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유전자 알고리즘 적용을 통한 향상된 RRS Logic 개발

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Improved RRS Logical Architecture using Genetic Algorithm

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Abstract : An improved RRS (Reactor Regulating System) logic is implemented in this work using systems engineering approach along with GA (Genetic Algorithm) deemed as providing an optimal solution to a given system. The current system works desirably and has been contributed to the safe and stable NPP operation. However, during the ascent and decent section of the reactor power, the RRS output reveals a relatively high steady state error and the output also carries a considerable level of overshoot. In an attempt to consolidate conservatism and minimize the error, this research proposes applying genetic algorithm to RRS and suggests reconfiguring the system. Prior to the use of GA, reverse−engineering is implemented to build a Simulink−based RRS model and re−engineering is followed to apply the GA and to produce a newly−configured RRS generating an output that has a reduced steady state error and diminished overshoot level.

Key Words : RRS, NPP, GA, PCS, DRCS, Control rods, Systems Engineering

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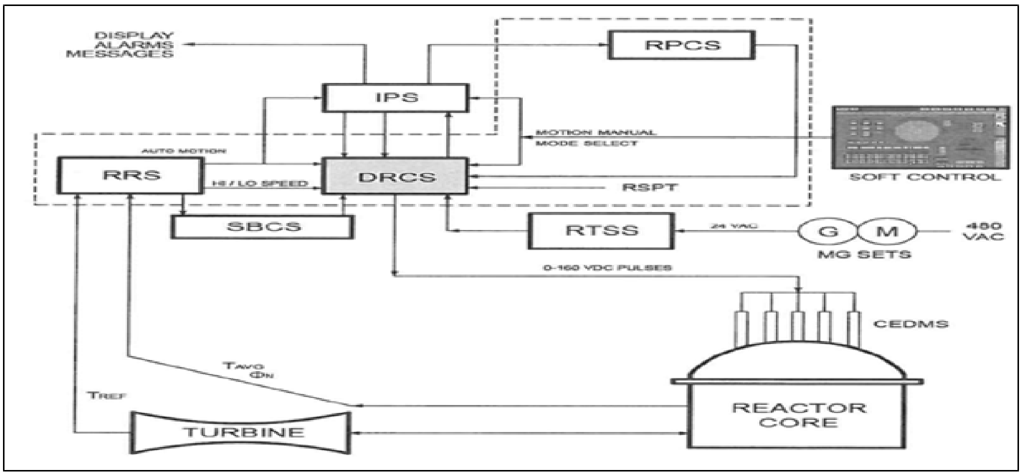
1. Introduction

RRS (Reactor Regulating System) is one of the performance related system of NPP (Nuclear Power Plant) and automatically manipulate CEDM (Control Rod Driving mechanism) by comparing Tavg (computed average temperature of the reactor inlet out outlet pipelines) to Tref (turbine power). The RRS logic employs primarily one lead-lag compensator and one lag compensator aimed to stably and rapidly regulating CEDM and minimizes the deviation between Tavg and Tref in an open-loop system. Since RRS is not complete with a feedback loop, its output still has a certain level of steady state error as well as relatively high overshoot. To address them, this research proposes optimizing them by developing the executable model of RRS with Matlab and retrofitting it with a sub-module with a GA (Genetic Algorithm) and eventually verifying the improved RRS in normal power operational modes and transient conditions).

Genetic Algorithms (GAs) are global, parallel, stochastic search methods, founded on Darwinian evolutionary principles. Many variations exist, including genetic programming and multi-objective algorithms. During the 1900s, GAs have been applied in a variety of areas, with varying degrees of success within each. A significant contribution has been made within control systems engineering. GAs exhibit considerable robustness in problem domains that are not conductive to formal, rigorous, classical analysis. They are not limited by typical control problem attributes such as ill-behaved objective functions, the existence of constrains and variations in the nature of control variables. GAs have also been applied to fault diagnosis, stability analysis, robot path-planning and combinatorial problems. Hybrid approaches have proved popular, with GAs being integrated in fuzzy logic and neural computing schemes. The GAs have been used as the population-based engine for multi-objective optimizers. Multiple, Pareto-optimal, solutions can be represented simultaneously [1]. As the GA is a proven methodology and has begun pervasive in industrial fields, this research gravitated to enhancing RRS performance with GA.

