Directly Controlled: $T_{AVG}$, $P_{impulse}$, RPM, Level

Not Directly Controlled: $T_{sat}$, $P_{rel}$, $m_{Steam}$, $P_{SG}$, $m_{FW}$
CONTROLLING $T_{avg}$ IMPLIES CONTROLLING $P_{SG}$

$$\hat{Q}_{avg} \approx (UA)_{SG} (T_{AVG} - T_{sat}) \text{ where } T_{sat} = T_{Sat}(P_{SG})$$

Given $T_{avg}$ and $\hat{Q}_{RX} = \hat{Q}_{avg} \cong \dot{W}_{r} / \eta \Rightarrow \Delta T$ across S/G Fixed $\Rightarrow T_{sat}$ of steam fixed $\Rightarrow P_{SG}$ fixed

To maintain $P_{SG}$ constant at higher powers implies

$T_{avg} \uparrow \Rightarrow \rho_{MOD} \downarrow \Rightarrow \rho(-)$

$T_{RX} \uparrow \Rightarrow \rho_{RX} \downarrow \Rightarrow \rho(-)$

Negative reactivity must be compensated for.

Solution $\Rightarrow$ Withdraw control rods.

To maintain $P_{SG}$ constant at lower powers implies

$T_{avg} \downarrow \Rightarrow \rho_{MOD} \uparrow \Rightarrow \rho(+)$

$T_{RX} \downarrow \Rightarrow \rho_{RX} \uparrow \Rightarrow \rho(+)$

Positive reactivity must be compensated for.

Solution $\Rightarrow$ Insert control rods.
Controlling $P_{\text{imp}}$ implies controlling Electrical Power

Electrical Power $\Rightarrow$ Reactor Power ($P_{\text{rel}}$) $\Rightarrow$ Turbine Impulse Pressure $\Rightarrow$ Core Av. Coolant Temp. ($T_{\text{avg}}$)
**Turbine Control**

![Diagram of Turbine Control Valve](image)

**P_{impulse} Controller**

Set Elec. $P_{rel} \Downarrow \Rightarrow$ Set Prog. $P_{impulse} \Downarrow \Rightarrow (P_{impulse} - \text{Prog } P_{impulse}) > 0 \Rightarrow$ Close down on turbine control valve $\Rightarrow P_{impulse} \Downarrow$

How is Prog $P_{impulse}$ determined?

Require $RPM_{T/G} = \text{Prog. } RPM_{T/G}$ (1800 @ all Elec. $P_{rel} \Rightarrow$ AC frequency)

With fixed $RPM_{T/G}$ and Elec. $P_{rel} \Rightarrow P_{impulse}$ uniquely specified

**RPM Controller**

$(RPM_{T/G} - \text{Prog } RPM_{T/G}) > 0 \Rightarrow$ Close down on control valve $\Rightarrow P_{impulse} \Downarrow \Rightarrow RPM_{T/G} \Downarrow$

Error signal for T/G controller controls both $P_{impulse}$ and $RPM_{T/G}$ utilizing Turbine Control Valves
Automatic Control System:

Operator sets Electrical Power (Load or Demand Setpoint) ⇒ Ref P<sub>imp</sub>
TCV moves which automatically sets high pressure turbine impulse pressure

Impulse Pressure ⇒ Automatically sets Programmed $T_{AVG}$ ⇒ Automatically moves control rods in or out to make $T_{AVG} = \text{Programmed } T_{AVG}$

Speed of rod motion $\propto |T_{AVG} - \text{Programmed } T_{AVG}|$

ISSUE: Time lags in system can result in undershoot/overshoot

Example: Step load increase
SOLUTION: Add an “anticipatory” signal based on the difference between turbine output and reactor thermal power

\[ E_1 = \frac{\dot{W}_{\text{load}}}{(\dot{W}_{\text{load}})_{\text{ref}}} - \frac{\dot{Q}_{\text{RX}}}{(\dot{Q}_{\text{RX}})_{\text{ref}}} \]

\[ E_2 = \text{Programmed } T_{\text{avg}} - T_{\text{avg}} \]

\[ E = G_1 E_1 + G_2 E_2 \]

Rod Speed \( \propto |E| \)
**S/G Level Control** (UTUBE)

Programmed level to assure S/G tubes covered to assure adequate heat transfer and separators not flooded.

