Operating Experience of Main Steam Flow-based Power Monitoring to OPR1000 Plants

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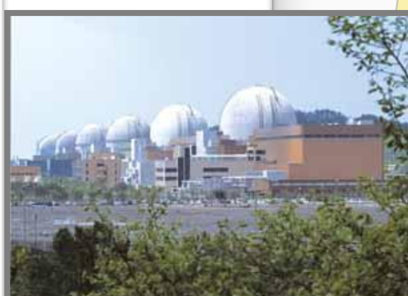
I. Introduction

❖ Nuclear Power Plants in Korea

- In Operation
  - 21 units
- Under Construction
  - 7 units
- Under Planning
  - 2 units

Ulchin
Operation - 6
Construction - 2



Yonggwang
Operation - 6

Wolsong
Operation – 4
Construction – 2

Kori
Operation – 5
Construction – 3
Planning – 2

I. Introduction

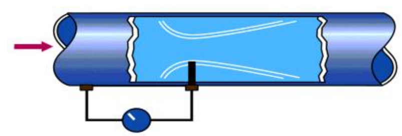
❖ Core Operating Limit Supervisory System (COLSS)

- Digitalized core monitoring system developed by ABB-Combustion Engineering in the 1970's.
- Provide core monitoring functions based on DNBR (Departure from Nucleate Boiling Ratio) and LHR (Linear Heat Rate)
- Generate a warning (alarm) when the core condition exceeds the LCO (Limit Condition for Operation)
- Use fixed in-core Rhodium detectors to generate core power distribution to be used in core monitoring
- Use the measured feedwater flows of steam generators to calculate secondary calorimetric power (BSCAL)

I. Introduction

❖ Experience in Feedwater Flow Measurement

- Feedwater Venturi Fouling
  - → Increased DP
  - → Erroneous High Mass Flow Rate
  - → Increased Calculated (Indicated) Reactor Power
- Reduce Plant Power Output below Licensed Level
  - → Loss of Electricity Generation

