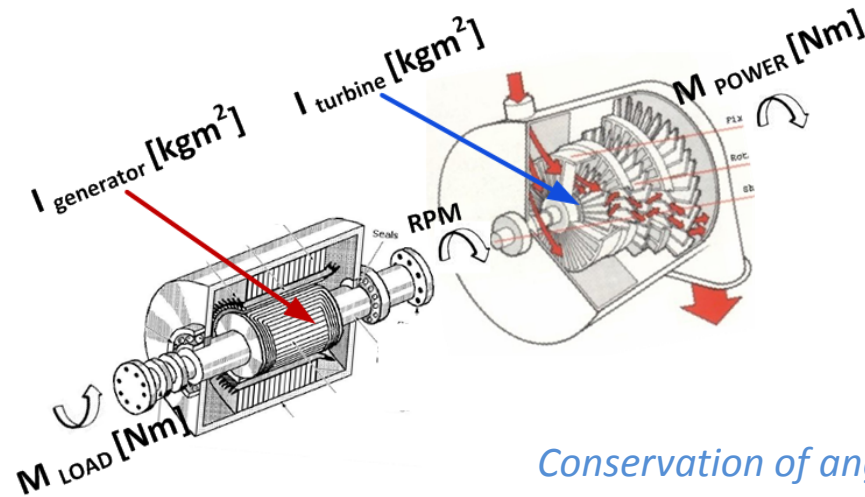
SPEED CONTROL (3)

Turbine Engine Analysis (2)



SPEED CONTROL (4)

Turbine Rotor Analysis (1)

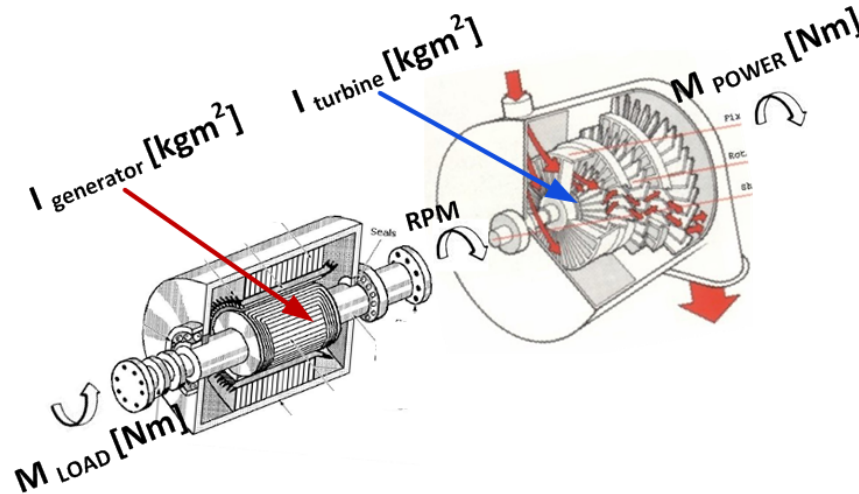


Conservation of angular momentum

$$M_{\text{POWER}} - M_{\text{LOAD}} = (I_{\text{turbine}} + I_{\text{generator}}) * \frac{d\omega}{dt}$$

SPEED CONTROL (5)

Turbine Rotor Analysis (2)



Supporting stuff

$$M[\text{Nm}] * \omega \left[\frac{1}{s} \right] = \text{Power} \left[\frac{\text{Nm}}{s} = W \right]$$

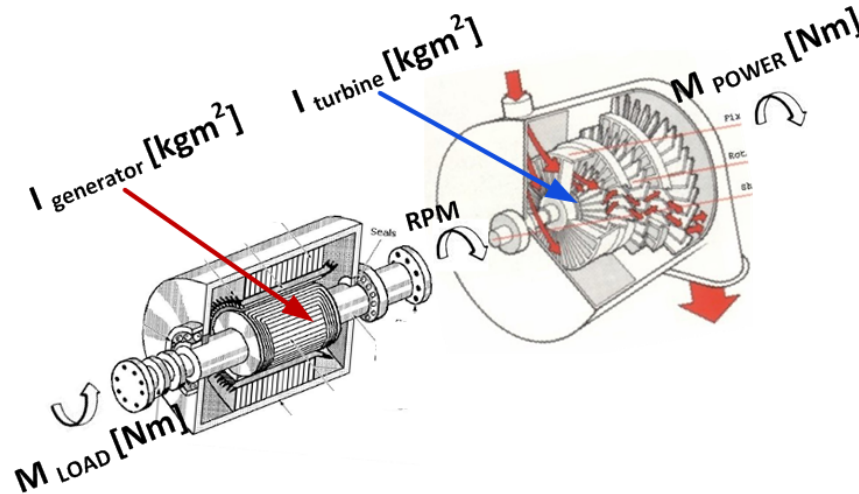
$$\omega = \frac{2 * \pi * \text{RPM}}{60}$$

$$(I_{\text{turbine}} + I_{\text{generator}}) * C = T_{\text{RunUp}} \left[\frac{\text{kgm}^2}{s} \right]$$

$$M_{\text{POWER}} - M_{\text{LOAD}} = (I_{\text{turbine}} + I_{\text{generator}}) * \frac{d\omega}{dt}$$

SPEED CONTROL (6)

Turbine Rotor Analysis (3)



$$M[\text{Nm}] * \omega \left[\frac{1}{s} \right] = \text{Power} \left[\frac{\text{Nm}}{s} = \text{W} \right]$$

$$\omega = \frac{2 * \pi * \text{RPM}}{60}$$

$$(I_{\text{turbine}} + I_{\text{generator}}) * C = T_{\text{RunUp}} \left[\frac{\text{kgm}^2}{s} \right]$$

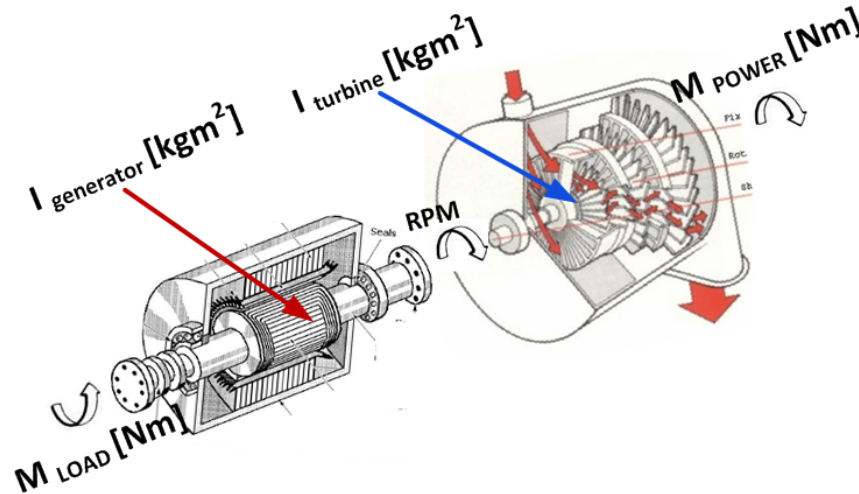
$$M_{\text{POWER}} - M_{\text{LOAD}} = (I_{\text{turbine}} + I_{\text{generator}}) * \frac{d\omega}{dt}$$

$$\text{POWER} - \text{LOAD} = T_{\text{RunUp}} * \frac{d\text{RPM}}{dt}$$

Conservation of angular momentum in Turbine Form

SPEED CONTROL (7)

Turbine Rotor Analysis (4)



$$M[Nm] * \omega \left[\frac{1}{s} \right] = \text{Power} \left[\frac{Nm}{s} = W \right]$$

$$\omega = \frac{2 * \pi * \text{RPM}}{60}$$

$$(I_{\text{turbine}} + I_{\text{generator}}) * C = T_{\text{RunUp}} \left[\frac{kgm^2}{s} \right]$$

$$M_{\text{POWER}} - M_{\text{LOAD}} = (I_{\text{turbine}} + I_{\text{generator}}) * \frac{d\omega}{dt}$$

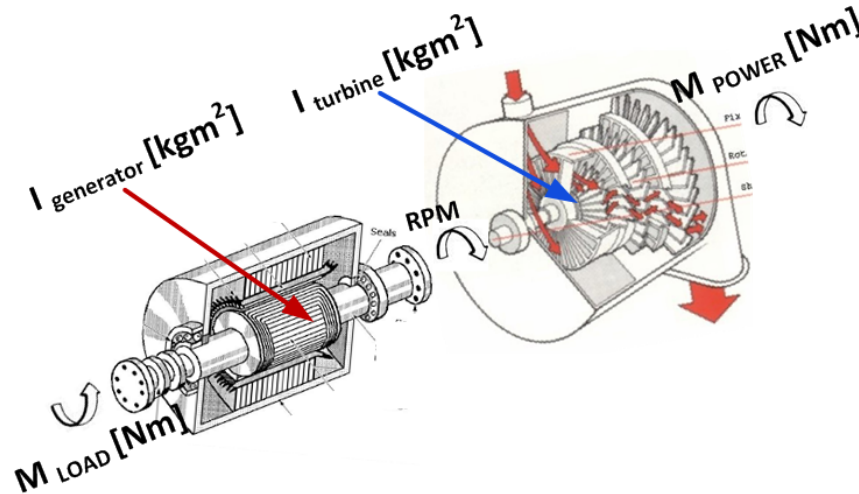
$$\text{POWER} - \text{LOAD} = T_{\text{RunUp}} * \frac{d\text{RPM}}{dt}$$

$$\Delta \text{RPM} = \frac{1}{T_{\text{RunUp}}} * \int_0^t (\text{POWER} - \text{LOAD}) dt$$

Time domain solution

SPEED CONTROL (8)