RRS interfaces with other systems depicted in Figure 1. RRS is the primary control portion

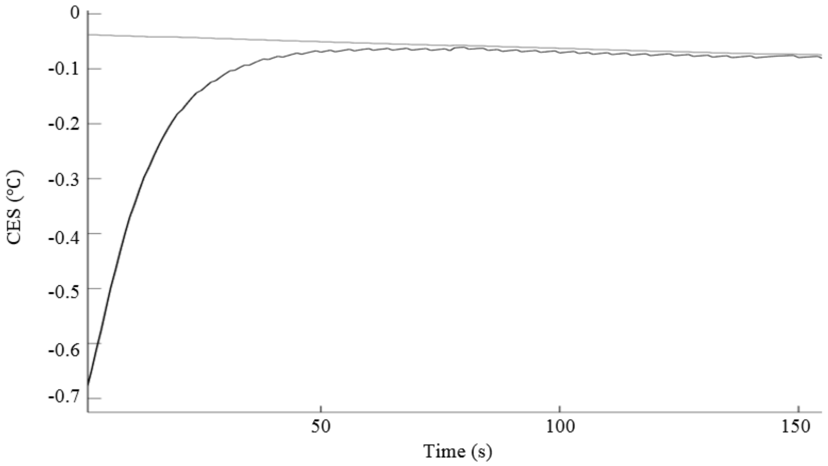


[Figure 1] RRS input and output at 25% power operation of PCS and is largely comprised of IPS (Information Process System), RPCS, DRCS and SBCS (Steam Bypass Control System).

The output of RRS is supplied to CEDM (Control Element Driving Mechanism) direction circuit which is used to determine the need for CEDM insertion or withdrawal. When the output is less than ± 0.1°C, no CEDM motion will be demanded in either direction. This 0.1°C dead band prevents unnecessary CEDM motion. When the error exceeds +0.1°C (Tavg > Tref) inward CEDM motion will be demanded at the rate determined by the CEDM rate circuit. Tavg denotes the average temperature of coldleg and hotleg. Coldleg is an incoming pipeline connected to reactor and hotleg is an outgoing pipeline between reactor and SG (Steam Generator). Tref is derived from the conversion from TLI to Tref according to a predetermined chart. TLI is obtained by measuring the blade pressure of the high pressure turbine. When the RRS output exceeds −0.1°C (Tavg < Tref), CEDM withdrawal will be demanded at the rate determined by the CEDM rate circuit. When the output exceeds 1.96°C, the AWP signal is initiated with CEDM fixed at the last position before the occurrence of the signal [2].

This research observed the RRS output at 25% power level of reactor in NPA (Nuclear Power Plant Analyser) and conceived an idea that the automatic withdrawal motion of the current system may result in an uncontrolled withdrawal of CEDM (Control Element Assembly Mechanism) as the current system generates an output of up to −0.7°C when the input stands at −0.201°C indicated in Figure 2. CEDM withdrawal motion initiates when the input level exceeds −1.1°C. When influenced by noise or disturbance, the input level becomes higher. Consequently, the output level may increase and end up with triggering unintended CEDM withdrawal motion.

This unintended withdrawal motion signifies that the withdrawal of CEDMs from subcritical or low−power conditions adds reactivity to the reactor core, giving rise to both the core power level and the core heat flux to increase together with corresponding increases in reactor coolant temperatures and reactor coolant system (RCS) pressure [5]. The withdrawal motion of CEDMs



[Figure 2] RRS input and output at 25% power operation also produces a time-dependent redistribution of core power. These transient variations in core thermal parameters result in a system approach to the specified fuel design limits, requiring the protective action of the reactor protection system (RPS), possibly posing a reactor trip.