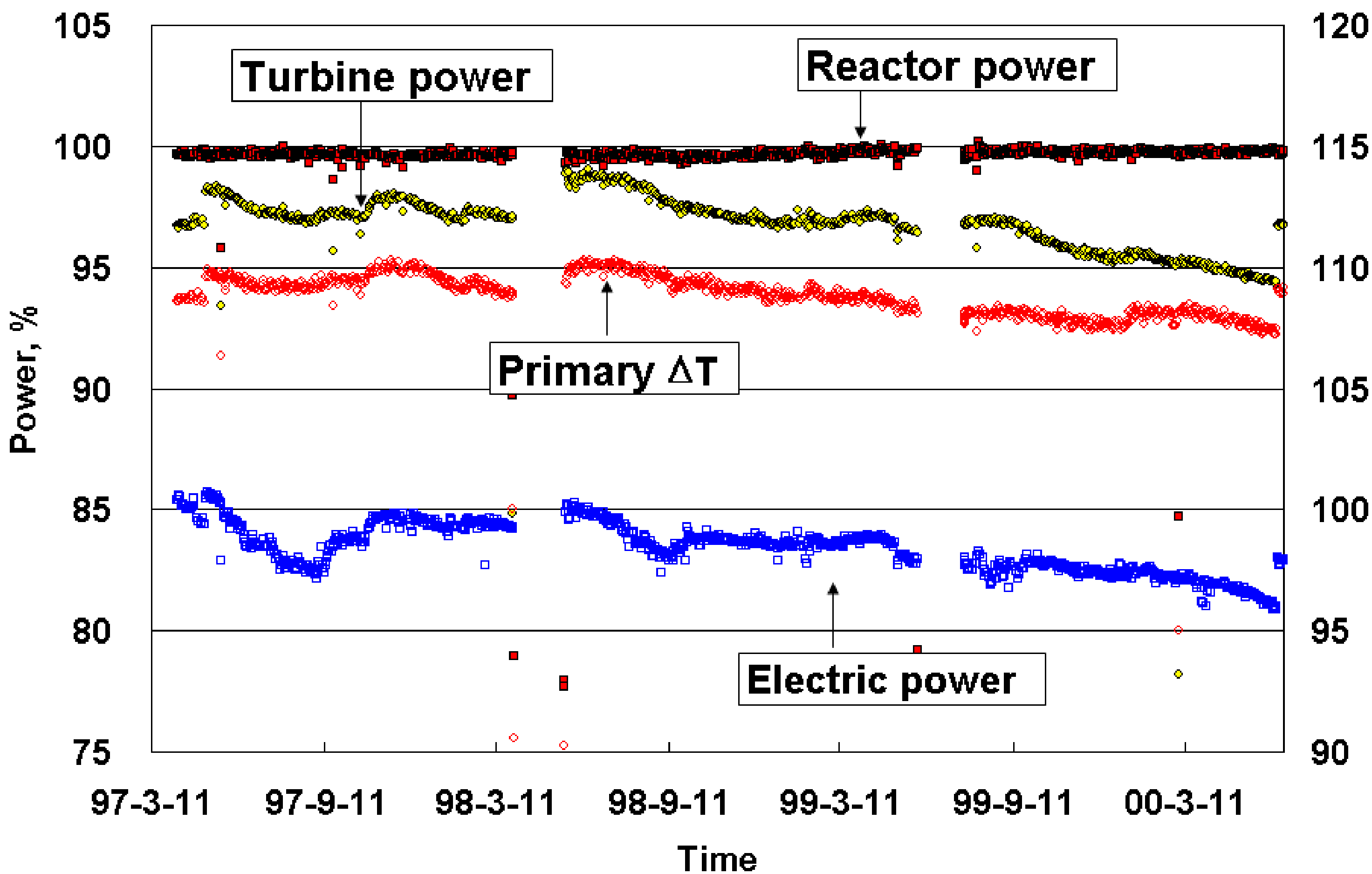


$$W \propto \sqrt{\Delta P}$$

Overall effect is an electricity generation loss!

I. Introduction

❖ Trends of Various Power Indicators in OPR1000 Plants



