DEVELOPMENT OF DESIGN SUPPORT TOOL USING INTEGRATED HIERARCHICAL CONTROL CHART (HCC) & IEC61131 FOR NUCLEAR POWER PLANT CONTROL

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Abstract

This paper proposes a new intelligent and highly automated Hierarchical Control Chart (HCC) and operations mapping solution for nuclear power plant operators that provides control system designers, developers and operators with a single view of all elements and systems across a power plant with the integrated interactive data access and information retrieval capabilities that enables a faster fault diagnostics as well aids in a more efficient decision making for the routine daily tasks.

1. Introduction

The objective of the new proposed automated Hierarchical Control Chart and operations mapping solution is to aid the control system designers, developers and operators with an automated tool for equipment, process lines and operations mapping, which offers a fast, intelligent and highly automated visual support for daily routine operations as well as a troubleshooting and fault diagnostic tool.

The proposed Hierarchical Control Chart technology enables to automate the exchange of information between the control system designers, programmers and operators on the basis of ISA S-95/S-88 [1] [2]. This will allow standardizing the terminology and object models used for the exchange of information by different systems at various stages of control system design, development, operation and troubleshooting. It provides an excellent tool for describing and comparing the process and control units, parameter variables and commands.

All over the world, as well as in Canada, nuclear power plants utilize different terminology for departments, groups, processes and parameters, often designed in-house and used exclusively by the personnel of that particular station or plant. Moreover, quite often the information that is exchanged between CANDU-based plants refers to the same activities and functions in a different manner.

Using ISA S-95/S-88 [1] [2] guidelines for integration of Enterprise and Control Systems enables future standardization and interoperability of control systems in CANDU-based plants as well as promotes communication with other members of European and international community at all levels of involvement of control system design, implementation, operation and troubleshooting.

The proposed automated Hierarchical Control Chart is integrated with an interactive knowledge database that enables a fast, automated access to the information about processes and parameters across the power plant domain. The information stored in the database and captures data at different levels of process and control hierarchy, as well as specifies how each piece of knowledge in the system is interconnected with the others. The proposed knowledge base contains trace information for each piece of knowledge defined which makes it easy to reuse, extend, and translate the contents in the future. The entire existing knowledge bases could be reused or incorporated into the new systems in their entirety or only in the relevant portions.

2. HCC application for control system design

The importance of well-designed operator interfaces for reliable human performance and nuclear safety is widely acknowledged [3] [4]. The design of modern control systems starts with the analysis of control goals and control hierarchy, which requires knowledge of all measured and control variables as well as determination of all of the components, processes and their relation.

Should a control system designer chose to use the existing paper-based process and connection diagrams they will be faced with time-consuming engineering materials that cannot be easily translated into CAD software, often bear hand-made comments or remarks and exhibit soiled, faded or worn-out ink.

Should they chose to use the existing plant simulators or graphical interfaces for the plant processes, they will be faced with multiple objects with bright contrasting colors as well as excessive labelling contributing to clatter on the user’s screen and providing highly specialized highly detailed level of information with the lack of distinction between process and control lines, making it hard for the user to trace the line’s origin and function [5].

Figure 1 below provides an example of how the proposed HCC solution could be employed among other tools to aid the control system designers.

