Enclosure 4

Engineering Evaluation

EC 25987

Calculation Framework for the Extended Flow Window Stability (EFWS) Setpoints

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I. Purpose and Description

The purpose of this Engineering Evaluation is to document the framework used to develop the design calculations that establish the Extended Flow Window Stability (EFWS) setpoints that support the Enhanced Option III Long Term Stability Solution..

The EFWS setpoints include a trip (scram) and alarm (rod block). The trip is being implemented as the Extended Flow Window Stability – High Scram in the Technical Specifications. The alarm is being implemented as the Extended Flow Window Stability – High Rod Block in the Technical Requirements Manual. The effect of the EFWS setpoints is to setdown (reduce) the APRM Simulated Thermal Power scram and rod block setpoints over a specific operating range and is activated at a pre-determined recirculation drive flow during a flow runback event from normal operations.

II. Background, Scope, and Justification for the EFWS Setpoints

The EFWS trip automatically prevents reactor operation in the Channel Instability Exclusion Region or CIER of the Power to Flow Operating Map. The CIER statepoints are provided in terms of reactor power and core flow. The CIER is developed by the fuel vendor in accordance with Reference 1 and confirmed or determined for each reload. If the reactor operates in the CIER, single channel thermal hydraulic instabilities are possible. The analytical basis for the CIER and the Enhanced Option III (EO-III) stability protection is described in Reference 1. The CIER calculation also provides the basis for uncertainty due to voiding in the bypass channel that is used in the EFWS setpoint analysis.

The EFWS trip is also designed to automatically protect the Natural Circulation Line (NCL) within the potential instability region on the Power to Flow Operating Map such that a reactor scram will occur following a double recirculation pump trip from initial operation in the Extended Flow Window. This provides backup stability protection for the OPRM function of the EO-III stability solution and is consistent with Section 4.0 part 6 of the NRC safety evaluation in Reference 1.

The EFWS setpoints are implemented in the plant by adjusting the parameter fields in the Average Power Range Monitor (APRM) Backup Stability Protection (BSP) Flow Bias function. For the purposes of this evaluation, the scope is limited to changes to the BSP setpoint parameters.

III. EFWS Setpoint Calculation Framework

The calculation framework involves a systematic application of statistical methods and existing NRC-approved MNGP setpoint methodology to determine a conservative set of EFWS setpoints. In addition to providing instability protection, the setpoints are designed to avoid spurious reactor trips during normal operational maneuvers in the approved portions of the Power to Flow Operating map. The EFWS setpoints are not designed to avoid a trip during a single recirculation pump trip from the EFW operating region.

The development of the EFWS setpoints from the CIER, the Power to Flow Operating Map, and the BSP Flow Bias function is documented by three separate calculations. The trip setpoints are evaluated and confirmed for each reload and documented in the COLR. Calculations I and II are used to provide the EFWS Scram Analytical Limits (ALs) and Operating Limits (OLs). Calculation III provides the EFWS Nominal Trip Setpoints (NTSPs) and Allowable Values (AVs) for the scram and the rod block. The required processes and methods used in each of these calculations are described below.

A. Calculation I - Core Flow Mapping

1. Purpose

The core flow mapping calculation develops an empirical correlation to predict reactor core flow from reactor power and recirculation drive flow.

2. Methodology

Data Gathering

Reactor core flow, recirculation drive flow, and thermal power data are required inputs to this calculation. The following data gathering methods are employed to assure data quality.

- A representative and statistically valid data set for various reactor operating conditions in the cycle is obtained from the Plant Process Computer archive function. Multi-cycle data are preferred unless reactor hydraulic conditions or instrumentation changes are such that data from a certain cycle are rendered inaccurate or obsolete for the operating conditions expected during the cycle where the EFWS setpoints are implemented.
- Filtering is applied to obtain data that is representative of steady state control rod power changes along constant recirculation pump speed lines.
- The relevant instrumentation calibrations are confirmed to be current.
- Inherent instrumentation effects such as time delays and sampling rate are noted and accounted for.
- Non-physical values are removed from the data set. Non-physical data may be identified as spurious step changes in values that are not consistent with other corroborating inputs during continuous routine steady state operating periods.
- It is permissible to include some simple data reduction techniques such as averaging of multiple points that do not change significantly over a given steady state time interval to remove essentially redundant values.