I. Introduction

❖ Needs for New Algorithm

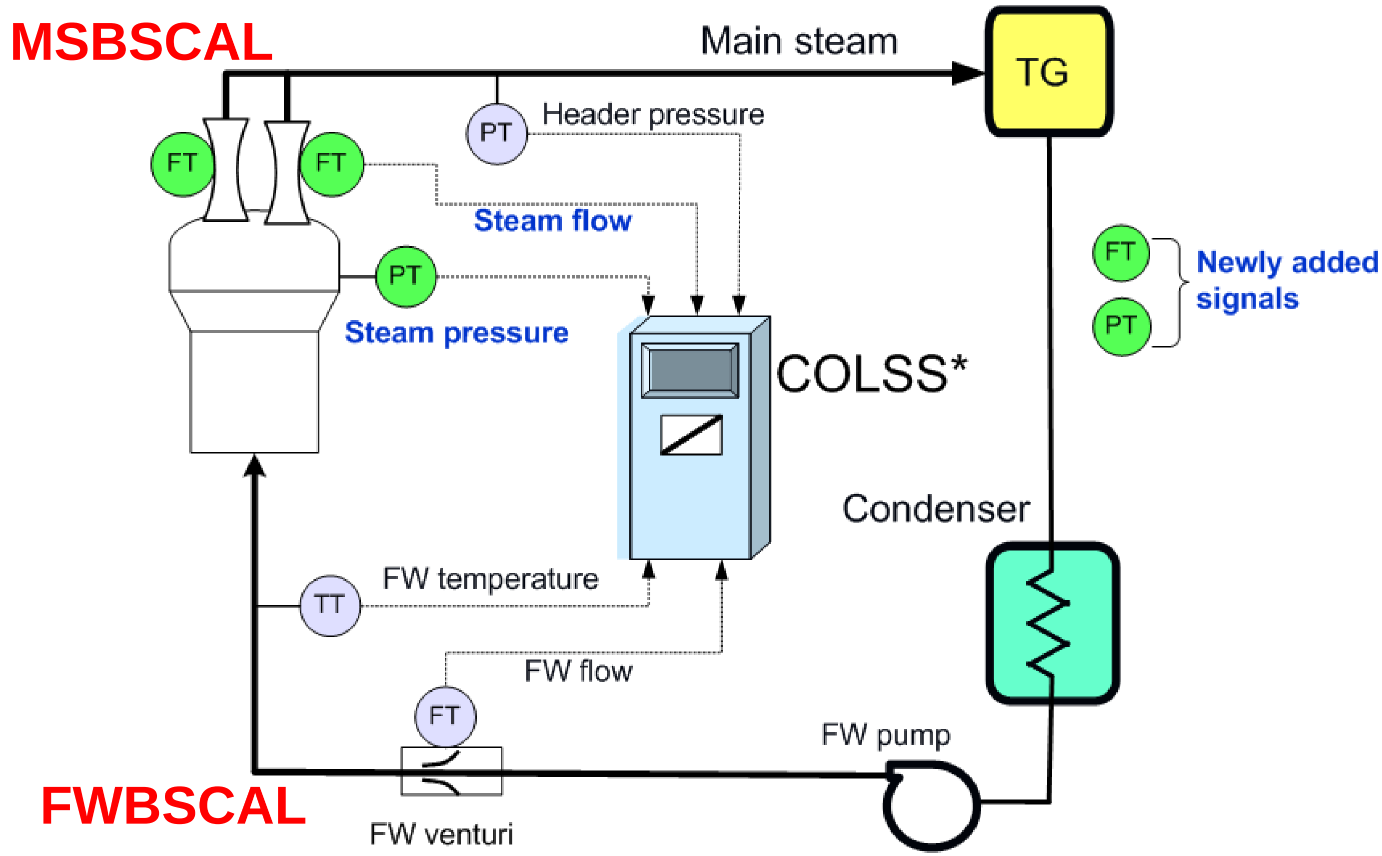
Application of <u>fouling-free based on main steam flow</u> in power calculation (MSBSCAL)