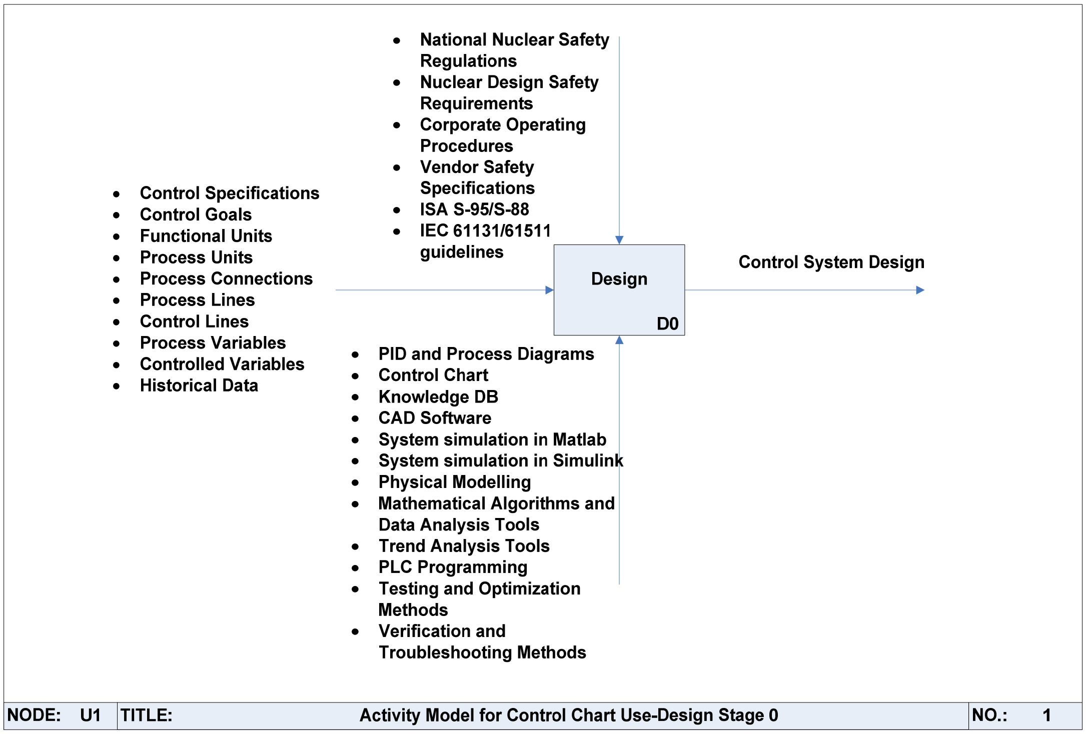

Figure 1. Activity model for HCC utilization for control system designers.

Below the above mentioned activity model is described in more steps. As shown in Figure 2, the proposed HCC solution could be used both at the data gathering stage as well as during the control system conceptual design period.

