Variable ROP Setpoints Remove Random Epistemic Detector Error

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Abstract

The mathematical basis of a fully automatic real-time variable setpoint design for ROP is outlined. Variable setpoints eliminate random epistemic detector error thus raising trip margin. Traditionally, snapshot detector reading simulations are used to calculate fixed setpoints making error unavoidable. With variable setpoints, only a fixed maximum setpoint level is pre-determined for the maximum reading detector. On-line detector readings prorate the maximum setpoint thus replacing detector simulations and epistemic error. Probability in real-time is compliant to that calculated for safety analysis. Also, the loss of regulation (LOR) is no longer confined to be spatially uniform and, with a feed-forward derivative term, slow.

1. Introduction

A debate has grown in the last few years with regard to raising reactor overpower (ROP) trip setpoints to delay and reduce reactor power derating due to heat transport system (HTS) aging. The Extreme Value Statistics (EVS) methodology[1] has targeted the statistical methodology for change without disclosing:

1. how over-conservatism in the setpoints design was ruled out
2. exactly which aspects of the statistical methodology require change

Industry proponents of the traditional method have reaffirmed the basis of neither the traditional method nor their disagreement with EVS.

This paper will show that real problem is a combination of:

1. the setpoint calculation and enforcement methodology
2. over-use of epistemic detector error where we have field detector data

The current design of setpoints and comparators for ROP, and other trip parameters, is inefficient for both safety and operation. The variable ROP setpoint scheme below best satisfies both safety and operational requirements. The fundamental problem with fixed setpoints is the necessity to include a random epistemic detection error for their inadequacy. The reactor doesn’t need this error when using flux detector readings. Epistemic random detector error is thus absolutely avoidable if real-time detector readings are fed, as one of three components, into the setpoint leg of trip comparators. The impact of aleatory calibration error is not discussed in this paper. This error cannot be eliminated but the reduction in trip margin can be minimized. Why? Detector readings and calibration are not random at all. Detector readings are tracked and always available to modify setpoints. Detector calibration is highly regulated and although described by an uncertainty, the process is more indiscriminate than random. We only pretend it is random in order to justify traditional assessments leading to fixed setpoints. We can then continue building logic circuits from the dawn of nuclear instrumentation. To be sure, no one is happy with the performance of current setpoint designs:

- Utilities want higher trip margins to stave off age related derating
- Regulators want Risk Informed Decision Making criteria for non-uniform/fast transients
- Designers need to redesign fuel, pressure tubes and HTS parameters on future plants.

Detector trip setpoint distributions are now very crudely imposed by designers compromising operating and safety performance. Alternatives to fixed setpoint designs are not discussed by senior designers. They, in turn, never present them to regulators or junior designers. It seems that no one has actually tried to solve the setpoint equations algebraically for unique solutions. Setpoint codes can easily model a variable setpoint circuit in Figure 1. The analysis and analog circuit is shown without needed clamps.