- The reactor operating conditions from which the data are derived are consistent with the expected reactor operating conditions in which the EFWS setpoints will be required to operate. If any significant changes in the reactor core hydraulic conditions occur during periods of EFW operation, these changes are evaluated in accordance with plant design change processes and accounted for in the calculation.
- Hydraulic data from the Core Flow Measurement System calibrations and core plate dp instrumentation may be reviewed as necessary to evaluate trends in the data.

Best Estimate Hydraulic Model

The reactor fuel vendor provides data from a best estimate reactor hydraulic model to support the development of the core flow correlation. The model applies to the range of core conditions that are expected during the operation of a fuel cycle. The hydraulic model output provides plots of constant recirculation drive flow (as a percentage of rated drive flow) and a plot of natural circulation flow on the Power to Flow Operating map for different exposures. These plots are inputs to the correlation. The purpose of this model is to provide an analytical input of reactor power and flow conditions from plant operating areas in the power flow map that are not available due to adherence to required operating constraints and to provide an analytical input for optimizing the correlation model by calibrating the correlation coefficients. The methodology uses an NRC-accepted BWR model benchmarked to operating data.

Correlation Development

The correlation develops an equation that maps reactor core flow to recirculation drive flow and reactor power, and is based on terms that address the fundamental physical phenomena in the reactor including two phase flow. The mathematical relationship of the mapped variables is needed for setpoint development as the CIER and the NCL are presented in terms of core flow and reactor power on the Power to Flow Operating map, and the EFWS setpoints are in terms of recirculation drive flow and reactor power. The correlation is used to project the EFWS setpoint trajectory on the power to flow map to demonstrate that the CIER and the NCL are protected.

An optimized regression model is used to develop the correlation coefficients. The performance of the correlation against operating data and the best estimate hydraulic model is evaluated in the calculation, and a region of applicability is also determined. In addition to the correlation equation, a conservative relative core flow uncertainty value in % core flow is determined from the standard deviations and the differences in the operating data and the correlation prediction for core flow at the EFW stability operating areas of concern. Where differences cannot be calculated due to lack of operating data (at very low flows that are operationally prohibited by the power to flow map boundaries), a conservative extrapolation of flow error is determined using a second order fit. The forced conformance of the correlation with inputs from the best estimate model serves to calibrate the coefficients in low flow areas. For the purposes of constructing EFWS setpoints, the correlation is optimized in the areas of setpoint operation that are consistent with the locations of the CIER and the NCL.

B. Calculation II – EFWS Setpoint Analytical Limits

1. Purpose

The safety related purpose of this calculation is to determine the Analytical Limits (ALs) for the Extended Flow Window Stability (EFWS) trip setpoint in terms of the setpoint parameters used in the APRM BSP flow bias function.

The secondary purpose of this calculation is to determine the separation between the EFWS trip and rod block Allowable Values (AVs) for input into the process instrument setpoint calculation (Calculation III) and to determine a bounding Operating Limit (OL) for comparison with the Rod Block (Nominal Trip Setpoint) NTSP that forms the basis for the scram setpoint OL.

2. Methodology

Error Adjustments to the Stability Protection Region Boundaries Formed by the CIER

The base CIER includes inherent conservatisms with respect to decay ratio and other stability variables. In addition to these conservatisms, the base CIER also includes a 5% power conservative offset applied as a bias to account for operational variations in bundle conditions. The offset shifts the CIER statepoints vertically down by 5%. The methodology for development of the base CIER is discussed in Section 3.2 of the NRC safety evaluation in Reference 1.