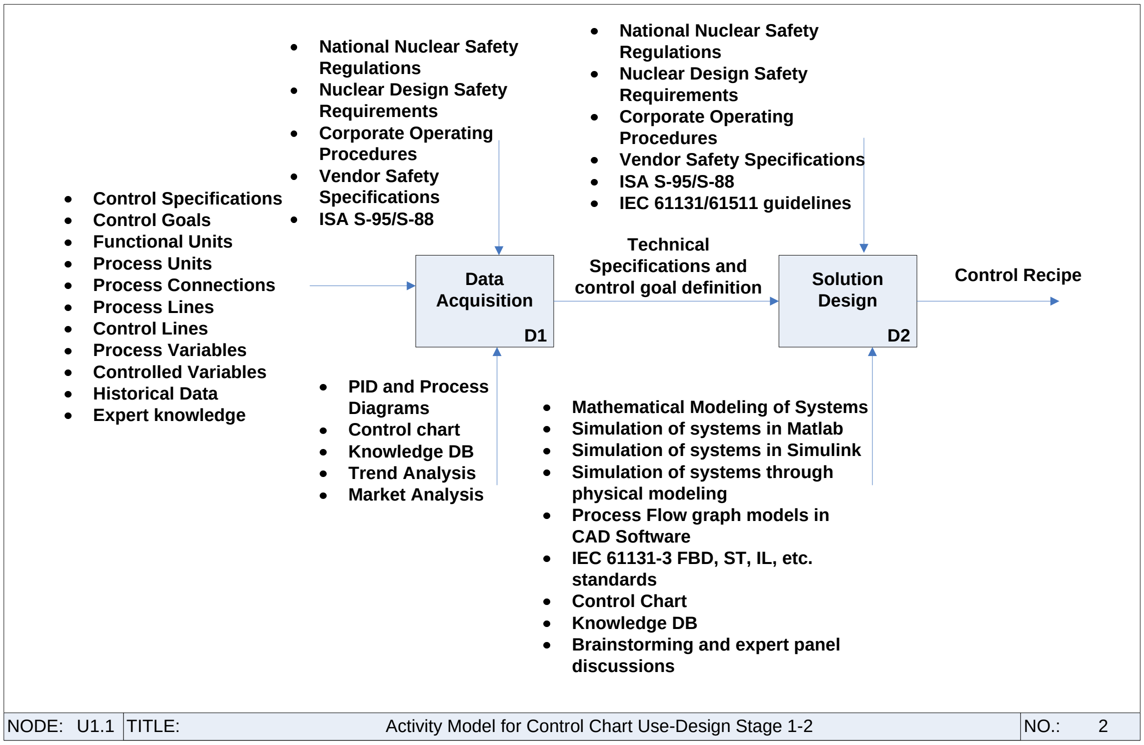

Figure 2. A break-down of Control System Design process with HCC utilization at the data acquisition and solution design stages.

3. HCC application for control system developers

Once the system has been designed and transferred to programming stage for implementation, to verify the system performance a control system programmer will often need to physically trace the line on the screen or paper diagram through a series of valves, pumps and tanks carefully paying attention to their status and functions. In modern nuclear power plants, software developers create logic ranging from something fairly simple, e.g. simulating current device conditions, to actuating safety alarms and reactor trip functions, which are vital to the plant safety and productivity. A minor mistake in a pipe or valve connection could be considered quite excusable for a control system programmer, most of whom are highly specialized IT experts or electric/electronic engineers, but could lead to absolutely devastating consequences for the power plant operation and public safety. This leads to enormous amount of time spent on verification and proofing of new control system at all stages of development prior to installation.

Figure 3 below shows the programming and implementation stage of the control system development where the proposed HCC solution is used to aid the control system programmers and developers.

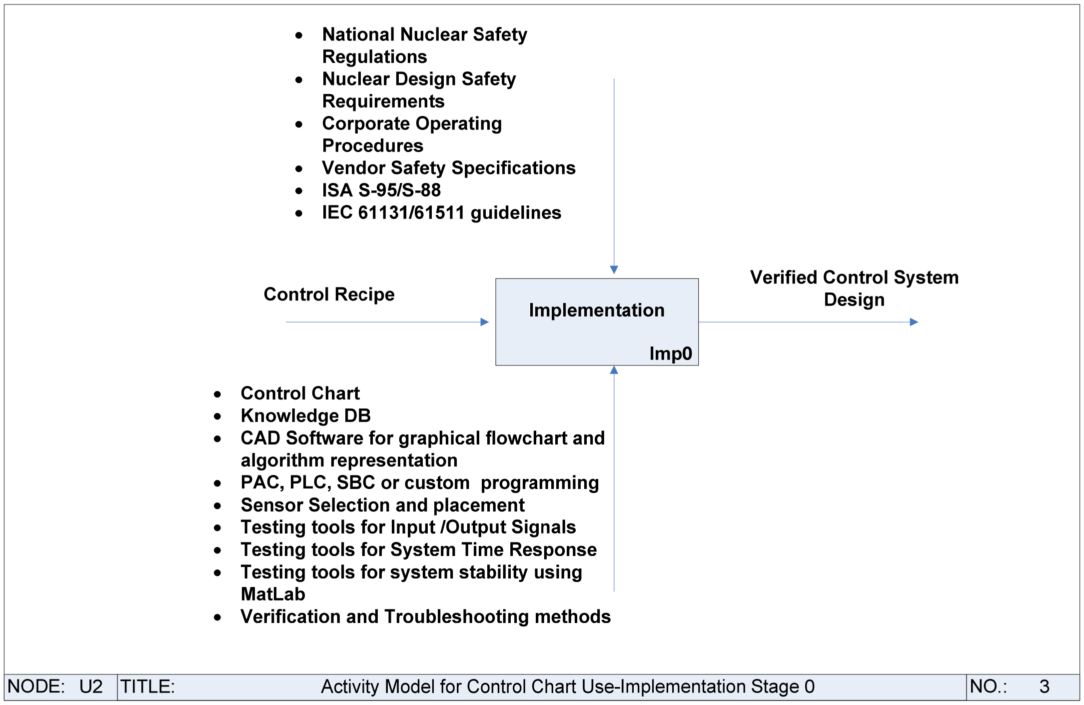

Figure 3. Control System Development Stage where the proposed HCC solution is used to aid the Control System programmers and developers.