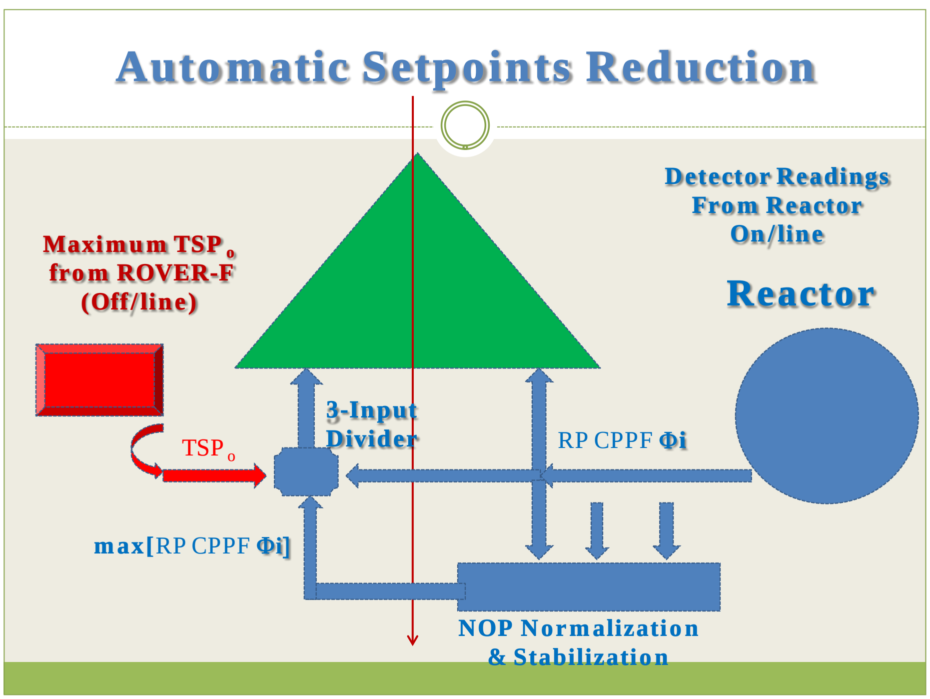

Figure 1 Variable On-line Trip Setpoints

2. ROP Deterministic Equations

To develop the needed equations for a deterministic or probabilistic approach, we need to establish trip and dryout margins and define their ratio as the safety margin for a given design basis fluxshape. The safety margin is used as the argument to the probability of trip before dryout calculations. The setpoints satisfy 98% probability on a 3/3 or w2/2 basis for licensing.

Margin to trip is: $\dfrac{\mathbf{TSP_i}}{\mathrm{RP} \cdot \mathrm{CPPF} \cdot \boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{100\%}}}$

Margin to dryout is: $\dfrac{\mathrm{CPRL}}{\mathrm{RP} \cdot \mathrm{CPPF}}$

Safety Margin is: $\dfrac{\text{Margin to dryout}}{\text{Margin to trip}}$

= ***readings at dryout*** / ***readings at trip***

$$\mathbf{SMi} = \frac{\mathrm{CPRL} \cdot \boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{100\%}}}{\mathbf{TSP_i}} \tag{1}$$

In licensing analysis, we explicitly run the ROP code. In the analysis for variable setpoints, we do not need to also run a real-time version of RFSP and ROVER-F (or SORO and SIMBRASS) which we don't have. We merely free up the setpoint so it can vary in real-time algebraically with detector readings in such a way as to preserve calculated probability with simulated readings. In this application, we will use real-time detector readings at any arbitrary peak detector reading continuously during operation. For this, we should preserve:

$$[\mathrm{CPRL}/\Phi_{max}]^{sim} = [\mathbf{CPRL}/\boldsymbol{\Phi}_{\mathbf{max}}]^{\mathbf{r/t}}. \tag{2}$$

With this addition, our safety margin equation for variable setpoints becomes:

$$\mathbf{SMi} = \frac{\mathrm{CPRL} \cdot \boldsymbol{\Phi}_{\mathbf{i}}}{\boldsymbol{\Phi}_{\mathbf{max}} \cdot \mathbf{TSP_i}} \tag{3}$$

The importance of the safety margin (**SMi**) parameter is that it directly drives the calculation of probability of trip before dryout ($\mathbf{Prob_{TBD}}$). The **SMi** equation conforms to the formulation in ISA67.04 standard for light water reactors within a CANDU convention.

Here:

TSPi	is the trip setpoint for loop **i** for any given fluxshape
RP	is normalized reactor power
CPPF	channel power peaking factor
$\Phi i^{100\%}$	normalized detector reading consistent with simulated peak detector reading
Φi	normalized detector reading for the given fluxshape at any peak detector reading

simulated $\Phi i^{100\%}$ and on-line $\mathbf{\Phi i}^{\mathbf{data}}$ is available

$\mathbf{\Phi_{max}}$ normalized detector reading for the given fluxshape (consistent with $CPRL^{100\%}$)

CPRL limiting T/A critical power ratio readings at 100% reactor power

Symbols in bold are field variables available on-line. Symbols not bolded are either only simulated (CPRL) or calibration factors which can only be changed by the control room operator (RP and CPFF) manually or via monitor computer.