Therefore the primary purpose of this research was to render the current system noise-robust and enhance the overall transient output signal and steady state error of the current RRS at every operational mode by conducting reverse and re-engineering whose approach features GA (Genetic algorithm) deriving the most optimized values for a given system.

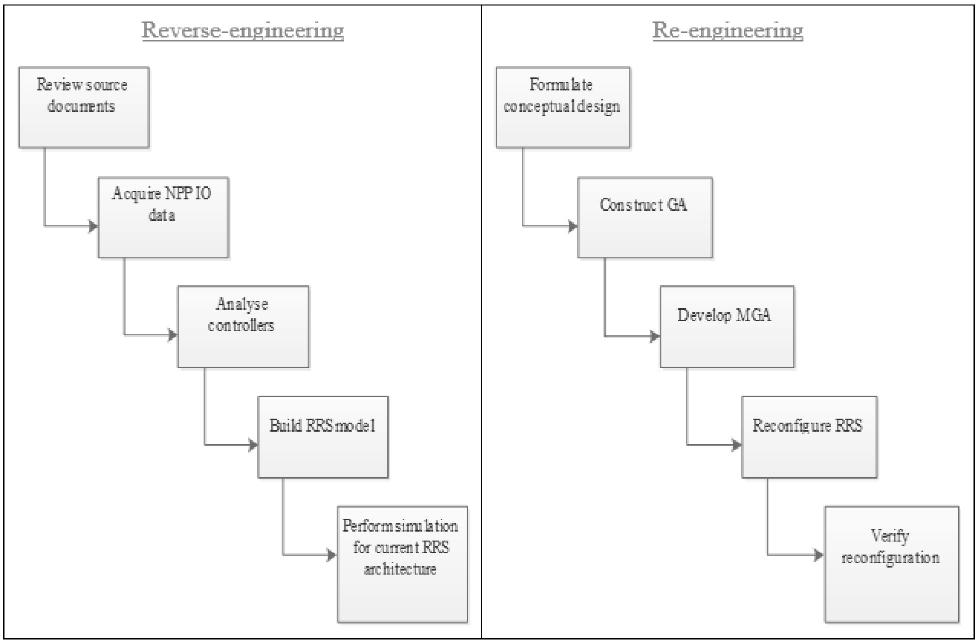
2. Theories and solution methods

The improvement methods for the current system featured reverse-engineering and re-engineering in Figure 3. The former one was exploited to identify the due constraints and controllers of this research by reviewing stake-holders requirements and later to construct the Simulink-based executable logical architecture of the RRS system by retrieving needed data from NPA (NPP Analyser), a real-life NPP simulator such as the inputs and output of the system and afterwards synchronise the output of the architecture and NPA by tweaking the systems major parameters.

Following the modelling of the current system, the re-engineering was entailed a) to devise the conceptual design of the improved RRS and b) to build the improved RRS using an existing GA model which were in turn tailor-made for this research. At the end, the theoretical and empirical verifications for the improved RRS were executed in order to substantiate the stability of the improved RRS.

2.1 Reverse-engineering

The NPA RRS inputs and output were collected



[Figure 3] Overall scheme of GA-based RRS logic architecture from the KINGS (Korea International Nuclear Graduate School) simulation room except the TLI (Turbine Load Index) value for which two methods were set forth. Then, the lead-lag, HPF and lag compensators of RRS were analysed. Afterwards, a RRS Simulink model was completed based on the NPS RRS inputs and output. DCD, URD and related upstream and downstream documents were reviewed to figure out controllers laid ahead of this research.