The EFWS setpoints use the base CIER with additional adjustments for uncertainty. The adjusted CIER is an expansion of the base CIER that results in a conservative region that must be bounded by the EFWS setpoint trajectory on the Power to Flow Operating map. The adjusted CIER used in the calculations for the EFWS setpoint development includes additional uncertainty terms to the base CIER associated with the following sources:

- Voids in the Bypass Channel
- Relative Core Flow Error of the Correlation (Modeling Accuracy)
- Core Flow Measurement System Uncertainty

In theory, the above errors could be converted to power and recirculation drive flow equivalents and included in the EFWS setpoint instrumentation calculation (Calculation III), but it is more efficient and conservative to apply these errors in reactor power and core flow terms as direct adjustments to the MNGP CIER power and flow statepoints that form the EFWS setpoint AL as described below.

The adjustment of the base CIER due to voids in the bypass channel is consistent with Section 4.0 part 7 of the NRC safety evaluation in Reference 1. The bypass voiding error affects the Simulated Thermal Power signal comparison with the APRM power signal. The APRM power signal would be reduced by the amount of the void error. The value for this error is provided by the fuel vendor at the NCL (Section 4.3 of Reference 2). The error is conservatively applied as a power bias that expands the CIER by shifting the CIER statepoints vertically down on the Power to Flow Operating map. The void power bias is in addition to the 5% power offset already added to the base CIER described above.

Note that the EFWS trip would be activated at drive flows well above the NCL (where drive flow is zero) such that the more severe bypass voiding at natural circulation operating conditions used in the determination of the void uncertainty value are unlikely to be present in the reactor at the time of actual EFWS trip initiation. In addition, the MNGP calculation adds an additional level of conservatism to the void error by assuming the error is applied in terms of percent rated power instead of percent current power at the NCL of approximately 72%.

The calculation includes normality testing of the relative correlation flow error consistent with the MNGP setpoint analysis. A factor is applied to the relative correlation core flow error from Calculation I to form an upper one sided tolerance interval at the 95/95 probability and confidence level consistent with the requirements of GE setpoint methodology.

The total correlation relative core flow uncertainty is formed by adding the relative correlation error at the 95/95 level to the underlying Core Flow Measurement System (CFMS) uncertainty. The standard value of CFMS uncertainty is scaled by a factor of 2 to account for some added uncertainty at lower core flows.

Although the total relative core flow error is random in nature, the total flow error is conservatively applied as a flow bias that expands the base CIER by shifting the CIER statepoints horizontally to the right on the Power to Flow Operating map. The application of the flow error in this manner has the effect of under predicting core flow, which is conservative as it results in a lower flow-biased scram setpoint.

3. Backup Stability Protection for Region I Using EFWS Trip Setpoints

The Enhanced Option III (EO-III) Long Term Stability Solution does not specifically include a requirement for an automatic scram upon entry into Backup Stability Protection Region I (Scram) on a flow runback event; however the MNGP EFWS implementation is designed to conservatively protect the nominal boundaries of Region I.

The EFWS setpoints are constructed to nominally bound the statepoints associated with the base Region I. In this case, the term nominal is being used to indicate that the additional CIER sources of error are not applied to the base Region I to form an adjusted and expanded Region I. This is accomplished by iterating the BSP Flow Bias parameters in the spreadsheet optimizer tool and graphically demonstrating that the base Region I is substantially bounded by the EFWS scram setpoint analytical limit trajectory on the power to flow map.

If all of the sources of error which are conservatively applied to the CIER discussed above are applied to the boundaries of Region I, the EFWS rod block and scram would prevent normal operation in large portions of the approved areas of the Power to Flow Operating map. In particular, if the errors used to form the adjusted CIER are applied to the base Region I to create an error-adjusted Region I, the adjusted Region I boundaries would shift further into the operating map and into lower rod lines not associated with instability conditions. As a subsequent result, the EFWS trip could initiate a scram during normal operation and an unnecessary challenge to safety systems.

Given that correlation flow error and void bypass error would not be expected to be significant during the period immediately after a two pump trip while recirculation drive flow is decreasing but still well above low flow and natural circulation conditions, and given that GE setpoint methodology is employed to the AL to construct nominal EFWS setpoints, it can reasonably be concluded that the EFWS signal would adequately perform this protective function by initiating a rod block and a trip prior to or before any sustained reactor operation in Region I.