Turbine Rotor Analysis (5)



$$M[\text{Nm}] * \omega \left[\frac{1}{s} \right] = \text{Power} \left[\frac{\text{Nm}}{s} = W \right]$$

$$\omega = \frac{2 * \pi * \text{RPM}}{60}$$

$$(I_{\text{turbine}} + I_{\text{generator}}) * C = T_{\text{RunUp}} \left[\frac{\text{kgm}^2}{s} \right]$$

$$M_{\text{POWER}} - M_{\text{LOAD}} = (I_{\text{turbine}} + I_{\text{generator}}) * \frac{d\omega}{dt}$$

$$\text{POWER} - \text{LOAD} = T_{\text{RunUp}} * \frac{d\text{RPM}}{dt}$$

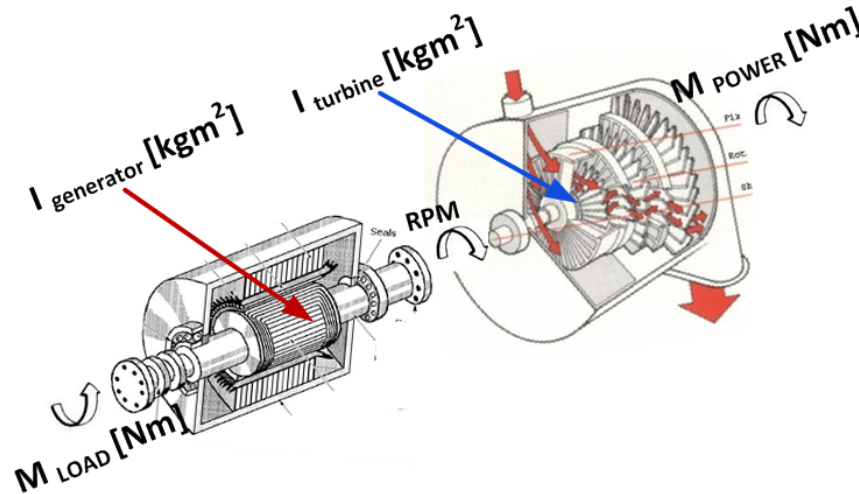
$$\Delta \text{RPM} = \frac{1}{T_{\text{RunUp}}} * \int_0^t (\text{POWER} - \text{LOAD}) dt \quad \text{Time domain solution}$$

Laplace Transformation



SPEED CONTROL (9)

Turbine Rotor Analysis (6)



$$M[Nm] * \omega \left[\frac{1}{s} \right] = \text{Power} \left[\frac{Nm}{s} = W \right]$$

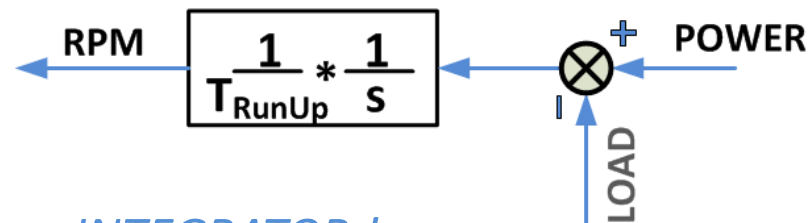
$$\omega = \frac{2 * \pi * \text{RPM}}{60}$$

$$(I_{\text{turbine}} + I_{\text{generator}}) * C = T_{\text{RunUp}} \left[\frac{kgm^2}{s} \right]$$

$$M_{\text{POWER}} - M_{\text{LOAD}} = (I_{\text{turbine}} + I_{\text{generator}}) * \frac{d\omega}{dt}$$

$$\text{POWER} - \text{LOAD} = T_{\text{RunUp}} * \frac{d\text{RPM}}{dt}$$

$$\Delta \text{RPM} = \frac{1}{T_{\text{RunUp}}} * \int_0^t (\text{POWER} - \text{LOAD}) dt$$

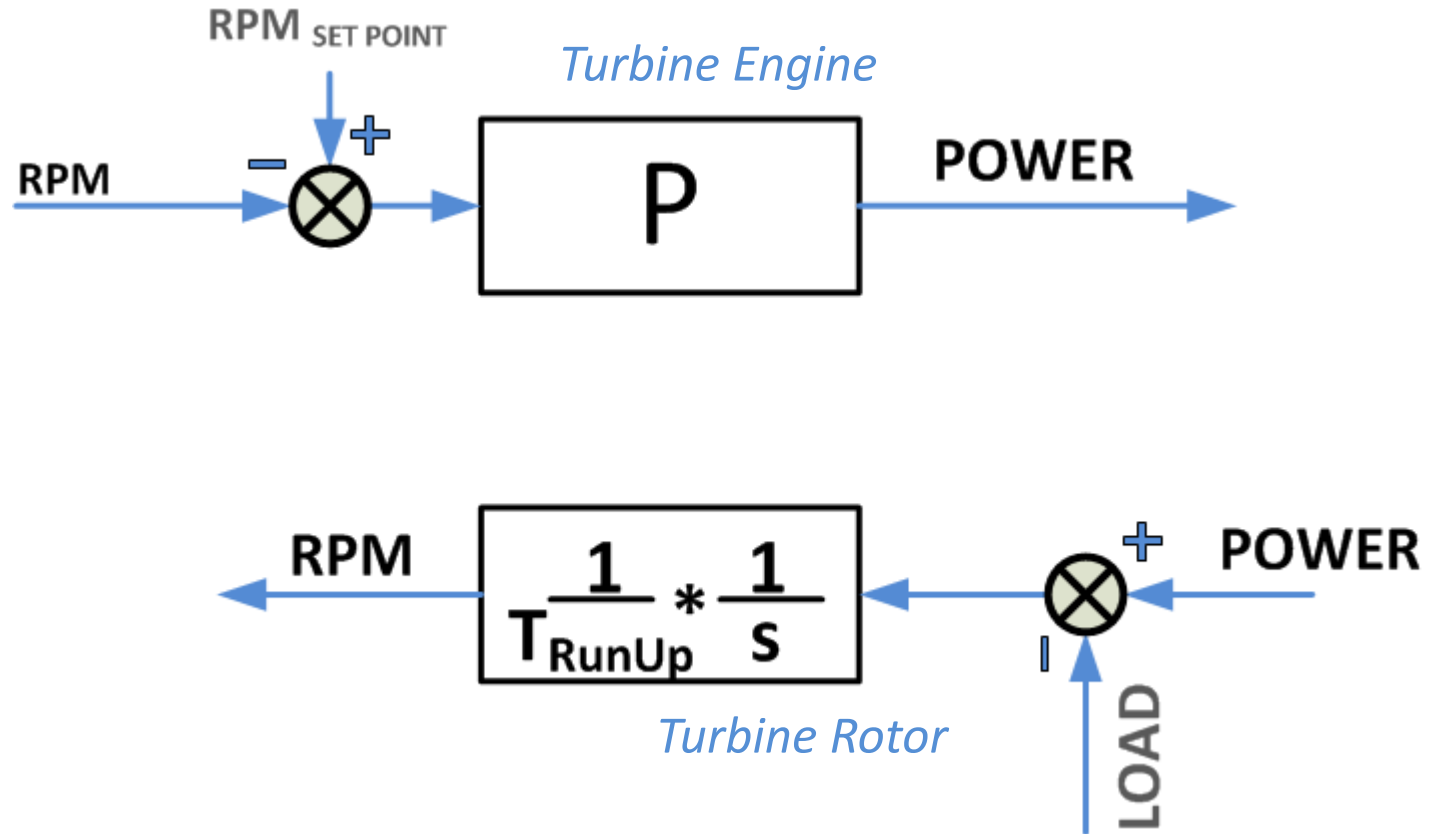


Turbine rotor is an INTEGRATOR !

<http://turbine.arirang.hr/linear-theory/10-2/102-2/>

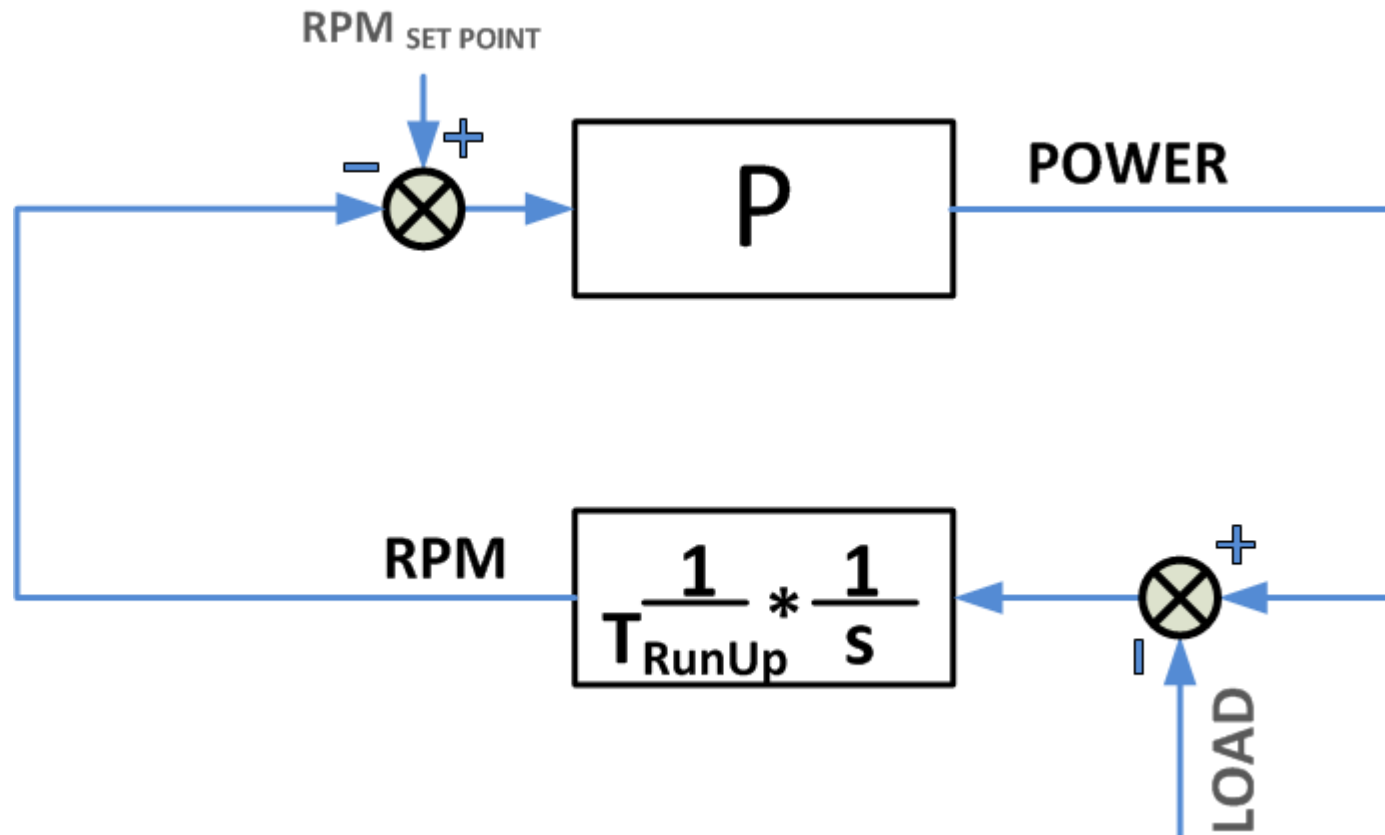
SPEED CONTROL (10)

Closing the loop (1)