2.1.1 Review source documents

DCD Tier 2 (Chapter 7 and 15) and URD documents state the design and technical requirements. The review of the documents leads to identifying their associated upstream and downstream documents ranging from 10CFR50 to industrial standards. On the basis of the review result, a RVTM (Requirement Verification Traceability Matrix) and the resultant RVTD (Requirement Verification Traceability Diagram) were developed to a) visually display the controllers stated in the aforementioned documents b) to figure out the RRS specific technical specification and c) to establish the work boundary and to remain compliant to every requirement of the above-mentioned documents.

2.1.2 Acquire NPA input and output data

The RRS inputs include Tavg [°C], Tref [°C], Rx_pwr (Reactor Power, %) and TLI (%). The resulting Tdev (Temperature Deviation, °C) is the RRS output. All of the inputs and output are requested to build a logical executable model on Simulink. The data acquisition is available in NPA, the MCR (Main Control Room) simulator of the APR 1400 NPP (Nuclear Power Plant). NPA offers a real-life MCR environment, complete with multifarious operator stations and LDP (Large Display Panel) placed on the front and instructor station that enables to trigger a number of predefined scenario inclusive of 5 power operational modes and to export trend data. The trend can be stored as a text file and converted to an Excel file for data analysis outside.

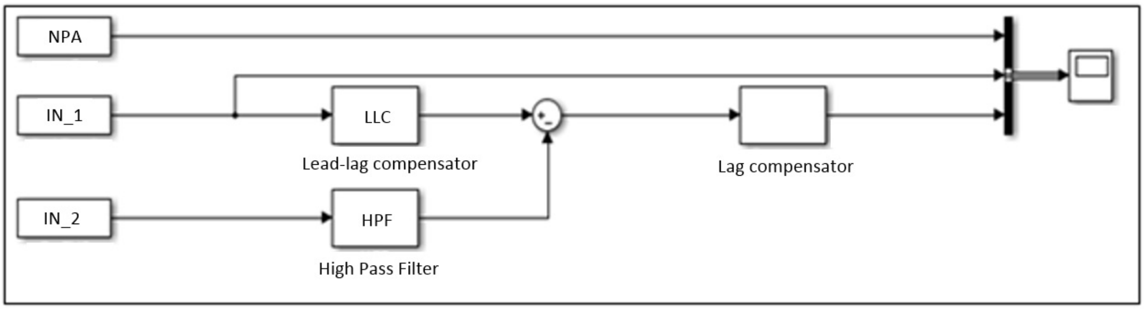
2.1.3 Analyse of the current lead-lag, HPF and lag compensator designs

Lead-lag compensator, HPF (High Pass Filter) and lag compensator constitutes RRS and each of their mathematical expressions were provided with DCD. The expression was examined to discover a gain, time constant, α and β of RRS and comprehend the functions of each compensator. Lead-lag compensator was placed at the beginning to capitalize on the best of both worlds from lead compensator and lag compensators. The lead compensator help the system upgrade the rising time while compromising the steady state error. The lag compensator can lead to refining the steady state error but result in aggravating the rising time.

2.1.4 model the current RRS using Simulink and synchronize the outputs of the NPA RRS and the Simulink model

a. Model the current RRS using Simulink

Following the acquisition of NPA data vital to build the NPA RRS model in Simulink and the analytic approach, the model was built with the Tref-TLI module. In the initial stage, TLI data extraction was not available from NPA which does not display the value on the screen. Thus, the module was included in the early