This equation assumes that the fuel channel determining CPPF has CPRL= CPR/CPPF. In actual reactor assessments, **SMi** has to be recalculated for each fuelling ripple distribution where the calibration to CPPF is more conservative. These recalculations are in principle identical and are fully captured by the function probabilistic function **F** (below).

It is noted that in order to calculate the probability of trip before dryout ($\mathbf{Prob_{TBD}}$),

1. probability density of dryout d**Q**(**x**)/d**x**
2. probability distribution of trip **P(x)**.

The probability of trip before dryout is given by:

$$\mathbf{Prob_{TBD}} = \mathbf{F}[\mathbf{SMi}] = \int \mathbf{P}[\mathbf{SMi}]d\mathbf{Q} = \int \mathbf{P}[\mathbf{SMi}]\frac{d\mathbf{Q}}{dx}dx$$

Where:

x abscissa is reactor power normalized to 1 at dryout

F[**SMi**] functional form of $\mathbf{Prob_{Trip}}$[**SMi**] for a safety channel given fluxshape

Note:

The function **F** has many other inputs but we will only vary **SMi** and freeze the rest

$\mathbf{F[SMi]^{SYS}}$ is 98% probability on 3/3 or w2/2 voting logic used for licensing

The product of the distributions of trip (**P**[x]) and dryout (**Q**[x]) is **P**[**x**]**Q**[x] or just **PQ**:

- differential of **PQ**

  d(**PQ**) = **P**d**Q** + **Q**d**P**

- the integral of d(**PQ**)

  $$\int_{0}^{\infty} d(\mathbf{PQ}) = \int_{0}^{\infty} \mathbf{P}dQ + \mathbf{Q}d\mathbf{P} = 1$$

  The interpretation of this result is that the "probability of trip before dryout" + probability of "dryout before trip" equal unity. This gives the rationale for the functionality of **F** above.

  From this, the relationship between these two events is: $\mathbf{F}[\mathbf{SMi}] = \int_{0}^{\infty} \mathbf{P}dQ = 1 - \int_{0}^{\infty} \mathbf{Q}d\mathbf{P}$

3. Mathematical Dilemma

To calculate setpoints, we use equation 3:

It has: 2 known values (CPRL and **Φi** from simulation)
2 unknown values (**TSPi** and **SMi**) per loop

Instantaneous **Φi** (not necessarily at 100% RP) are also available on-line in real-time via ROP instrumentation. This stream of values has thus far played a role in neither traditional nor EVS setpoint calculations.

The mathematical problem is that the trip setpoint distribution cannot be solved algebraically with only simulated **Φi** (one equation, 2 unknowns). This is why an arbitrary or non-algebraic method has been traditionally used to determine setpoints. The meaning of setpoints in the absence of field readings is meaningless. Are we trying to protect the simulated values or the reactor? Furthermore, spatially uniform and slow loss of regulation (LOR) "requirements" are imposed on the safety analysis for using readings from only one snapshot simulation. These problems apply also to EVS. These are what Risk Informed Decision Making (RIDM) requirements are attempting to address. Whatever algebraic or functional variation setpoints should have had is forever lost in this arbitrary "fixed setpoint" method. In place of a proper setpoint algebraic functionality, people merely add an aleatory type penalty in setpoints via detection epistemic uncertainty. With a real-time fully algebraic solution, this epistemic uncertainty is eliminated.

The technical definition of LOR embodied in **SMi** is now also arbitrary and problematic. In order to "determine" setpoints, we currently:

1. assume one time average simulation of $\mathbf{\Phi_i}$, **BP** (for **CCP**) and **CP** suffices
2. assume a simulation at 100% reactor power
3. assume $\mathbf{\Phi_i^{100\%}}$ is scaled until nominal dryout i.e. CPRL·$\mathbf{\Phi_i^{100\%}}$
4. assume $\mathbf{TSP_i}$ is "fixed" usually at a value TSP_o independent of fluxshape and loop
5. assume that the LOR proceeds slow in rate

Since fixed setpoints now make safety margin quite dependent on detector readings (fluxshape), the case to case and loop to loop deterministic variations hurt both operating and safety margin. The reason is that fluxshapes change but fixed setpoint do not. We create few detectors that are ahead of many others thus stranding their safety coverage participation. This penalizes the setpoints of the few detectors. Simultaneously, the margin to trip is hurt because the high reading detectors would otherwise trip first with lowered fixed setpoints. It would seem that operating and safety performance are two sides of the same coin. Another way to say this is that the probability variation will be very strong between cases with only one covering detector and those with several. This can be easily verified looking at the vast spread in case to case probability tabled in any ROP submission.