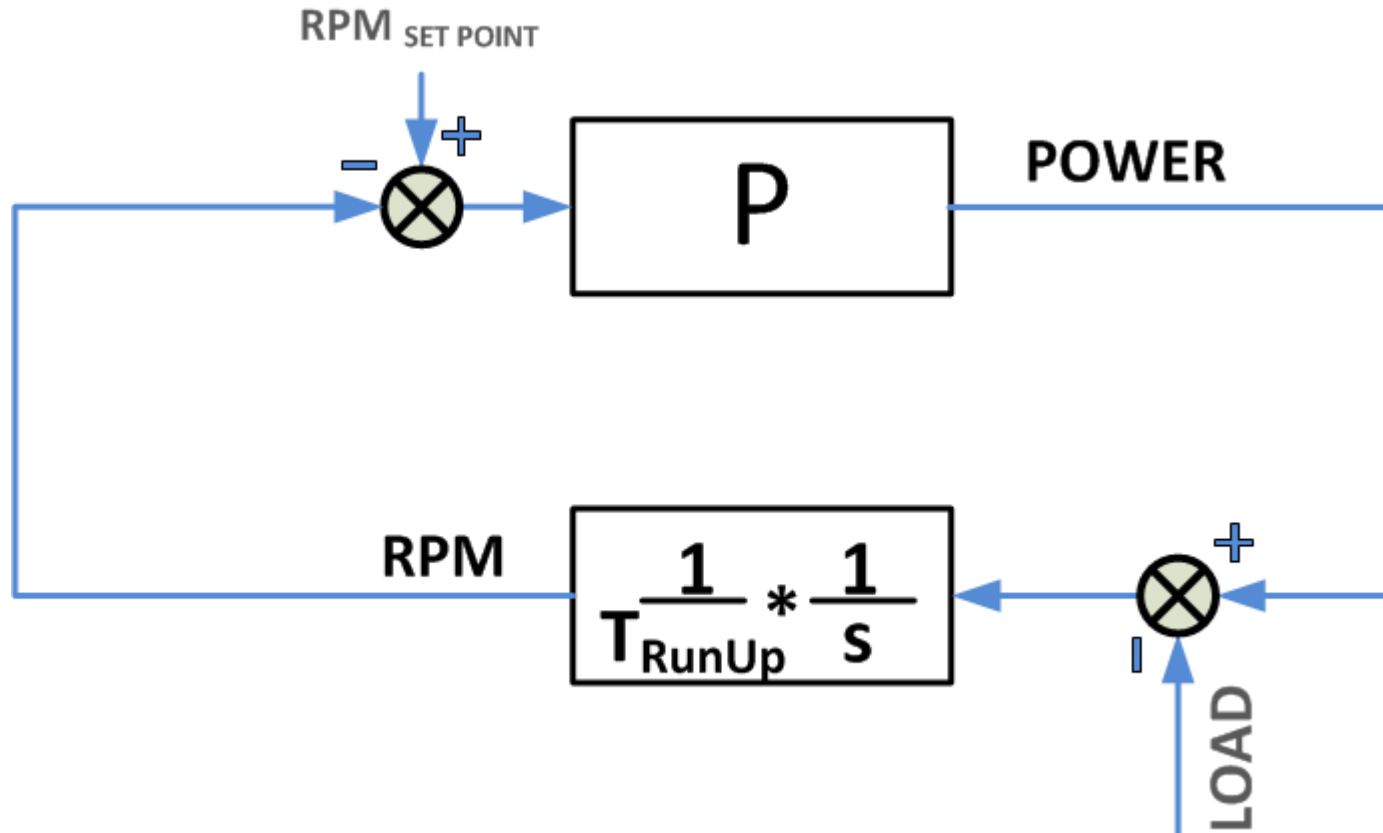
SPEED CONTROL (11)

Closing the loop (2)



SPEED CONTROL (12)

Closing the loop (3)



Closed Loop Control Theory can be applied.

Time domain, Linear theory, frequency domain, Nyquist, etc.

However, all the theory itself has a limited engineering use because of numerous assumptions and approximations applied.

Results are not more than “just an educated guesses”.

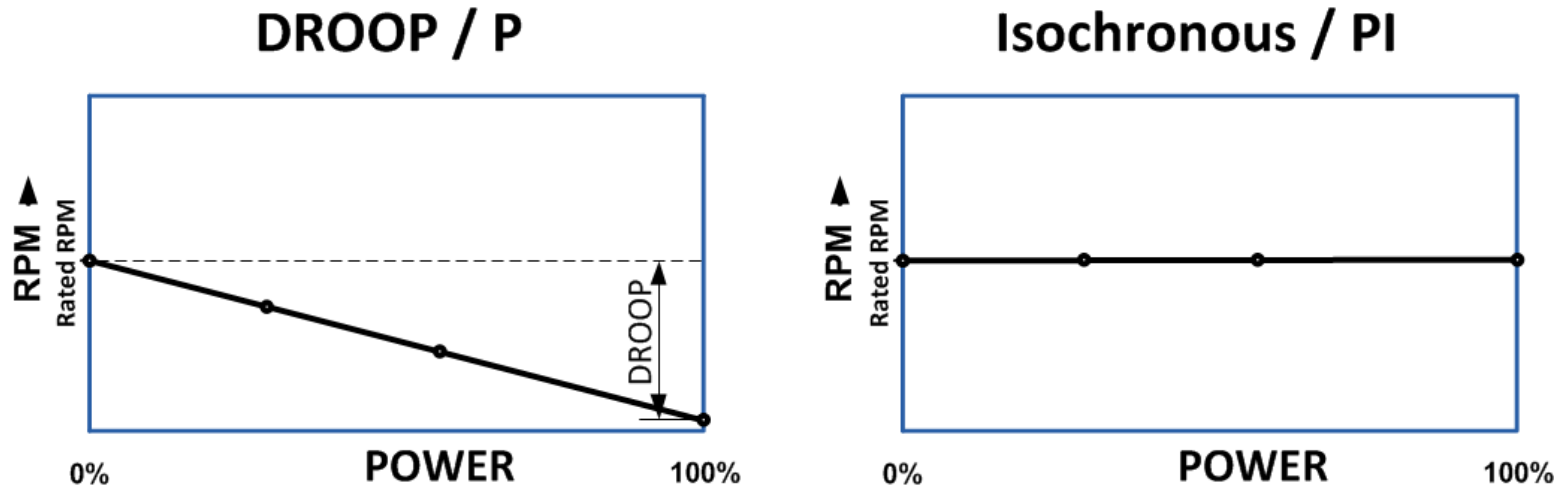
In the real world linear systems don't exist at all!!!!

TURBO-GENERATOR CONTROL AGAINST MECHANICAL DRIVE CONTROL

- Turbo-generator control is much more demanding than mechanical drive control.
- Mechanical drive unit is always in closed loop speed control mode ONLY.
- Turbo-generator unit goes through three different modes. They are:
 - **Closed Loop Speed Control.** Active in two situations:
 - During run-up to operating speed;
 - While generator is in island operation supplying power alone
 - **Parallel operation with other units.** Active while generator is in island operation supplying power in parallel with other generators.
 - **Open loop control.** Active when generator is operating with public grid;
- Controls need to switch seamlessly between the operating modes at any time;

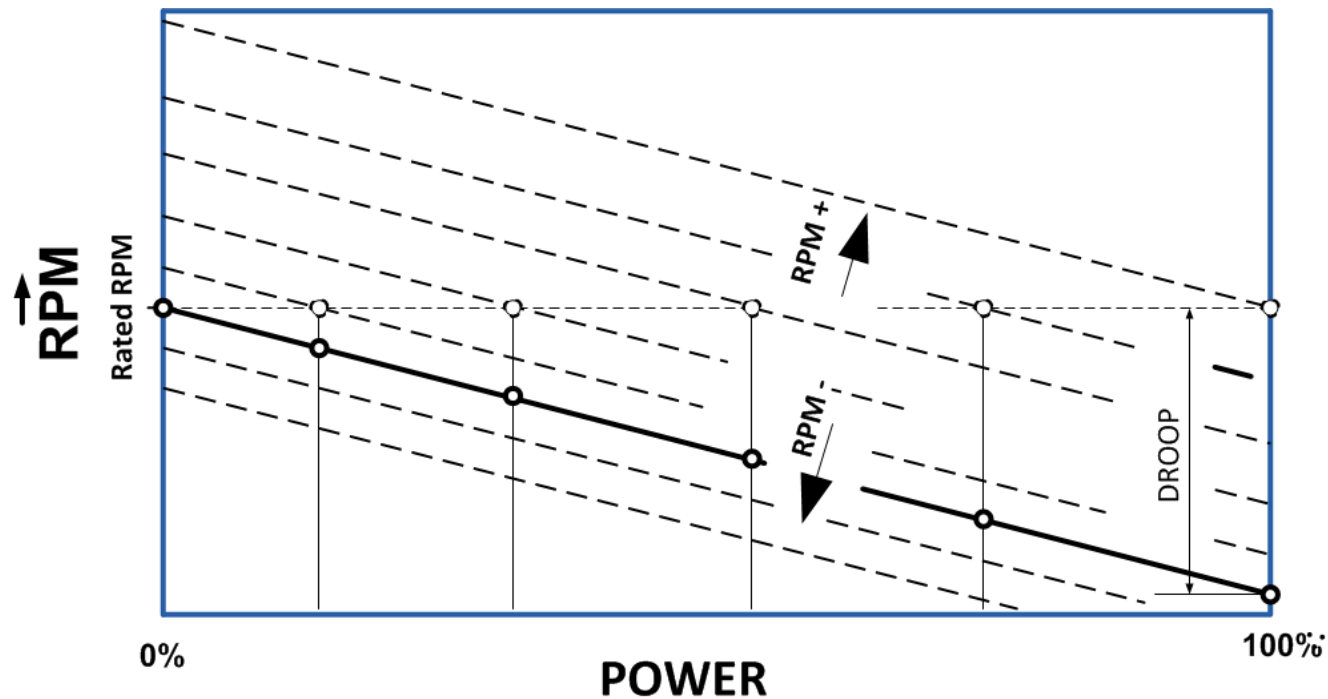
DROOP(USA) / P CONTROL (Europe) (1)

- DROOP/(P) Control is required to enable stable operation in parallel mode.