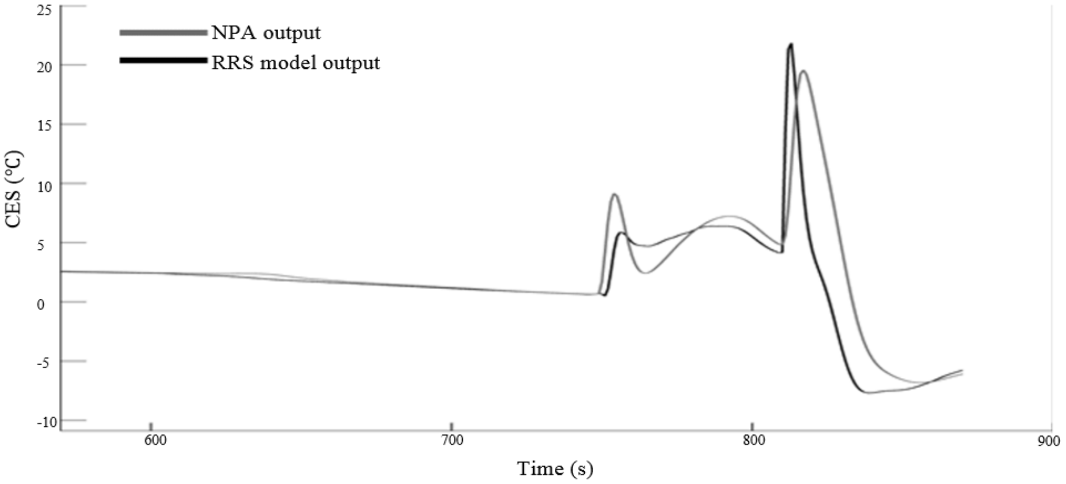
[Figure 4] Simplified version of RRS

modelling of RRS.

Later, the module was omitted as the extraction was enabled owing to the help of an expert who were engaged in the NPA development and the converting module was not employed in further experiment on account of the available extraction. The first subtraction of Tavg and Tref were substituted by IN_1 and the second subtraction of TLI−Tref was replaced with IN_2 to construct a simplified version proposed in Figure 4 and facilitated this research.

b. Synchronize the outputs of the NPA RRS and the Simulink model

Figure 4 was executed and generated an output signal which was concurrently compared with the output of NPA, the left top of Figure 4. The scope of Figure 4 illustrates 2 outputs; one from NPA and the other from the model as indicated in Figure 5. There was an output signal mismatch between the two outputs. The mismatch appears to be ascribed to the different platform of NPA and Simulink. To fix this issue, the parameters of the compensators and filter were adjusted manually numerous times and run. This process was iterated until the discrepancy became infinitesimal. The tweaking result displayed a marginal discrepancy and represented the output almost identical to NPA. The tweaked model was named hereinafter as the NPA RRS and named as SNPA.



[Figure 5] NPA and model scope output

2.2 Re-engineering

In the wake of the document review and the RRS Simulink model, this research came to devise a conceptual model for an improved RRS system that was prospected to refine the performance of the current RRS system. To that end, GA was suggested to be employed to create an additional LLC (lead-lag compensator). The GA platform was Labview and designed to compute the most optimized parameters for LLC. Next, the parameters were plugged into another Labview model converting them into a mathematical expression to be implemented into LLC. Having MGA (Modified Genetic Algorithm) fully developed, this research launched a task of discovering the feasible ranges of each parameter. MGA exhibited a poor performance with wider ranges but after numerous iterations, this research gained the feasible ranges. MGA was added with one more TF and the total TF was formed for the stability verifications. The outcome of the verification was delineated in the following result section.

2.2.1 Formulate the conceptual design of improved RRS logic

The chief objective of this research was to design the improved RRS (IRRS) finely following its IN_1 to optimize the steady state error by exploiting a GA (Genetic algorithm). There are 3 TFs dictating the RRS performance and this research planned to reorganize the current logic to contribute to the overall enhancement of the RRS output. With regard to the envisioned enhancement, this research proposed an additional LLC (lead-lag compensator) at the end of the current lag compensator.

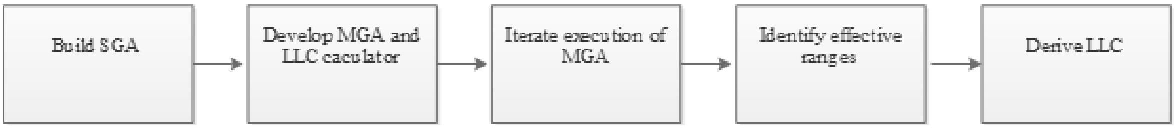
2.2.2 Construct GA for the development of an additional LLC [4]

a. Develop Labview-based GA

A book named "GA learning with Labview was reviewed which elaborates on fundamental Labview functions and steps to build a SGA (Simple GA) model to compute the most optimized parameters for PID controller. Figure 6 portrays the brief procedures to develop the additional LLC using GA.