I note that safety margin is only the ratio of $\dfrac{\textbf{\textit{readings at dryout}}}{\textbf{\textit{readings at trip}}}$ during the LOR.

This ratio has nothing to with detector readings during steady state operation before the LOR.

3.1 Mathematical Solution

For variable setpoints, we shall make only one assumption instead of five. That is, safety margin is invariant, 1/α, and setpoints become:

$$\mathbf{TSP_i} = \alpha \frac{\mathbf{\Phi_i}}{\mathbf{\Phi}_{max}} \tag{4}$$

This remaining restriction can be dropped by using optimality criteria in continuous analysis.

The symbolic calculation of probability with constant safety margin in Section 6, will give us three things:

1. the value of α
2. confirmation licensing and real-time setpoints agree with Equation 4
3. link to condition required for zero epistemic detector error (Section 8)

This definition is now independent of fluxshape, detector readings or loop number. You would expect that both deterministic and probabilistic criteria would be much less variable for fluxshapes, detector readings or loop numbers. The rate of LOR will require a feed-forward extension to the variable setpoint concept which will be shown later. For now, let me note that we require only one assumption for constant safety margin instead of five. This is a better strategy with more favourable operating and safety performance. The goal should still be to have no arbitrary assumptions. Perhaps, we could explore criteria in continuous variables for optimal setpoints.

4. Probabilistic Equations

With **SMi** defined, the trip probability distribution for random errors only becomes:

$$\mathbf{Prob_{trip} = P(x) = 1 - \prod_i 1 - erf\left[\frac{x - \frac{1}{SM_i}}{\frac{\sigma_{det}}{SM_i}}\right]} \tag{5}$$

Also, the dryout probability distribution[2] for random errors only becomes:

$$\mathbf{Prob_{d/o} = Q(x) = 1 - \prod_j 1 - erf}\left[\frac{\mathbf{x} - \frac{cprl_j}{cprlo}}{\sigma_{d/o}}\right] \tag{6}$$

The probability of trip before dryout remains:

$$\mathbf{Prob_{TBD}} = \mathbf{F}[\mathbf{SMi}] = \int \mathbf{P}[\mathbf{SMi}]d\mathbf{Q} = \int \mathbf{P}[\mathbf{SMi}]\frac{d\mathbf{Q}}{dx}dx \tag{7}$$

Where:

σ_{det} is the random detector error
cprlj is rippled cpr of fuel channel j
cprlo is most limiting rippled cpr of any fuel channel
$\sigma_{d/o}$ is the random dryout error
$\mathbf{Prob_{d/o}}$ or **Q** is probability of dryout
$\mathbf{Prob_{Trip}}$ or **P** is probability of trip
$\mathbf{Prob_{TBD}}$ Single safety channel representation shown here

The fundamental disagreements between a traditional probabilistic formulation and an EVS probabilistic formulation are:

1. Treatment of random errors (epistemic and aleatory for detection and dryout)
2. Inclusion of a fluxshape weighting (FSW) to boost limiting cases

Correlated uncertainties in traditional statistics can be included by convolution to both **P** and **Q**. This affects the distributions of **P** and **Q** but the important parameter for licensing is probability of trip before dryout ($\mathbf{Prob_{Trip}}$) which can still remain as an unspecified function **F**.

5. Current Fixed Setpoint Methodology

Traditional and EVS setpoint methodologies use a method based on “fixed” not “variable” setpoints. That is, both methods impose an arbitrary non-variable functionality to the unknown **TSPi**. The fixed setpoints are uniformly scaled until a 98% probability is achieved. This is an imposed fit and not a true algebraic solution of the equation. We do not normally solve algebraic or differential equations by predetermining the functional variation with a desired variation, doing a best fit and then dealing with the scatter by adding an uncertainty which was created by the fitting process and not the data. We have chosen to ignore measured **Φi** data which must be available for the monitoring of the ROP trip parameter itself. This directly leads to random epistemic detector error. An error, after all, is what we cannot know and not what we knowingly or unknowingly ignore.