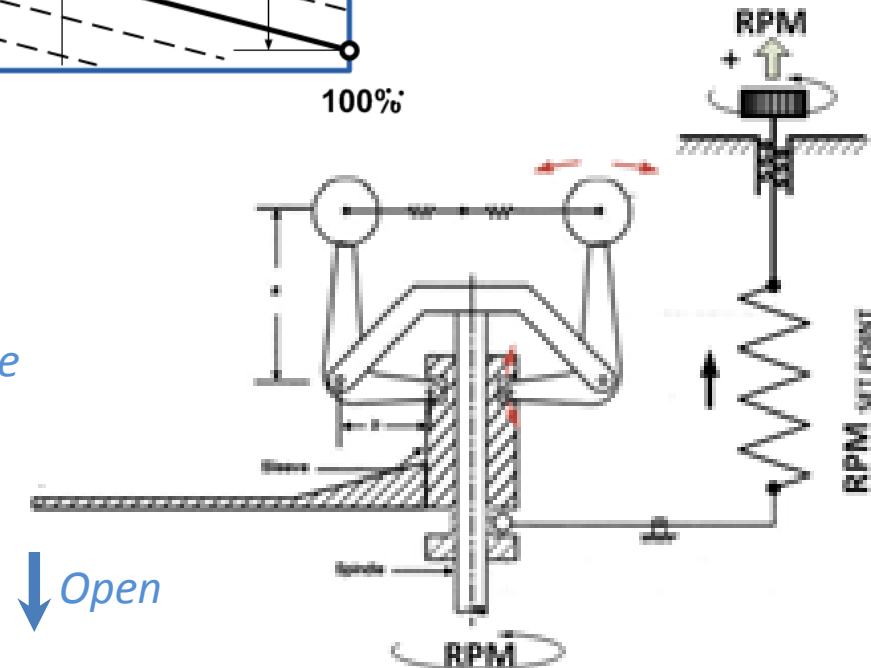
- Isochronous – All operating points are at the same speed.
- DROOP – Each operating point is defined by its own POWER and RPM.
- Operating on grid is an extreme case of parallel mode. Generator operates in parallel with “another generator of a huge inertia”.
- Why DROOP is needed <http://turbine.arirang.hr/tmc-playground/exercise/> (Lab.1)

DROOP(USA) / P CONTROL (Europe) (2)



Keep going **RPM+** to maintain the rated speed after loading.
Keep going **RPM-** to maintain the rated speed after unloading.

With this governor **RPM+** and **RPM-** is achieved by turning the knob "RPM"

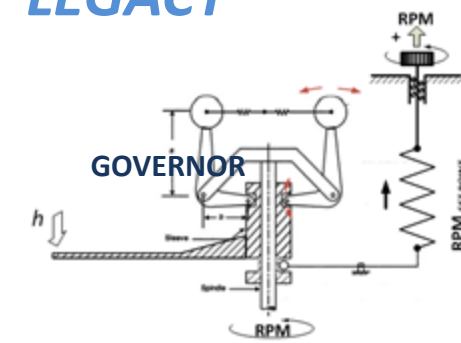


DROOP(USA) / P CONTROL (Europe) (3)

LEGACY

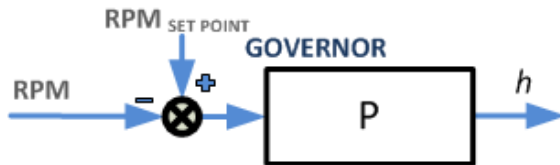
How it's done

TODAY



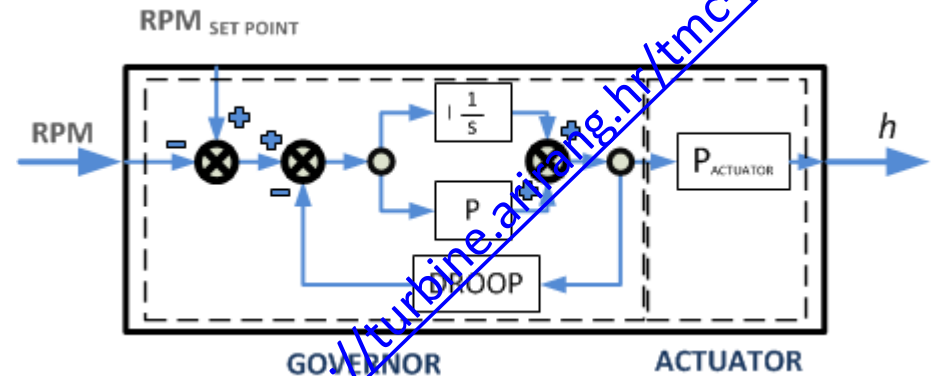
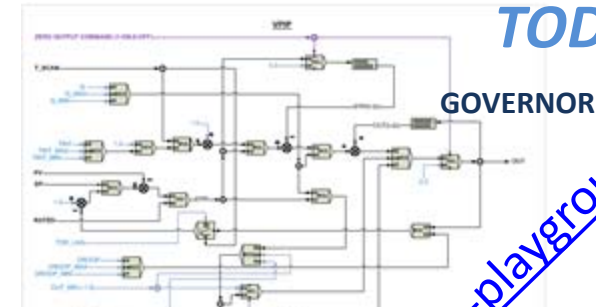
PLC Algorithm

Mechanical



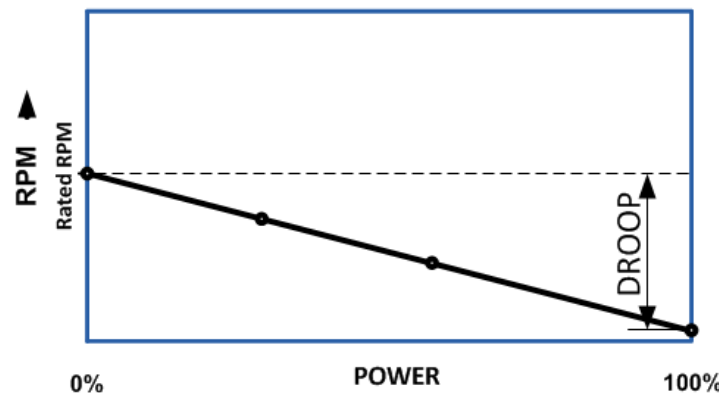
P -> Gain

$$\text{DROOP} = \frac{1}{P}$$



DROOP / P

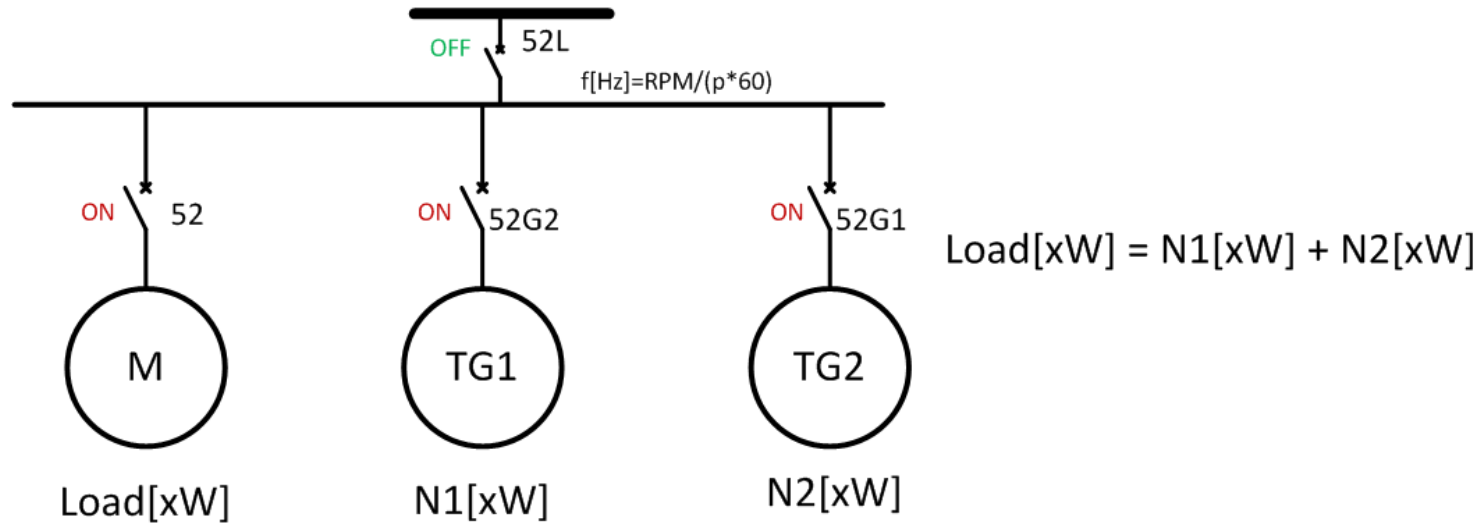
- *P is the only one that is tunable;*
- *P sets the DROOP and effects the stability at the same time;*



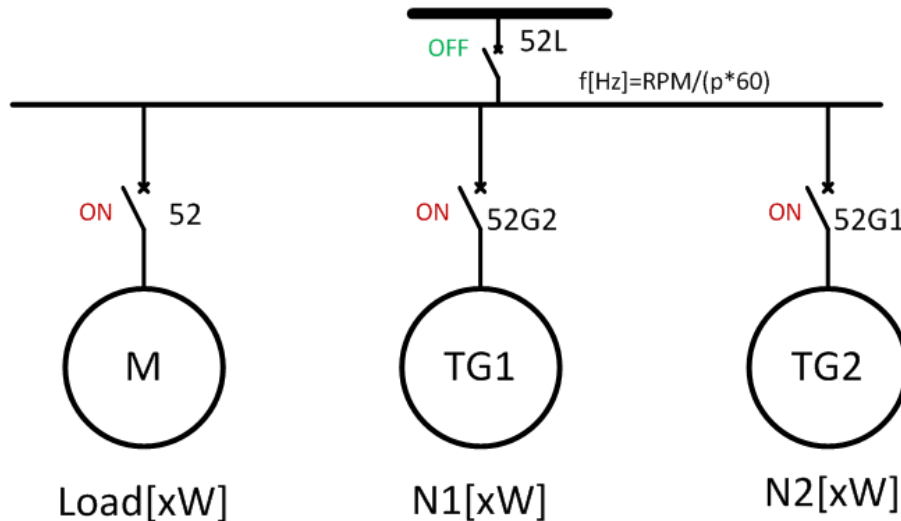
- *Tunables are I, P, DROOP;*
- *I, P tuned for stability;*
- *DROOP has only a minor effect to stability*

<http://turbine.alang.hytmc-playground/>

PARALEL OPERATION (1)