<u>Main Steam Flow</u>

- Little experience in Fouling
- Closer Indicator to Actual Reactor Power
- No Additional Hardware Change/ Modification

II. Theory and Algorithm

❖ Plant Monitoring System (Power Calculation)

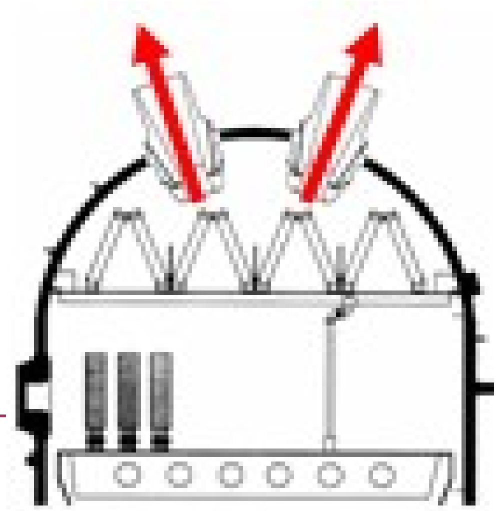


* COLSS: Core Operating Limit Supervisory System

II. Theory and Algorithm

❖ Main Steam Flow Measurement Equation for MSBSCAL

$$W_{MS} = \frac{\pi d^2}{4}\left[\left(\frac{C \cdot F_a \cdot Y}{\sqrt{1-\beta^4}} \cdot \frac{\sqrt{\Delta P}}{\sqrt{v_s}}\right)_1 + \left(\frac{C \cdot F_a \cdot Y}{\sqrt{1-\beta^4}} \cdot \frac{\sqrt{\Delta P}}{\sqrt{v_s}}\right)_2\right]$$



$$W_{MS} = \frac{\pi d^2}{4} \cdot \frac{F_a \cdot Y}{\sqrt{1-\beta^4}} \cdot \frac{2\sqrt{\dfrac{\Delta P_1 + \Delta P_2}{2}}}{\sqrt{v_s}} \cdot (MSCF)$$