6. Variable Setpoint Methodology

We require measured values of **Φi**, in addition to those simulated, to obtain unique and exact setpoint solutions. This supplies the missing information for a full algebraic solution of **TSPi**. However, the measured values of **Φi** are a real-time stream, i.e. **Φi(t)**. The calculation update to the setpoints would have to be in real-time as well. We shall see how the probabilistic equations are used to calculate the probability of trip before dryout. We will be in a position to fully solve symbolically the probabilistic real-time setpoint of each loop algebraically. To lighten the load with dealing with 2 shutdown systems and 3 safety channels, let us simplify the algebra and use function **F** to calculate probability for a single safety channel. A full demonstration of variable setpoints would involve an actual licensing run at some point anyway.

Let us:

1. Assign the real-time fluxshape, $\boldsymbol{\Phi_i^{r/t}(t)}$
2. Set $\mathbf{Prob_{TBD}}$ **= F**[**SMi**] to 95%, with <u>simulated</u> readings for a single safety channel
    a. On a 2/3, w2/2, or 3/3, probability is estimated over .993, .903, .858 respectively
3. Use same function**, F**[**SMi**], with <u>real-time</u> readings to calculate trip probability
4. Impose that the probability with simulated and real-time readings is equal

$$\mathbf{F}\left[\mathrm{CPRL}\cdot\left[\frac{\Phi_i}{\Phi_{max}\cdot \mathrm{TSP}_i}\right]^{sim}\right] = 95\% = \mathbf{F}\left[\mathrm{CPRL}\cdot\left[\frac{\boldsymbol{\Phi_i}}{\boldsymbol{\Phi_{max}}\cdot \mathbf{TSP_i}}\right]^{\mathbf{r/t}}\right] \tag{8}$$

The arguments to **F** must be equal, for a given fluxshape at any reactor power, for simulation and real-time compliance:

$$\mathrm{CPRL}\cdot\left[\frac{\Phi_i}{\Phi_{max}\cdot \mathrm{TSP}_i}\right]^{sim} = \mathbf{F}^{-1}[95\%] = \mathrm{CPRL}\cdot\left[\frac{\boldsymbol{\Phi_i}}{\boldsymbol{\Phi_{max}}\cdot \mathbf{TSP_i}}\right]^{\mathbf{r/t}} \tag{9}$$

F and $\mathbf{F^{-1}}$ require that ratio Φi/TSPi = Φ_{max}/TSP_o for each detector in real-time and also simulations. This equation could serve as a deterministic criterion on its own.

From this, we get**:**

$$\left[\frac{\Phi_i}{\Phi_{max}\cdot \mathrm{TSP}_i}\right]^{sim} = \left[\frac{\boldsymbol{\Phi_i}}{\boldsymbol{\Phi_{max}}\cdot \mathbf{TSP_i}}\right]^{\mathbf{r/t}} \tag{10}$$

$$\mathbf{TSP_i^{r/t}} = \mathrm{TSP}_o\left[\frac{\boldsymbol{\Phi_i}}{\boldsymbol{\Phi_{max}}}\right]^{\mathbf{r/t}} \tag{11}$$

The value of parameter α in our assumed variable setpoint variation in Equation 4 is TSP_o.
The loop trip setpoints in real-time vary are linearly with the loop detector readings.

If we subtract the derivative (feed-forward) from **Φi** in Equation 11, we give the shutdown system ~1s to turn over an overpower transient and still not exceed the slow LOR setpoints.

$$\mathbf{TSP_i^{r/t}} = \mathrm{TSP_o}\left[\frac{\mathbf{\Phi_i} - \frac{d\mathbf{\Phi_i}}{d\mathbf{t}}}{\mathbf{\Phi_{max}}}\right]^{r/t} \tag{12}$$

Only the constant TSP_o comes directly from licensing calculations. This confirms the earlier statement that you cannot determine the instantaneous field setpoints until you have real-time detector reading data.