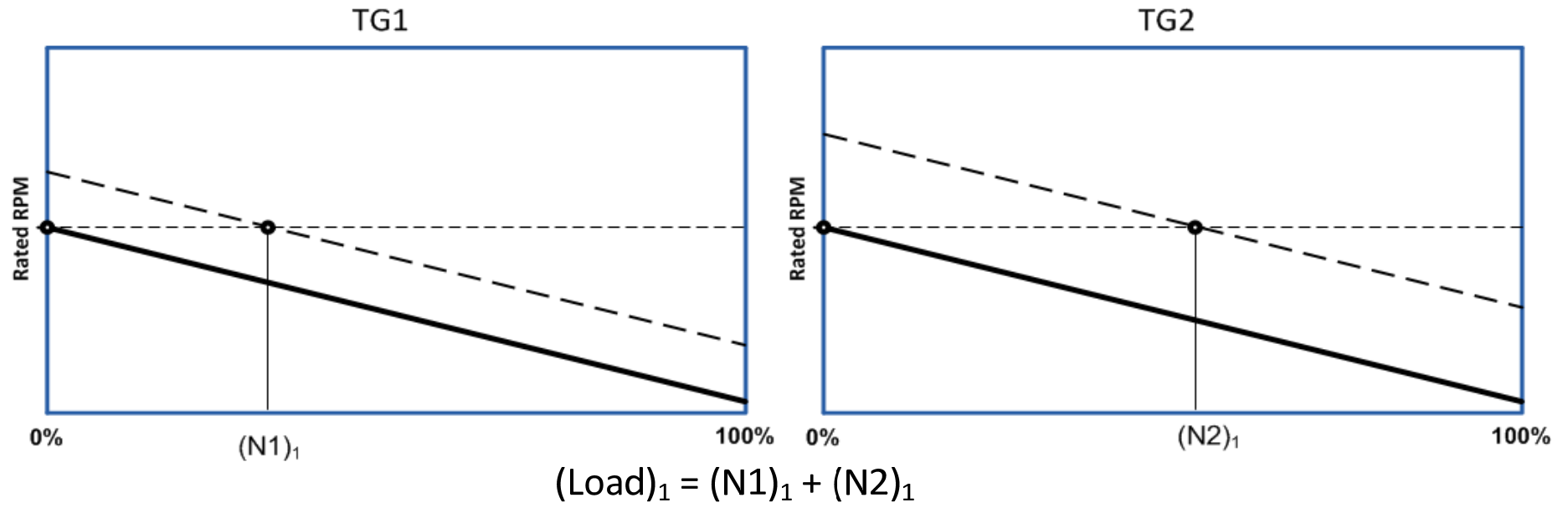


PARALEL OPERATION (2)

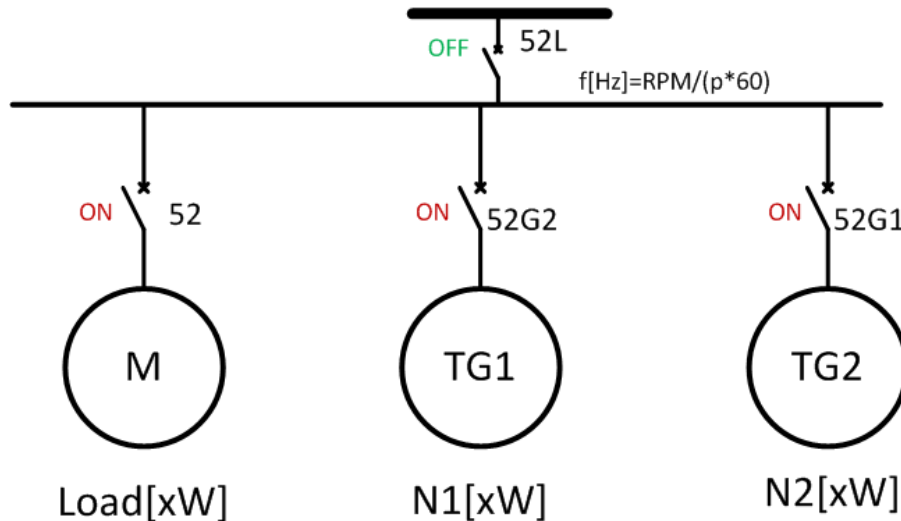


$$\text{Load}[xW] = N1[xW] + N2[xW]$$

Steady State

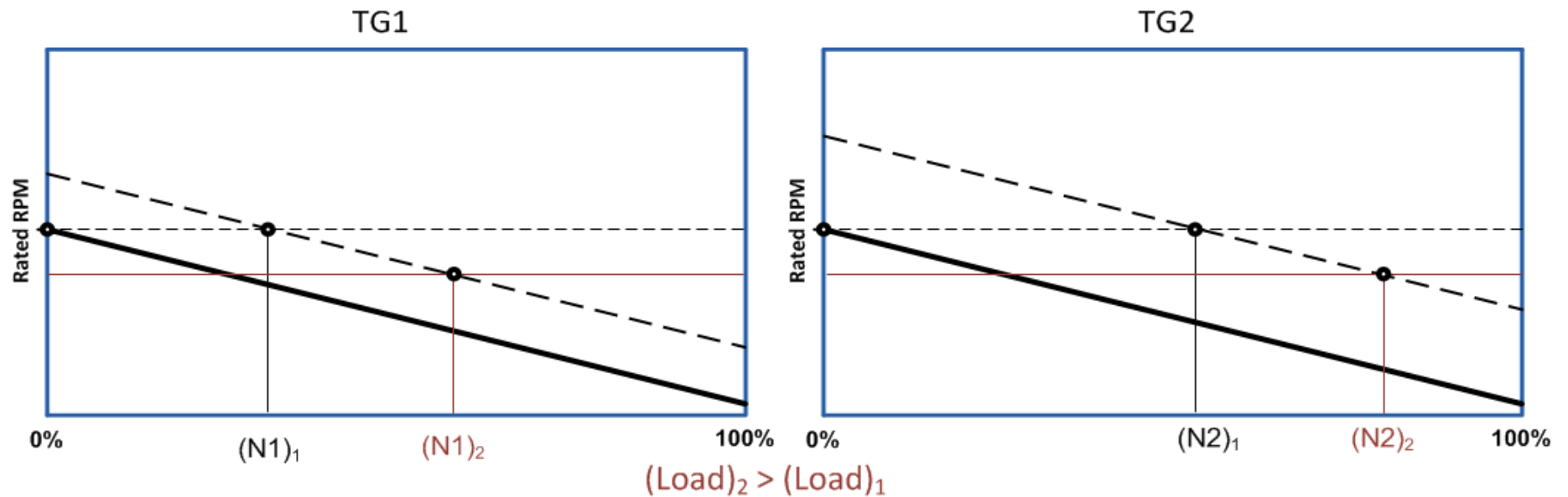


PARALEL OPERATION (3)



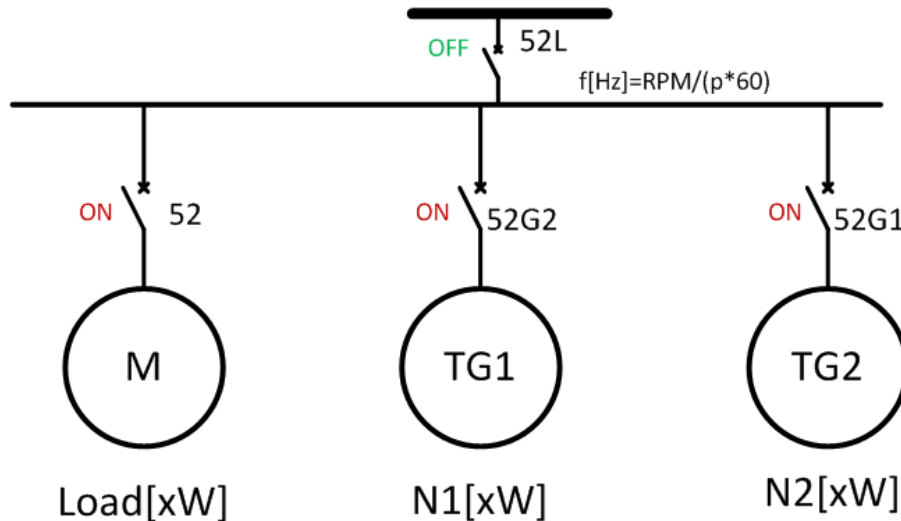
$$\text{Load}[\text{xW}] = N1[\text{xW}] + N2[\text{xW}]$$

Loading Up

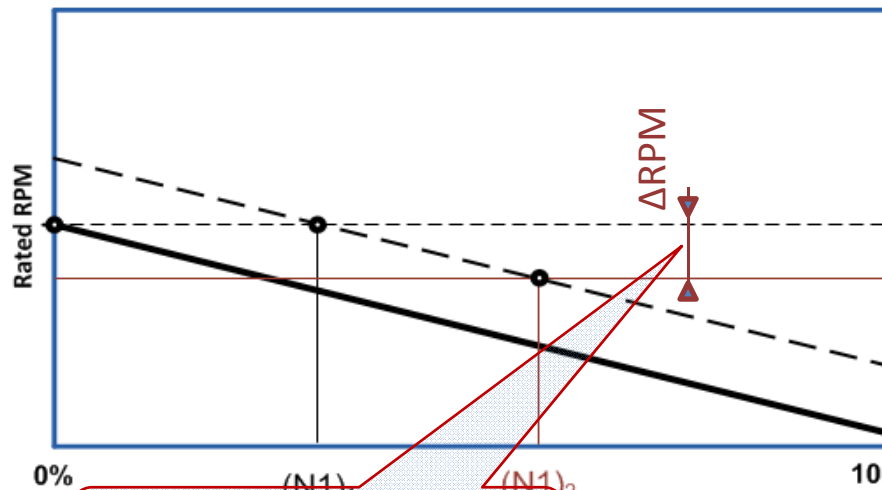


$$(\text{Load})_2 = (N1)_2 + (N2)_2$$

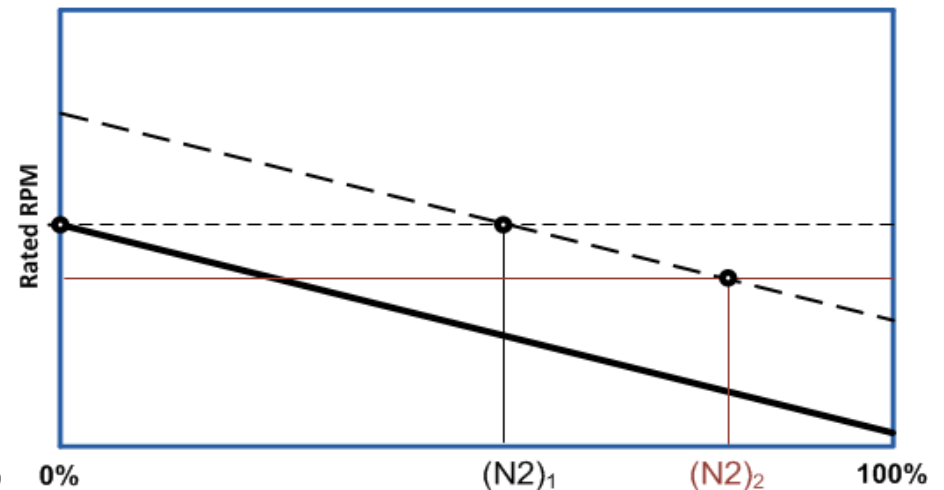
PARALEL OPERATION (4)