![Graph](image)

1. **S/G level correct.**
   
   If Steam Mass Flow Rate = F/W Mass Flow Rate $\Rightarrow$ S/G level constant.
   
   If S/G level correct, adjust F/W Flow Rate such that it equals Steam Flow Rate.
   
   *Adjustment done by valve and/or variable speed F/W Pump*

2. **S/G level not correct.**
   
   Adjust F/W Flow Rate (adjust FCV) to bring steam generator level to programmed value.

   \[
   E_1 = \dot{m}_{FW} - \dot{m}_{steam} \quad \text{Anticipatory}
   \]

   \[
   E_2 = Level_{SG} - \text{Programmed Level}_{SG}
   \]

   \[
   E = G_1E_1 + G_2E_2
   \]
**PRESSURIZER CONTROL**

The pressurizer does not impact RCS response to a load maneuver, but must be controlled to maintain safety margins and system integrity.

**Prz level**

Electrical $P_{rel} \Rightarrow$ Programmed $T_{AVG} \Rightarrow$ Primary loop Av. Water Density $\Rightarrow$ Primary Loop Water Volume $\Rightarrow$ Unique Prz Level (Programmed Prz Level)

Prz level maintained by CVCS

Prz level $\geq$ Prog. Prz level $\Rightarrow$ CVCS Charging Rate $\leq$ CVCS Letdown Rate.

<table>
<thead>
<tr>
<th>Automatic Control System</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{avg} \Rightarrow$ Programmed Prz. Level $\Rightarrow$ CVCS Rate dependent upon Prz. Level $\leq$ Programmed Prz. Level</td>
</tr>
<tr>
<td>When $T_{avg} \rightarrow$ and Prz Level = Prog. Prz level $\Rightarrow$ CVCS Charging Rate = CVCS Letdown Rate.</td>
</tr>
</tbody>
</table>
Prz Pressure

- Objective: Hold Primary System P constant $\Rightarrow P_{\text{set point}}$
- Assume SS operation $\Rightarrow P = P_{\text{set point}}$

Prz Heaters on sufficient to offset heat losses from Prz and spray circulation (some to keep Prz chemistry same as rest of RCS & Minimize Thermal Shock)

Electrical $P_{\text{rel}}$ $\uparrow$ (↓) $\Rightarrow T_{\text{AVG}}$ ↓ (↑) initially $\Rightarrow$ Prz level ↓ (↑) $\Rightarrow$ Prz P ↓ (↑)

Automatic Control System

$$
\begin{align*}
(Prz P - P_{\text{Set Point}}) > 0 \Rightarrow & \text{Prz Heaters Output } \downarrow \\
(Prz P - P_{\text{Set Point}}) < 0 \Rightarrow & \text{Prz Heaters Output } \uparrow
\end{align*}
$$

If $(Prz P - P_{\text{Set Point}}) > \Delta P_{\text{Set Point(1)}}$ $\Rightarrow$ Prz Sprays $\uparrow$ $\Rightarrow$ Prz Steam Condenses $\Rightarrow$ Prz P ↓

If $(Prz P - P_{\text{Set Point}}) < \Delta P_{\text{Set Point(2)}}$ $\Rightarrow$ Backup Heaters On $\Rightarrow$ Prz P ↑

Longer Term Effect:

Elec. $P_{\text{rel}}$ $\uparrow$ $\downarrow$ $\Rightarrow$ Prog. $T_{\text{AVG}}$ $\uparrow$ $\downarrow$ $\Rightarrow$ $T_{\text{AVG}}$ $\uparrow$ $\downarrow$ via $T_{\text{AVG}}$ control $\Rightarrow$ ...
Figure 7-6. NSSS Integrated Plant Control System