Figure 4 below shows in more details where the proposed HCC solution could be used to aid the control system developers and programmers during the implementation stage as well as for testing and verification purposes.

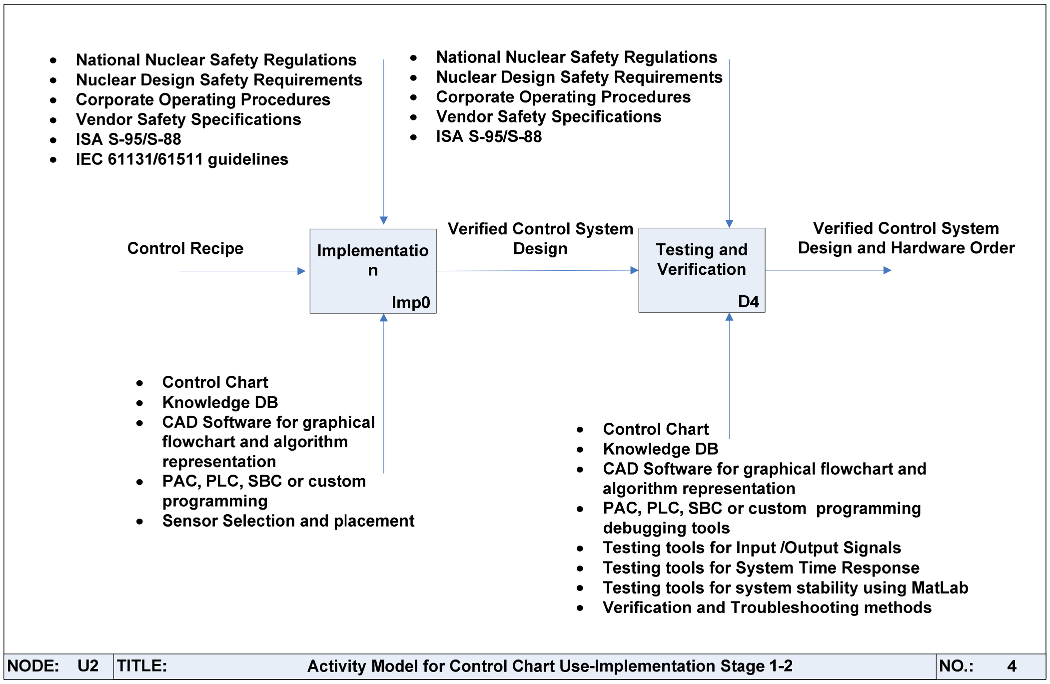

Figure 4. Implementation stage of the control system development showing that the proposed HCC can be used to benefit the control system programmers as well as testers and troubleshooters.

4. HCC application for control system operators

Once the control system is complete and installed at a power plant, it is a common scenario, well described in literature [6], that quite often a process operator is faced with an emergency situation where the operator is overwhelmed by a huge amount of information that has to be processed at a very high speed in a limited time, which increases the operator workload and making it almost impossible to deal with the emergency [6].

This is even more crucial for the nuclear power plants, where the control room operators supervise and monitor all major plant systems and equipment, often mentally translating and interpreting information from multiple sources. Typically, control room personnel comprise five or six operating crews working around the clock. Each crew spends part of their four, five or six week cycle rotating on each of the shifts - days, afternoons, and nights lasting up to 12 hours. This system has proven itself to be very successful in CANDU-based power plants, however, it is highly dependent on the knowledge and expertise of the control room operators who have to be carefully selected and spend approximately eight years in training.