II. Theory and Algorithm

❖ Steam Generator Power

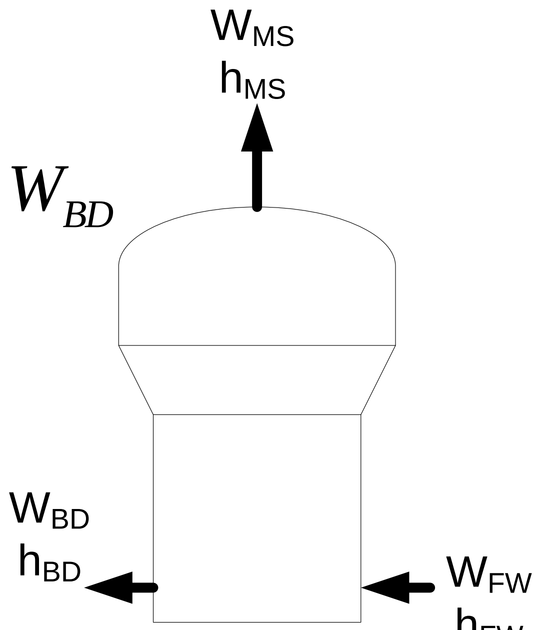
$$Q_{SG} = W_{MS} \cdot h_{MS} + W_{BD} \cdot h_{BD} - W_{FW} \cdot h_{FW} + \sum(\text{Loss \& Gain})$$

$W_{MS} = \textit{Main}$ Steam Flow (Measured)

$W_{FW} = \textit{Feedwater}$ Flow ($\textit{Calculated}$) $= W_{MS} + W_{BD}$

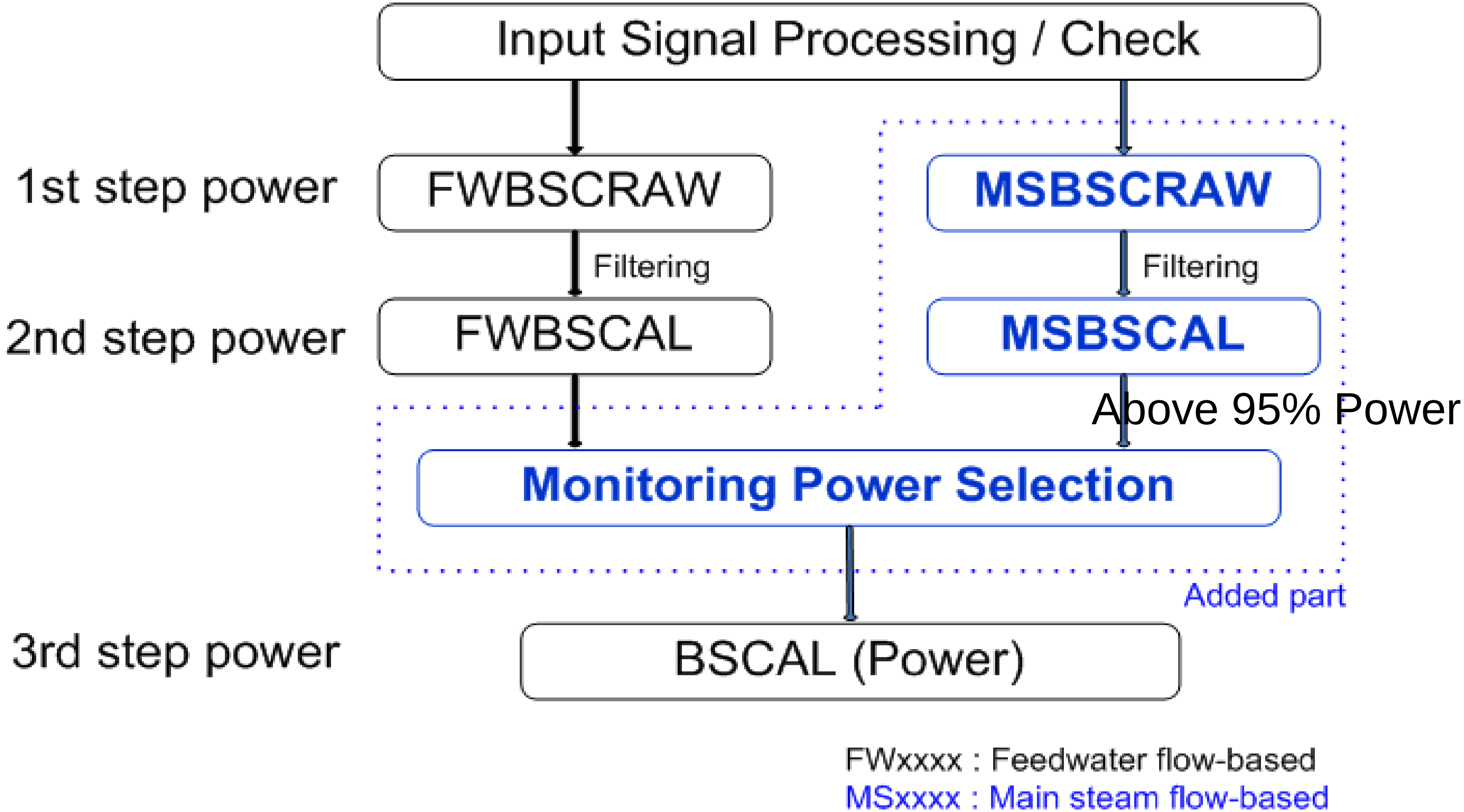
$W_{BD} = \textit{Blowdown}$ Flow (Constant)