$$\text{Load}[\text{xW}] = N1[\text{xW}] + N2[\text{xW}]$$



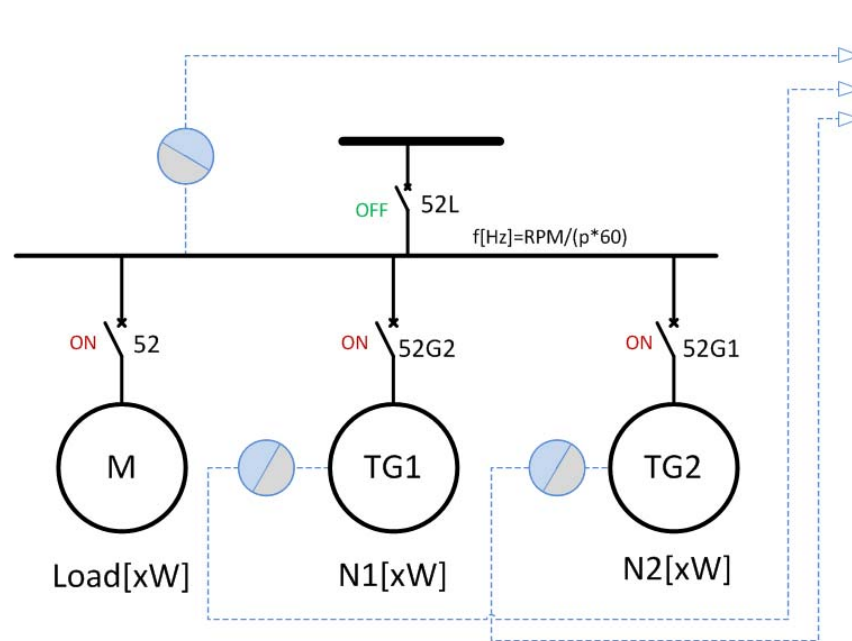
ΔRPM is a consequence of DROOP/P control



$$(\text{Load})_2 > (\text{Load})_1$$

$$(\text{Load})_2 = (N1)_2 + (N2)_2$$

PARALEL OPERATION (5)

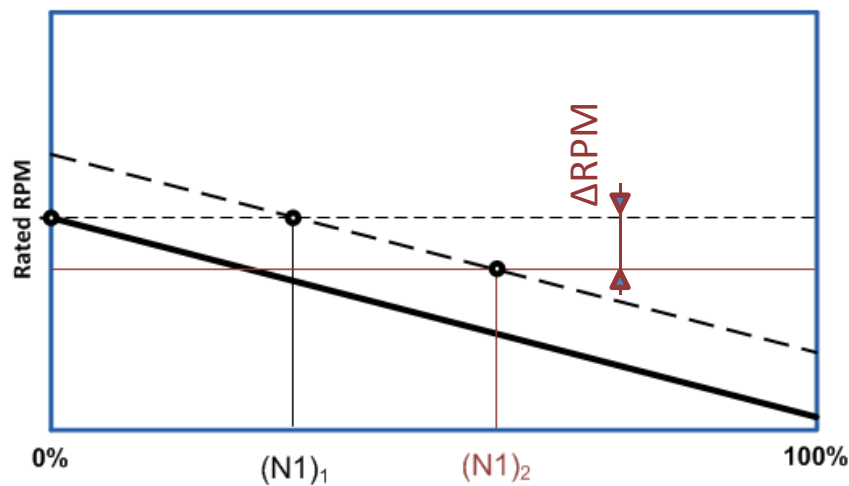


Load Sharing System

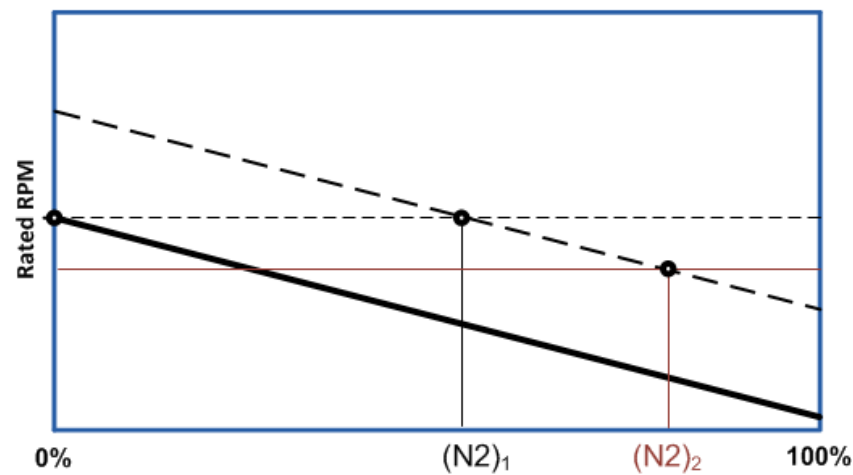
(TG1)RPM SET POINT

(TG2)RPM SET POINT

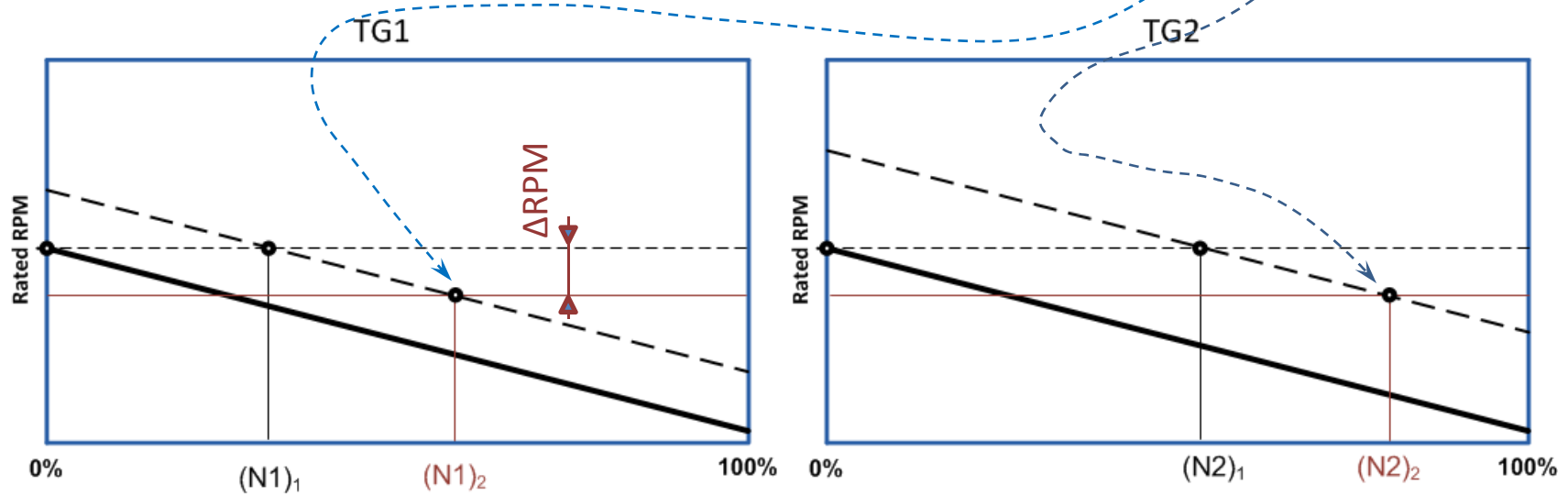
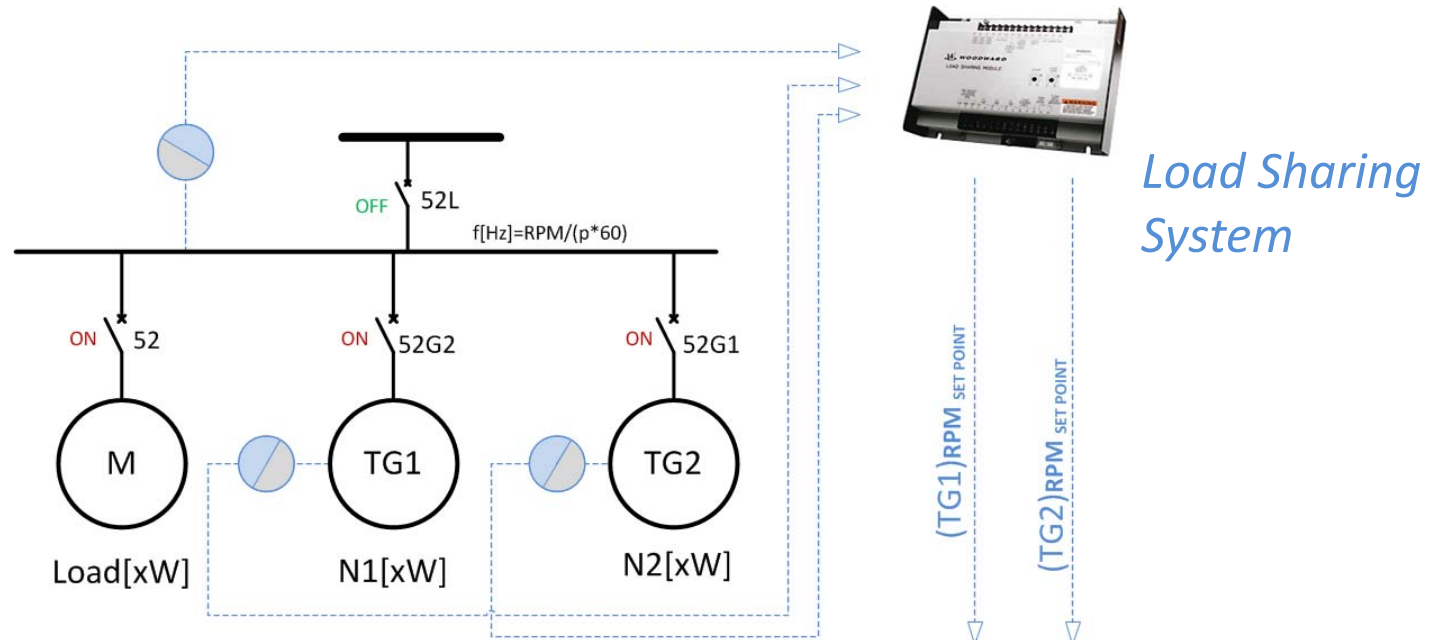
TG1