Even though increased advancements in evolution of digital technology and process automation have lead to the replacement of operating panels with dedicated instruments by general-purpose workstations, time required for analysis of operating events with potential fault propagation scenarios and consequences across the power plant domain still remains the leading cause of the loss of plant production and operational availability. Long working hours as well as the effects of concentrated mental work (including prolonged visual work) can cause the excessive fatigue and reduce the operators' ability to maintain awareness of equipment location and the process relations across the plant, leading to the obvious implications for workplace and public safety.

Field studies [4] showed that in a scenario where the plant procedures are written on paper, the operators have to browse the paper procedures volumes continually, going from general diagnostic flow charts to the detailed manual actions and procedure check-lists and vice-versa, which consumes valuable time during emergency situations, as well as routine fluctuations. Considering the complexity of modern nuclear power plants, the amount of time spent on retrieving and filtering paper-based information by plant operators increased up to a point where it became a factor in hindering operators' performance and creating additional grounds for operation errors.

Operational experience worldwide has demonstrated that the accuracy, completeness and efficiency with which work is performed in the plant control centre is a key enabling factor in attaining effective plant operation. [7].

In modern nuclear power plants, many computerized operating procedures systems such as computer based procedures (CBP), computer procedures (COMPRO), computer procedure systems (CPS), nuclear emergency operating support systems (NEOS), computerized control rooms (CR), emergency operating procedure tracking systems (EOPTS) [8] , and so on have been developed to support operators in their daily routine. The proposed automated control chart solution is a highly automated, visually-enhanced system that provides nuclear power plant operators with a single view of all elements and systems across the power plant domain.

Figure 5 below shows a general view of how the proposed HCC solution could be used by the control room operators and support personnel at a power plant.

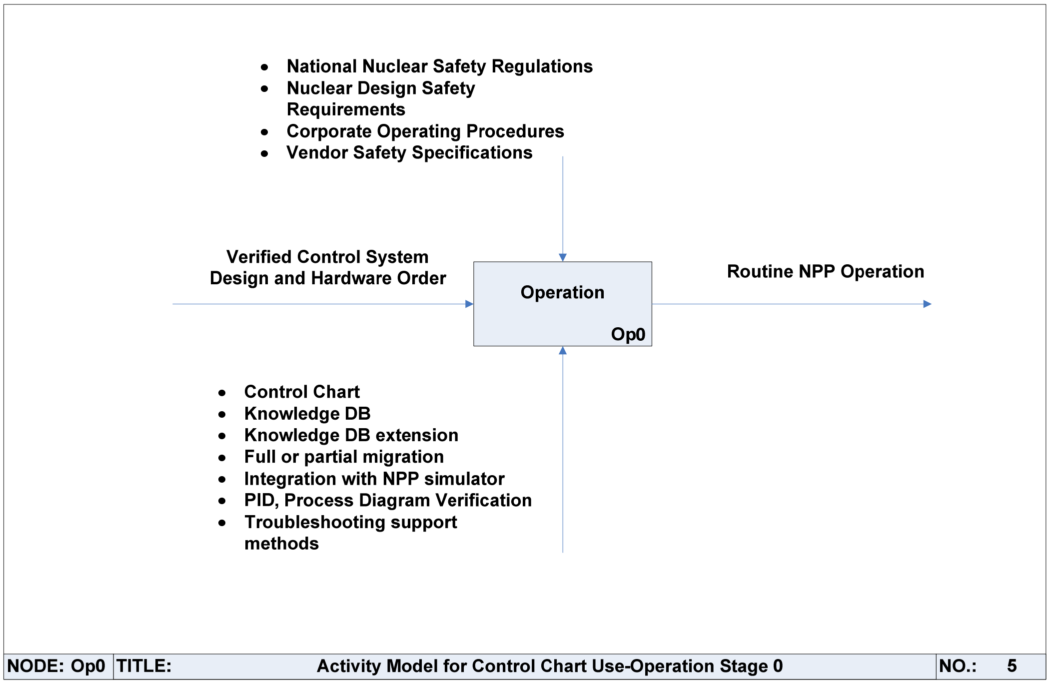

Figure 5. Routine operation stage of the control system where the proposed HCC is being used to aid the control room operators and support personnel.