$h = \textit{Enthalpy}$



II. Theory and Algorithm

❖ Procedure for COLSS Power Calculation Algorithm



II. Theory and Algorithm

❖ Thermal Power Calculation Uncertainty Check

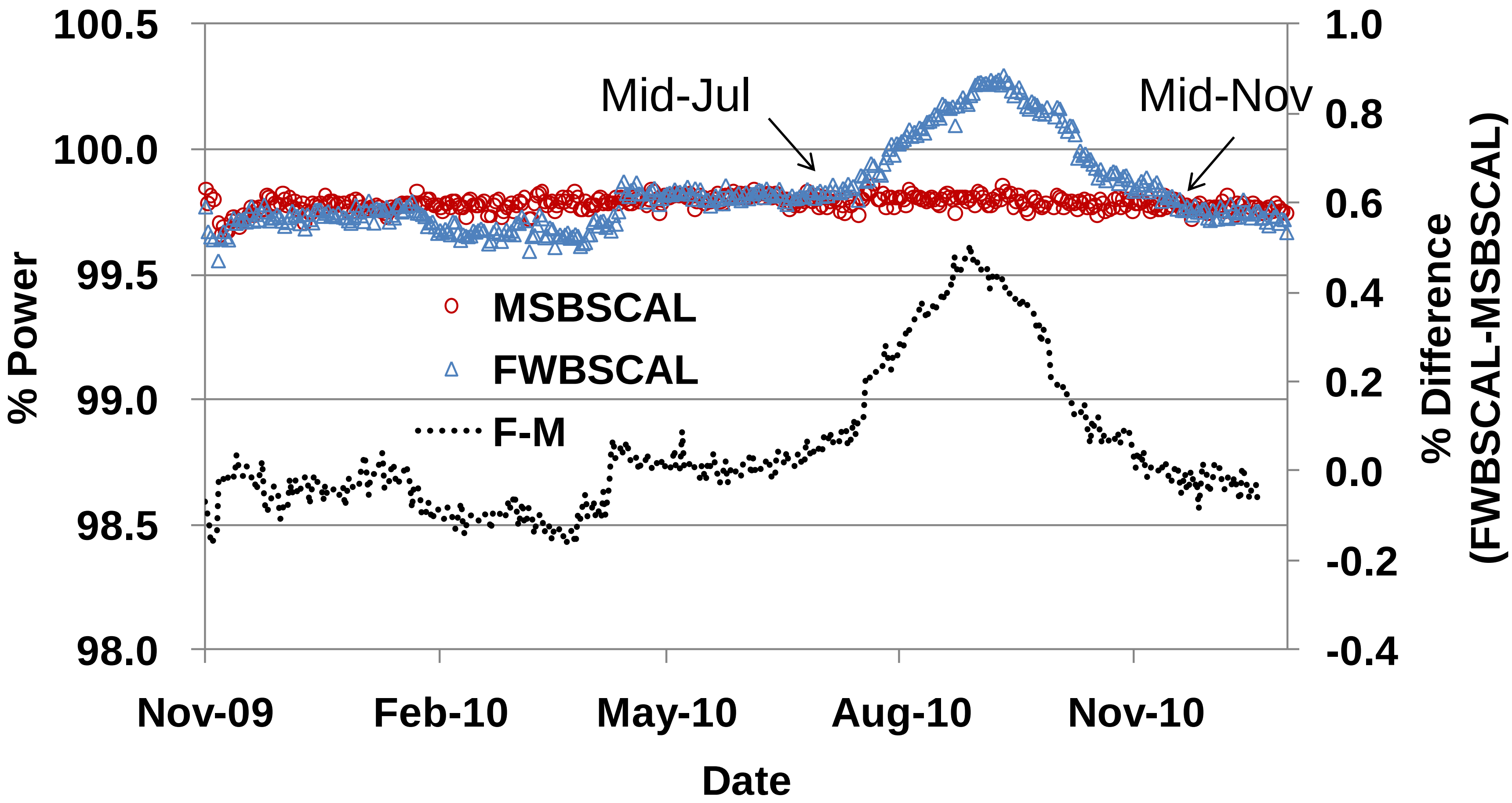
- FW-based Power Uncertainty : ~ 1.0% (2σ)
- MS-Based Power Uncertainty: < 1.5% (2σ)