There is an added benefit to constructing the EFWS trip AL in this manner. This method obviates the need to separately apply errors to the NCL, which would shift the NCL into the normal operating area of the power to flow map and create a non-physical result. By including Region I within the trajectory of the EFWS trip AL, the NCL points of concern, which are completely enclosed by the Region I boundaries, will simultaneously be protected with significant margin that is in well in excess of the flow and power bias errors conservatively applied to the base CIER as described above.

4. EFWS Analytical Limits

The method for determining the EFWS Analytical Limits involves generating the Power/Flow map regions of interest, adjusting the base CIER statepoints for uncertainty, and applying the core mapping correlation to determine an appropriate value for the analytical limit such that the setpoint projection on the Power to Flow Operating map fully protects the adjusted CIER, Region I (as discussed above), and the NCL.

The EFWS setpoint trajectory on the map is determined by iterating the input parameters of the APRM BSP Flow Bias function that form the setpoint: Slope, Constant Power Line, Constant Flow Line and Flow Breakpoint. The trajectory is constructed to demonstrate (graphically and numerically) that the stability regions of concern are bounded. The steps in this demonstration include the use of spreadsheet goal seeking functions to back out the corresponding drive flows from the required core flow and reactor statepoints that form the stability regions. Then the spreadsheet optimizer tool is used to determine an optimized set of setpoint parameters from all of the necessary constraints of the problem.

The scram operating limits can be similarly determined by including adders to the Analytical Limit input parameters and determining the subsequent impact to the trajectory into the Power to Flow Operating map and the impact on Scram Trip Avoidance (STA) margin. The setpoint trajectory with adders should not affect normal operational maneuvers. The scram OL is typically set to the rod block NTSP, which is consistent with STP setpoints. The Scram and Rod

Block setpoint separation for the EFWS setpoints is designed to provide adequate warning of the trip signal to the operator and is consistent with the separation for this function that is used in the non-EFWS STP flow biased setpoints.

Operational limits are typically formed from trip avoidance margins following a normal operating transient. The salient normal operating transient for this setpoint is a single recirculation pump trip. Given that MNGP methodology nominally protects stability protection Region I which expands the area of protection on the Power to Flow Operating map, no margin to the single recirculation pump trip is expected. The MNGP implementation for EFWS trip avoidance is limited to normal operational maneuvers and does not demonstrate margin to a single pump trip. For Calculation II, the MNGP operating margin is evaluated by plotting a setpoint trajectory with adders that are consistent with instrumentation errors on the Power to Flow Operating map and graphically demonstrating that margin exists to normal power maneuvers as described above. Calculation III includes an evaluation of Spurious Trip Avoidance (STA) margin probabilities using standard probability metrics in accordance with GE Setpoint Methodology.

C. Calculation III – Plant Instrumentation Setpoints for the EFWS Setpoints

1. Purpose

The safety related purpose of this calculation is to develop the plant EFWS trip setpoints (AVs and NTSPs) that account for instrumentation errors from the Analytical Limits provided by Calculation II. The non-safety related EFWS Rod Block NTSPs and AVs are also developed in this calculation. The calculation III outputs are consistent with the input parameter fields in the BSP flow bias function of the APRM channels for the scram and rod block instruments.

2. Methodology

The methodology used for calculation III is the existing GE instrument Setpoint Methodology for Reactor Protection System instrumentation and Control Rod Block instrumentation channels as it applies to the PRNMS. Monticello is committed to the GE Setpoint Methodology for instrument Setpoint calculations associated with safety limits and Technical Specifications in accordance with MNGP USAR section 7.1. The methodology is documented in GE NEDC-31336P-A, "General Electric Instrument Setpoint Methodology," September 1996 and GE-NE-901-021-0492, DRF-A00-01932-1, "Setpoint Calculation Guidelines for the Monticello Nuclear Generating Plant," October 1992.

There is no accommodation for Single Loop Operation (SLO) in the determination of instrumentation errors for the EFWS setpoints. SLO is not permitted during EFW operation.

III. References

1. AREVA Topical Report ANP-10262PA, Enhanced Option III Long Term Stability Analysis, Revision 0, May 2008

2. ANP-3295P, Monticello Licensing Analysis for EFW (EPU/MELLA+), Revision 0, April 2014