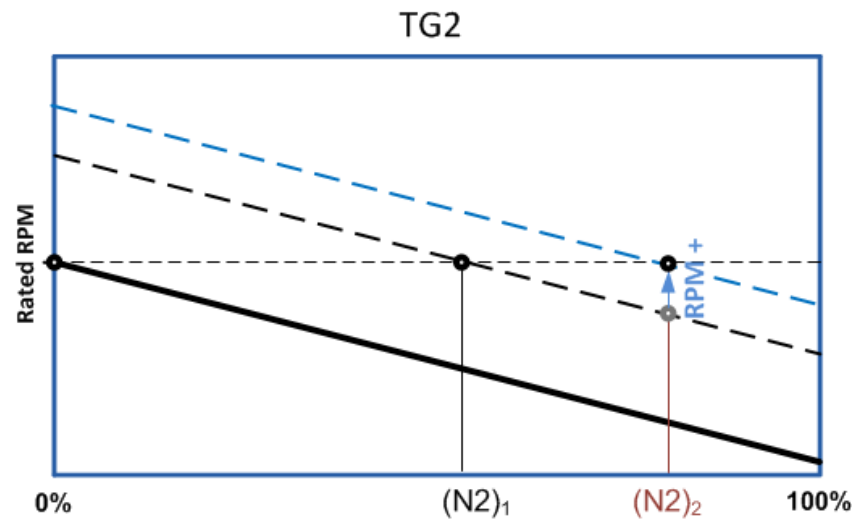
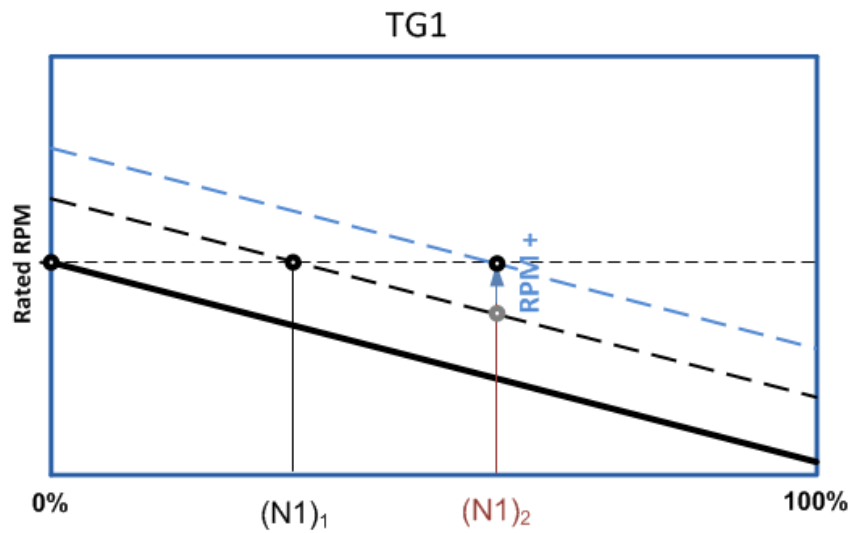
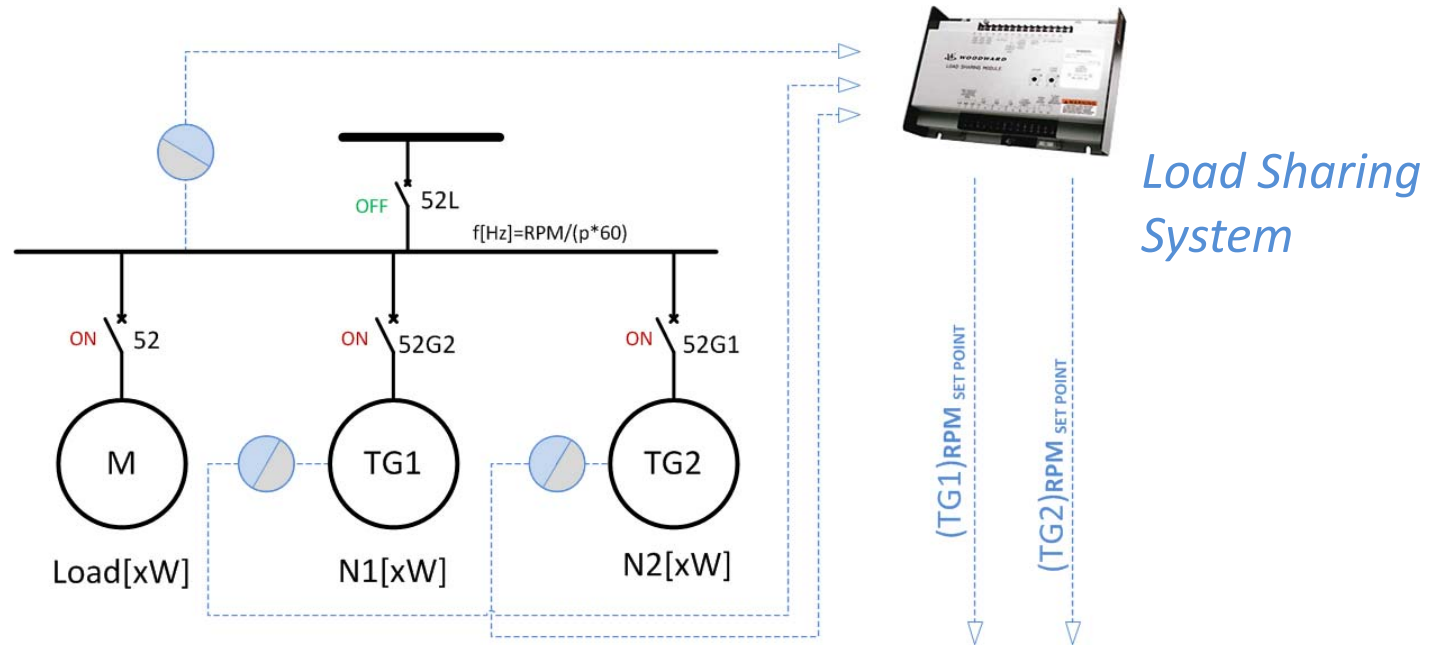
TG2



PARALEL OPERATION (6)



PARALEL OPERATION (7)

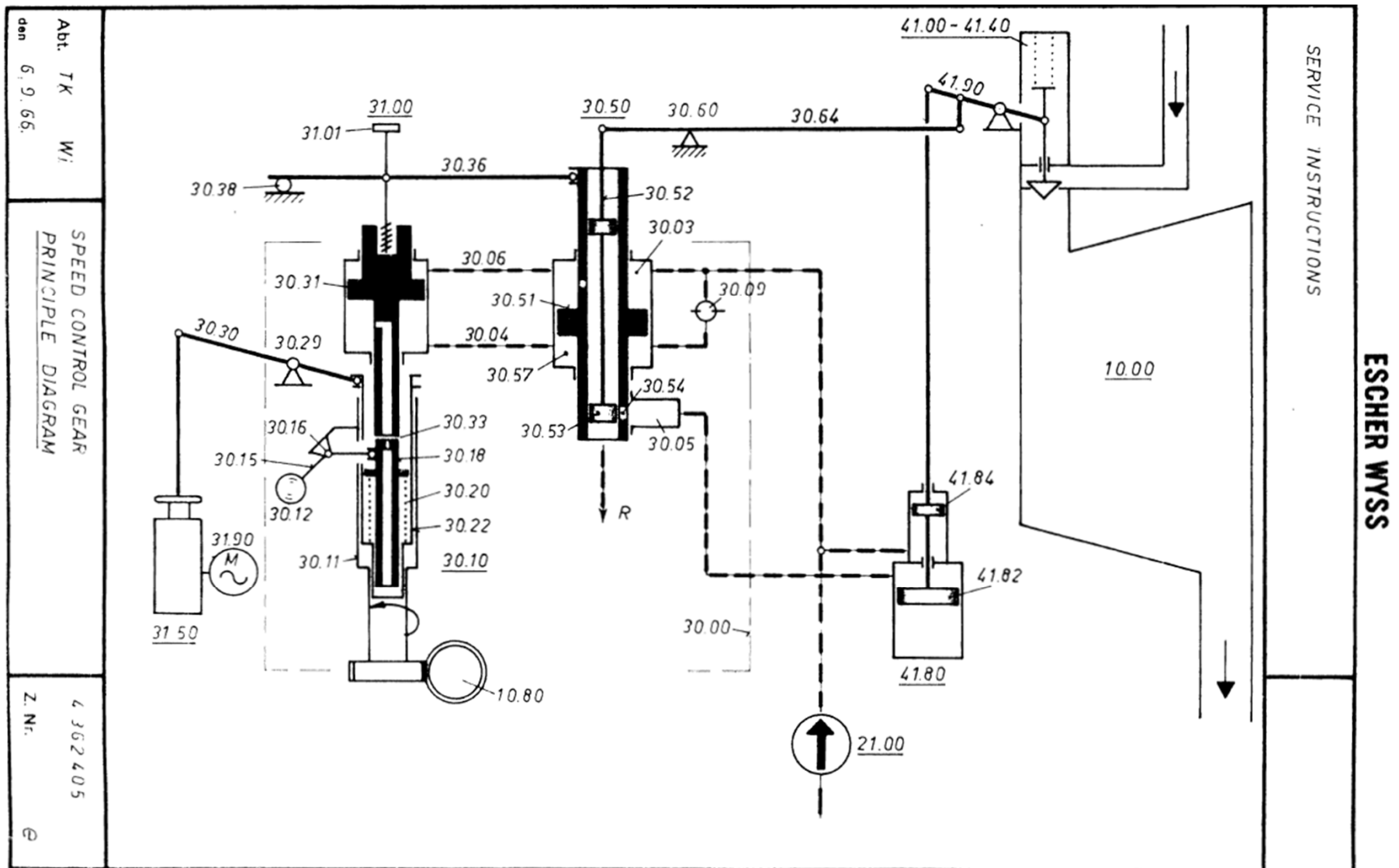


PARALEL OPERATION (8)