Still well below the current 2.0% safety analysis margin

(No additional analyses needed)

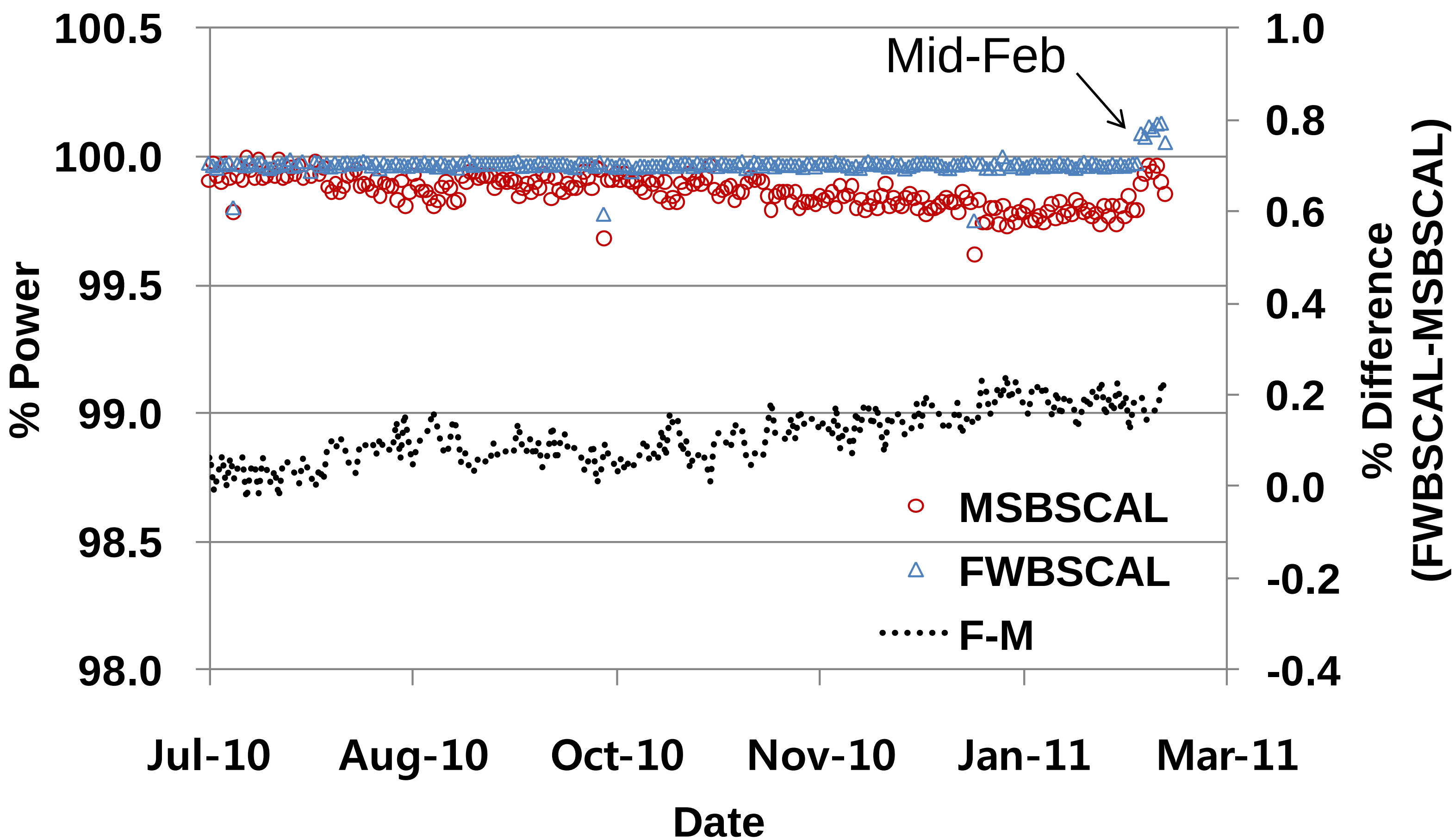
III. Application and Results

❖ Feedwater Venturi Fouling (YGN-4)



III. Application and Results

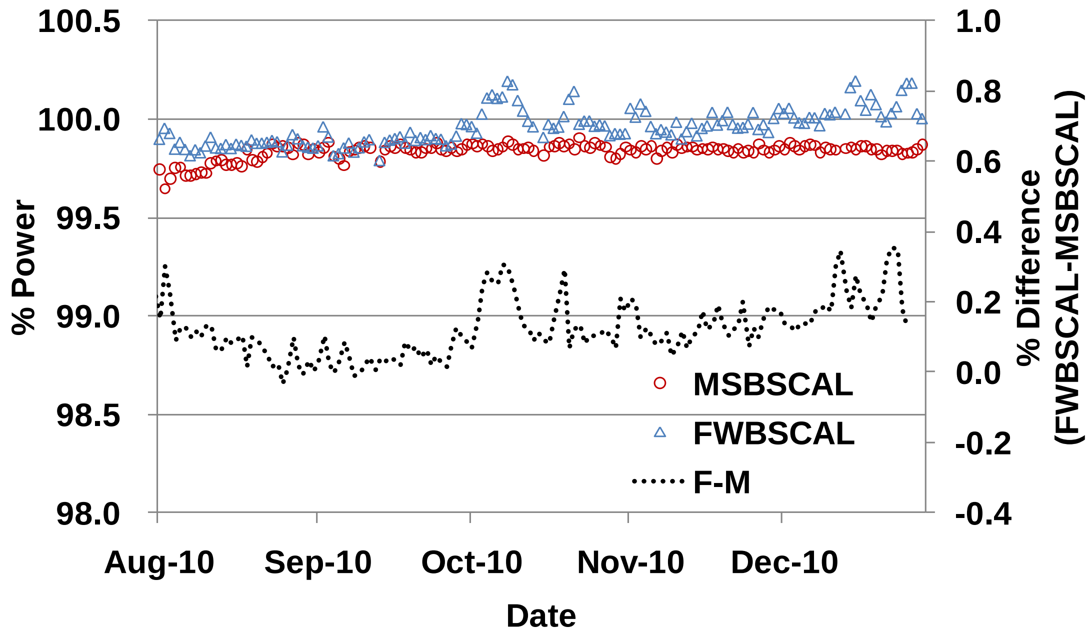
❖ Feedwater Venturi Fouling (YGN-5)



III. Application and Results

❖ Large Standard Deviation of FWBSCAL (UCN-4)

Standard Deviation		
PLANT	FWBSCAL	MSBSCAL
OPR1000-A	0.0478	0.078
OPR1000-B	0.0522	0.1585
OPR1000-C	0.0893	0.0558



IV. Conclusion

❖ Improved Thermal Power Calculation Methodology, MSBSCAL…

- Simple Algorithm without Hardware Change
- Simple Calibration Process - Just One Time at BOC
- Improvement of Electrical Efficiency by Fouling-Free Thermal Power Calculation

Application and Verification was successfully completed to OPR1000 plants

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Thank you.