The GA model encompasses numerous sub-modules listed below.

- Initial population: The number of initial population should be inputted before running the GA and the GA produces the initial population inclusive of a preset number of chromosomes.
- Fitted population: Once upper and lower limits are defined, only chromosomes within the ranges are singled out for the next steps
- Reproduction: Objective functions and its resultant fitness functions are predefined before the module is run. The fitness function prioritizes the chromosomes and the reproduction sub-module determines which of the first chromosomes will be reproduced by 14% in the second population



[Figure 6] Additional LLC development scheme

- Crossover: Reproduction does not fill the initial population, some of whose chromosomes are discarded in response to the reproduction rule of eliminating low-performing populations. The crossover probability (Pcross) is generally set to 85%.
- Mutation: As the last step, mutation occurs by 1%.
- Decoding: It converts binary expression to real type numbers.
- Performance indexing: It judges the performance level of the outputted chromosomes from the reproduction, crossover, mutation and yield the best chromosome among the population
- Elitism: It belongs to the recovery process of deceased superior chromosome in the previous population are discarded following the crossover or mutation. The chromosome substitutes for a low-performing chromosome in the current population
- Scale: At the almost end of the optimization, most of the chromosomes have similar finesses, implying fewer choices are available and thereby hampering further optimization.

This research constructed every sub-module constituting SGA by referring to the book and comprehended their functions and after all verified that the constructed model ran as intended.

b. Develop an additional LLC and LLC calculator

The Labview library only provides a lag or lead compensator. Subsequently, referring to the book, this research devised a LLC comprised of 3 of the library elements; lead, lag and serial connector. Soon, the LLC calculator forming the mathematical expression of the LLC based on the MGA output was made.

c. Replace PID with the proposed lead-lag compensator

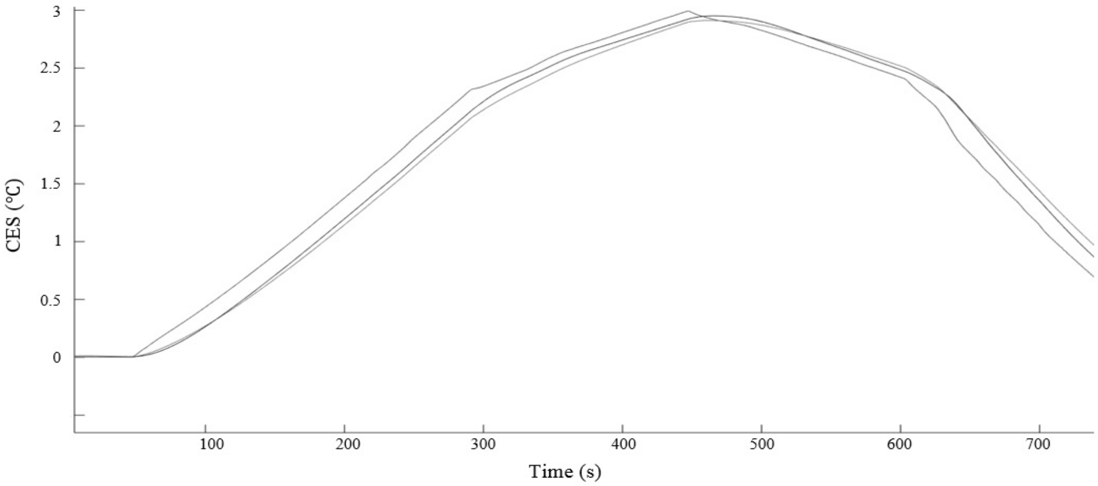
The proposed LLC was called in SGA and was replaced with the existing PID and rewired with the surrounding modules. This contains 3 major parameters; gain, time constant and beta. This result led to developing a MGA (Modified GA) that was devised to derive the optimized gain, time constant and beta which were defined as X1, 2, 3 respectively.