This formulation will allow the ROP code to be run for safety analysis, as usual, and supply the TSP_o that will later be used to quickly transform and generate real-time setpoints on the fly. Sometimes, we loosely speak about required setpoint levels being a function of fluxshape when we mean the setpoint distribution. Note that this variable setpoint functionality can only reduce setpoints below a maximum value of TSP_o.

A self consistency test of Equation 11 is to see if β times the simulated readings ($\mathbf{\Phi_i}^{\mathbf{r/t}} = \beta\Phi_i^{sim}$) and likewise maximum readings ($\mathbf{\Phi_{max}}^{\mathbf{r/t}} = \beta\Phi_i^{sim}$) were put into the real-time $\mathbf{\Phi_i}^{\mathbf{r/t}}$ equation, whether the $\mathbf{TSP_i^{sim}}$ would result. The right hand side becomes:

$$\mathbf{RHS} = \left[\frac{\Phi_{max} \cdot TSP_i \cdot \beta\Phi_i}{\Phi_i \beta \Phi_{max}}\right]^{sim} \tag{13}$$

$$\mathbf{RHS} = \left[TSP_i\right]^{sim} \tag{14}$$

With the proposed variable setpoints, the calculated SDS stationary safety margin (SM_o) and probability of trip before dryout become a stationary value for any design basis fluxshape in real-time: i.e. $\mathbf{Prob_{TBD}^{SYS}} = \mathbf{F}[SM_o] = 95\%$.

Setpoint can easily be generated in real-time with analog hardware or digital hardware every loop cycle. The stream of **Φi** is input and simultaneously transformed into an output stream of **TSPi**. Without field measurements, one could easily say that there is no real reactor to protect. The notion of protection becomes meaningless. Risk Informed Decision Making (RIDM) for trip/no trip can best be made using all available relevant plant Information. Surely, real-time measured detector readings must have as much legitimacy as those simulated for use in safety.

7. Process Trips in CANDU 6 PDC's

There is a decided similarity in variable setpoints between ROP, Pressurizer Level and Boiler Level trips in CANDU 6. The calculation of setpoint requires simple arithmetic operations without, parallel simulation, looping, convergence issues nor the requirement to explicitly calculate probability of trip before dryout. That is inherently not needed with this algorithm either. Pressurizer and Boiler Level setpoints are a function of reactor power and require 2 Programmable Digital Controllers (PDC) per safety channel. Boiler Level in Ontario plants is established by a two tier setpoint via hardware in Bruce and a trip computer in Darlington. In any case, a single fixed setpoint is clearly inadequate. This is pretty much the pattern for all trip parameters. For example, the High Pressure trip can have a fixed level based on a slow rate less a derivative term to bring the trip quicker and avoid a transient overpressure. The Log Rate trip might better become a log trip with a switched hi/lo setpoint minus the log rate. This would make both SDS able to pick up rates below 15%/s and avoid spurious trips at very low power due to poison clouds generating log rates above 15%/s.

8. Random Epistemic Detector Error

The most interesting thing about ROP detectors is that they have absolutely no measurement error (see Equation 1). With respect to dryout, we do apply bundle and channel power uncertainties. Dryout error becomes relevant because we want to trip (before dryout) with a given probability. Knowing that we eventually trip in an LOR is not sufficient.

The formula for determining the traditional relative epistemic random detector error (and uncertainty) from commissioning data is:

$$\boldsymbol{\varepsilon}_{\mathbf{i}} = \frac{\boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{sim}} - \boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{meas}}}{\boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{sim}}} \tag{15}$$

$$\boldsymbol{\sigma}_{\mathbf{det}}^{\mathbf{epi}} = \sqrt{\frac{\sum \boldsymbol{\varepsilon}_{\mathbf{i}}^{2}}{\mathbf{n}}} \tag{16}$$

Note:

$\boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{meas}}$ in commissioning data, $\delta\Phi_i^{meas}$ resets aleatory errors by removing the calibration offsets

$\boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{sim}}$ is now the basis for calculating setpoint (Φ_i^{set}) using simulations but need not be

We might ask: How else can one calculate trip setpoints?