5. HCC main functions and features

The proposed new ACC system will serve for all, but not limited to, following purposes:

- Promotes visual recognition of equipment location and process connections across the power plant domain;
- Improves operator awareness of the overall structure of the power plant, which is particularly useful for new employees and operators in training;
- Allows to access required initial information in a fast, consistent and error-free manner;
- Helps to visually map process alarms and faults to the corresponding physical location of the equipment throughout the plant, thus promoting communication with the maintenance department and assisting in troubleshooting activities;
- Make more efficient use of available control room resources through support for visualization of operation and improved standardized naming conventions, hence reducing operating errors, time and workload, and improving operation efficiency and communication between various departments and individual employees.

6. HCC design and implementation process

Figure 6 below shows the processes and tools involved in the design and implementation of the proposed HCC.

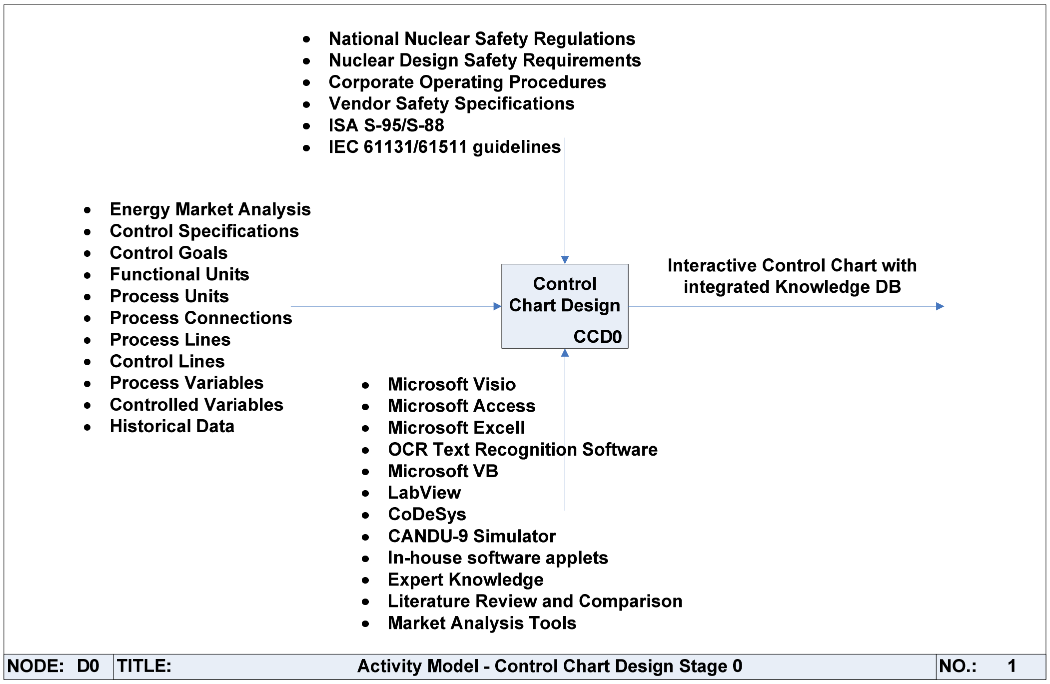

Figure 6. Overall view of the HCC solution design.

As shown in Figure 6, the design of the proposed HCC solution is highly modular which allows easy corrections, extensions, migration and data import/export on as needed basis for an easy integration and collaboration with the existing control systems already in use in Canada and worldwide, as well as providing the convenience of smooth and easy customization for proprietary software and applications.

7. HCC user interface

Figures 7 below shows the proposed HCC user interface with some of the available functionalities.