d. Execute of MGA and search for the effective upper and lower ranges

MGA was executed numerous times to search for the effective rages of the 3 parameters. The rages are generally established by experiences or comparison with analogous systems. The enormous iterations were inevitable as this research pioneered the GA application into the RRS. The process of one execution involved a) the insertion of the upper and lower ranges of each parameters and b) the insertion of X1, 2, 3 into LLC to form the mathematical expression of X1, 2, 3 c) the Simulink scope analysis which was the most crucial step to ultimately judge the output of MGA. The accomplished LLC was drawn in IRRS which then was executed, generating a scope illustrated in Figure 7.

e. Form the total TF

In order to analyse the stability of IRRS, the total TF should be calculated be utilized in the analysis of Bode diagram, Routh Hurwitz, Root locus. This research adopted equivalent TF diagram and generated the total TF. Afterwards, the total TF was derived by the multiplication of each TF of IRRS. Soon, the individual TF was translated into the below Matlab coding to



[Figure 7] Scope output of IRRS

accurately calculate the total TF and the Matlab derived the total TF.

3. Results

This research attempted to devise an improved RRS using genetic algorithm aimed at obtaining the most optimal parameters of each TF of the current RRS and consequently to diminish the steady state error and overshoot of the current RRS. To that end, multiple methodologies were put forward and implemented with appreciable outcomes. At the beginning, the concept for an improved RRS logic was proposed and it was followed by erecting SGA as well as LLC plus LLC calculator. Soon SGA was modified by replacing the PID sub-module of SGA with the developed LLC. Later, the iteration to identify the effective upper and lower ranges of each parameter was executed and the selected parameters established IRRS. At the end, the IRRS was run and generated an appreciable output. In this section, IRRS was verified theoretically and empirically by means of conventional methods, the 4 power operational modes (100%, 75%, 50%, 25%) and one transient condition provided by NPA.

4. Conclusion

In this research, the NPA model with Simulink was derived using the schematic diagram of the current RRS. The model was compared with the actual output of NPA with a trend step of 1 sec. Afterwards, the concept of IRRS was laid out which was designed to retrofit the current RRS with an additional lead-lag compensator. The parameters of the compensator ranging from gain, time constant α to β were determined as the dominant factors to be optimized. An existing GA model was exploited to be familiarized with the GA concept and the model was tailored to feature the lead and lag compensator. In the wake of the MGA completion, it was run numerous times to discern the acceptable ranges of the parameters. When the range becomes substantially wide, the MGA model is prospected to fail to discover the optimized values. Consequently, the values were employed to create IRRS.

Figure 2 was the starting point of this research reflecting a substantial level of overshoot and the level was close to the predetermined dead band. To systematically address this issue, this research devised IRRS by executing the above-mentioned methodologies and verifying it with multiple theoretical and empirical measures. All of them infer that IRRS can successfully cope with the issue. In spite of the input standing at −0.1°C, SNPA was marked at up to −0.7°C adjacent to the predefined dead band of −1.0°C. On the contrary, IRRS displayed a lower level of overshoot with a great deal of margin for the dead band. The output line of SNPA contains conspicuous unstable oscillations while IRRS overall indicated a smoother output line.

Apparently, it is recognized that the overall enhancement of control rod manipulation ascribed to the improved RRS will minimize noise-induced CEDM motions and the alarm frequency and will revert back to a steady state condition in a faster manner.

5. Further study

This research used a Simulink-based RRS model named SNPA which still carries a marginal discrepancy with SNPA. The Further study will concentrate a work of building IRRS in NPA and empirically verifying IRRS in NPA.

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