In the field we are presented with a situation where we could use a fraction **x** of the simulated detector readings and thus (**1-x**) of on-line detector reading for setpoints.

The detector readings at the setpoint ($\boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{set}}$) become:

$$\boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{set}} = (\mathbf{1} - \mathbf{x})\boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{meas}} + \mathbf{x}\boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{sim}} \tag{17}$$

The error in the readings for setpoint using Equation 15 becomes:

$$\boldsymbol{\varepsilon}_{\mathbf{i}}^{\mathbf{x}} = \frac{(\mathbf{1} - \mathbf{x})\boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{meas}} + \mathbf{x}\boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{sim}} - \boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{meas}}}{\boldsymbol{\Phi}_{\mathbf{i}}^{\mathbf{sim}}} \tag{18}$$

Using Equation 16, we get:

$$\sum\sqrt{\frac{\varepsilon_i^2}{n}} = x\sqrt{\frac{\sum\left[\frac{\left(\Phi_i^{sim} - \Phi_i^{meas}\right)}{\Phi_i^{sim}}\right]^2}{n}} \tag{19}$$

Re-expressed, Equation 19 is:

$$\sigma_i^x = x\sigma_{det}^{epi} \tag{20}$$

It would be very difficult to actually produce simulated flux detectors in transients and apply them to both $\mathbf{\Phi_i}^{set}$ and corresponding $\boldsymbol{\varepsilon}_i^x$. Also, if we did possess such data, how and why would we feed it to a computer to churn out flux detector readings and error components for setpoint calculations, get them approved by management and the regulator? However, it would be very easy to use only real-time measurements to reduce setpoints during slow and fast transients.

This "hypothetical" experiment has only two practical cases:

Case 1:

No measured readings allowed in setpoint leg of comparators (only simulations), **x=1**,

$$\sigma_i^x = \sigma_{det}^{epi} \tag{21}$$

This is exactly the ransom epistemic detector error traditional design approach of fixed setpoints.

Case 2:

Only measured readings (no simulations) allowed in setpoint leg of comparators or **x=0**,

$$\sigma_i^x = 0 \tag{22}$$

Detector uncertainty is a function of **x. 1-x** is the *Information Switch* or amount of on-line information allowed to update setpoints.

If **x**=1, the epistemic detection carries the full simulation uncertainty because no amount of detection information (fluxshape) is allowed to change setpoints. If **x**=0, the epistemic detection uncertainty is zero because the full amount of detection information is allowed to update setpoints.

How does $\mathbf{\Phi_i}^{set}$ vary with **x**?

This, in the new vernacular of variable setpoints, is like asking, when is $\frac{d\mathbf{\Phi_i}^{set}}{d\mathbf{x}} = \mathbf{0}$?

Differentiating $\mathbf{\Phi_i}^{set}$ (Equation 17) wrt **x**, we get:

$$\Phi_i^{meas} - \Phi_i^{sim} = 0 \tag{23}$$

$$\Phi_i^{sim} = \Phi_i^{meas} \tag{24}$$

This is the same solution as setting Equation 15 to zero.

9. Conclusion

It has been shown that variable real-time ROP setpoints can be algebraically determined with the set of simulated and each set of on-line detector reading data bypassing any need for statistics. This is consistent with there being no need to carry an epistemic detector random error. Dryout, on the other hand, is not directly tracked and unknowable, to some extent, even if measured. For this reason dryout should continue to use traditional statistics. Breaking up random errors into epistemic and aleatory components but vary their statistical treatment is both arbitrary and wrong.

Only errors in maximum detector readings remain with variable setpoints. These may still use a statistical method but become correlated errors and no longer detector random. The epistemic portion of the Simulation Ratio detector error may have to be calculated a little differently than it is now. The aleatory calibration error only on maximum detector readings is also correlated and must now be calculated for each fluxshape from simulated readings, channelization and the aleatory calibration uncertainty. The hope is that the limiting cases can point to only a few detectors where it may be advantageous to calibrate a little differently.

10. References

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