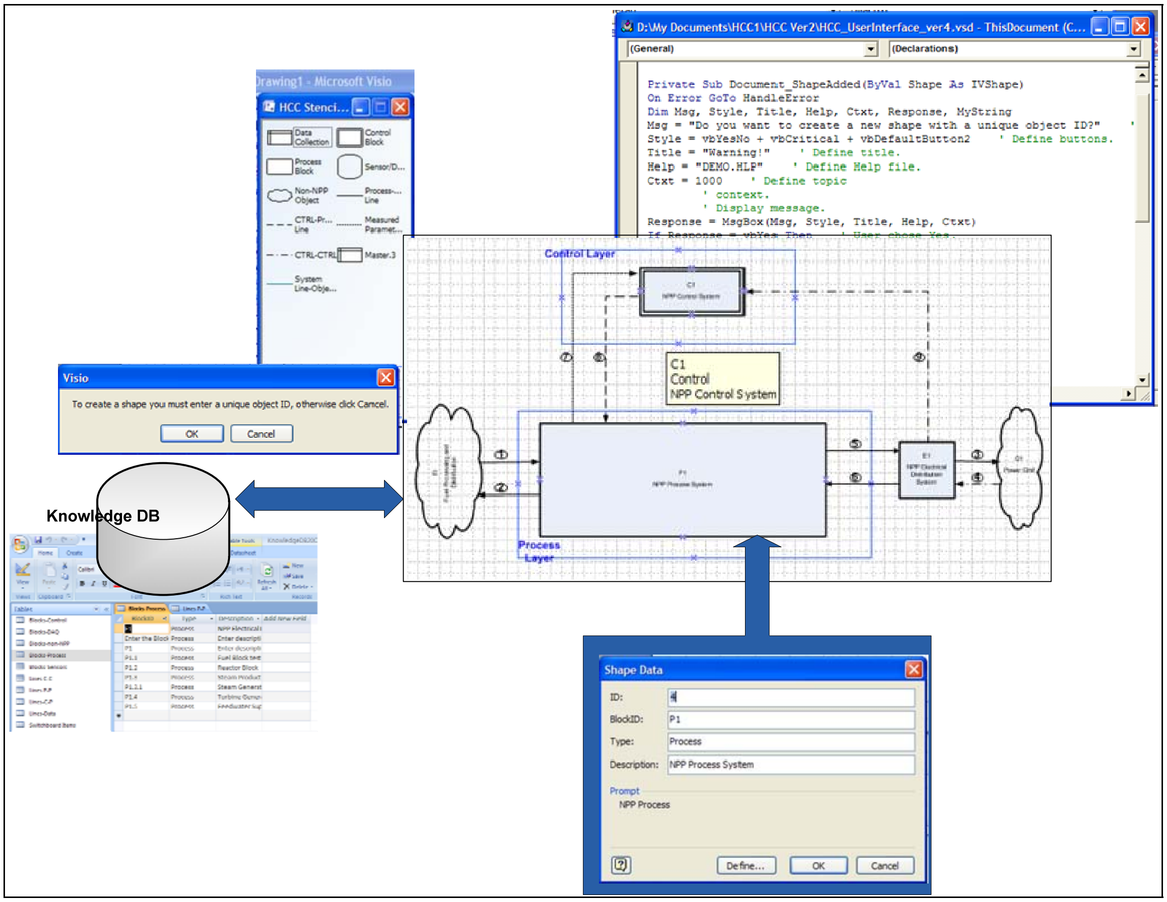

Figure 7. HCC user interface with some of the available capabilities.

8. Conclusions

The proposed Hierarchical Control Chart solution (HCC) is a new tool that can prove to be a useful aid at all stages of the NPP control system design, development and operation. Its interactive user interface combined with the integrated knowledge database provides control system designers, testers, troubleshooters or users with a single view of all elements and systems across a power plant with an accurate and fast information retrieval capabilities reducing the time spent on proofing and verification of the NPP control system paper-based or still CAD drawings, hence increasing the process efficiency and eliminating unnecessary grounds for human error.

Its standardized ISA S-95/S-88 [1] [2] interface enables interoperability of control systems in CANDU-based plants in Canada as well as with other members of international nuclear community at all levels of involvement of control system design, implementation, operation and troubleshooting.

9. References

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