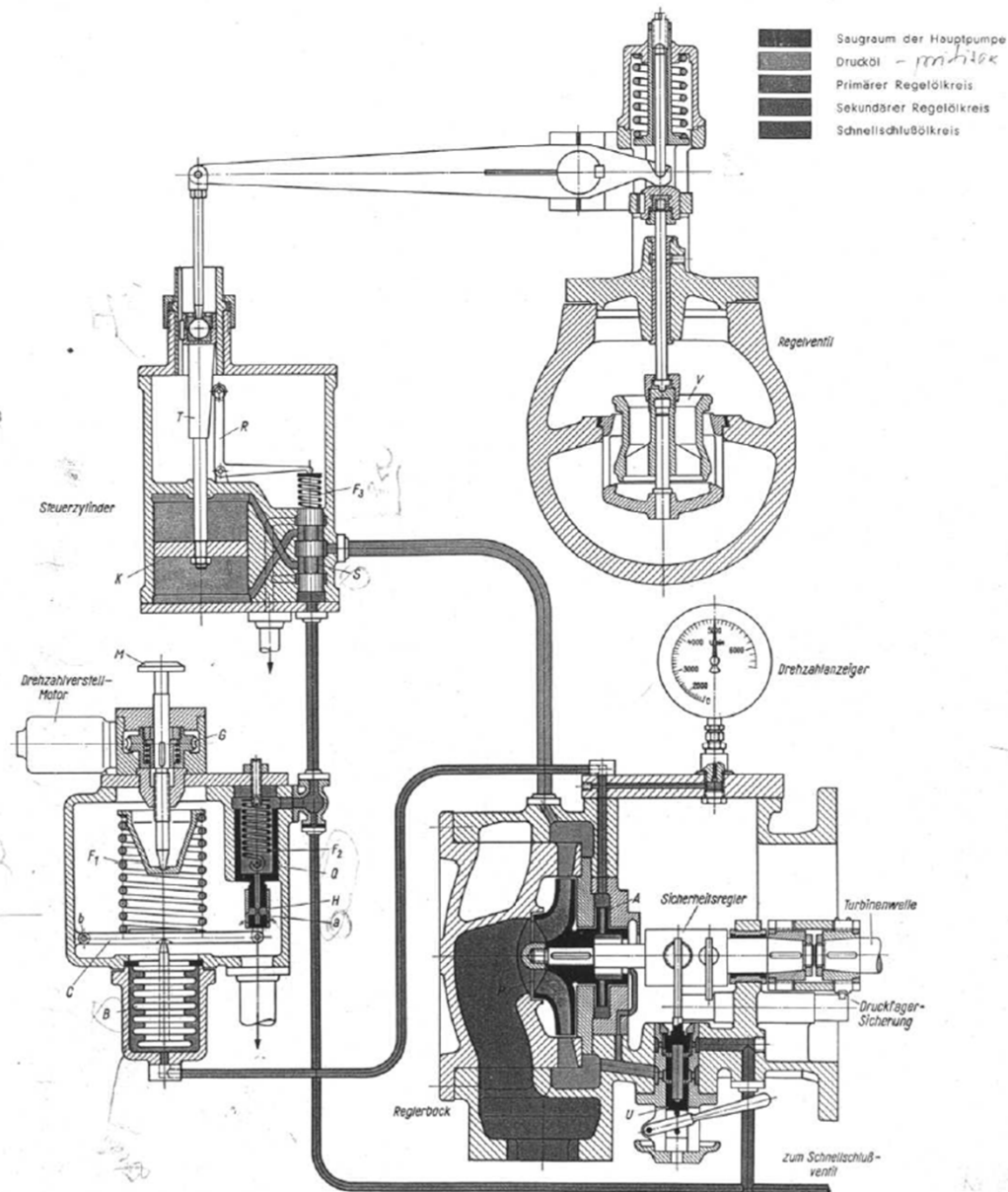
<http://turbine.arirang.hr/tmc-playground/exercise/>

(Lab 2)

TURBINE CONTROLS BASICS EXAMPLES (1)



TURBINE CONTROLS BASICS EXAMPLES (2)



Siemens Classic
Steam Turbine
Governor System

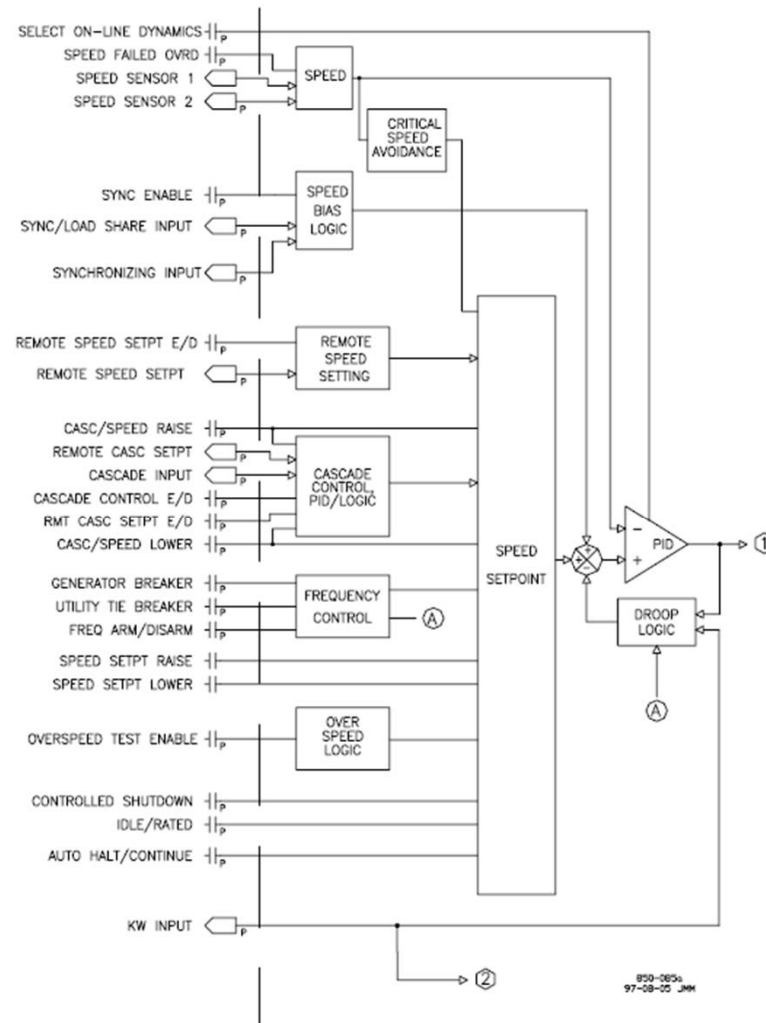
No flywheel !
Impeller instead !

TURBINE CONTROLS BASICS EXAMPLES (3)

505 Digital Governor

Manual 85017V1

*WOODWARD UG 8 (options)
The most successful
mechanical governor*

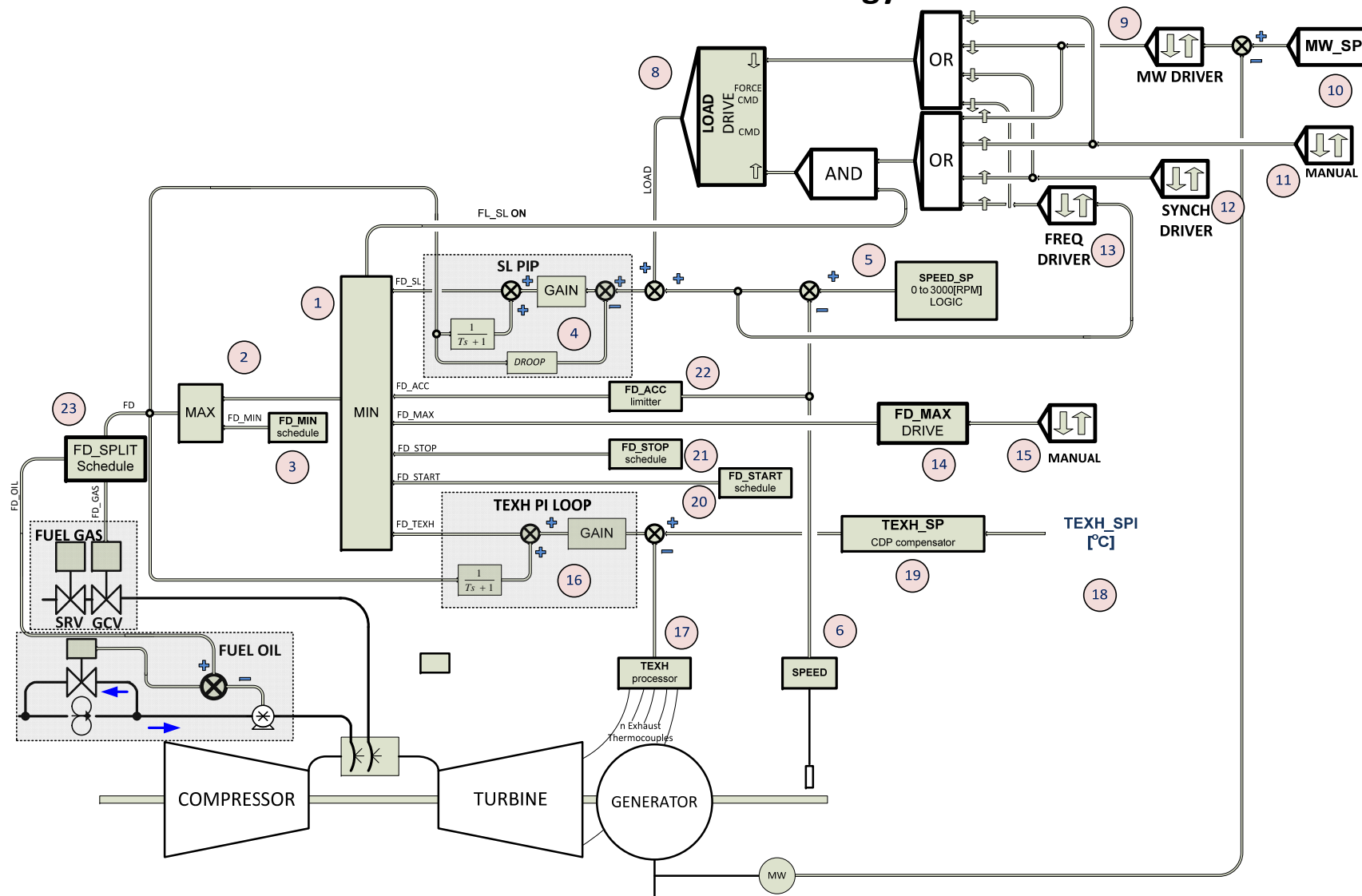


*WOODWARD 505 (options)
The most successful
Electronic governor*

*Fixed structure;
Good documentation;
Works well for most of the cases;
Cant fix unit specifics !*

Figure 2-3. Overview of 505 Functionality

Gas turbine Control Strategy Basics



Detailed Description in a separate document

DISCUSSION !