An AE/CxA Team Approach to Specifying Control Systems Logic and Integration

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Synopsis

Building commissioning has demonstrated that clearly understanding and documenting control logic and control systems integration early in the project addresses important issues that otherwise become costly to resolve during functional testing. At a minimum, control logic and integration need to be well understood and documented before control programming begins and before FPT procedures are written. By working as a team, the design engineer and the commissioning provider can perform a process during design that allows control logic and integration issues between equipment, systems and disciplines to be resolved such that procedures and responsibilities are clearly specified. This allows Pre-functional testing checklists and the commissioning functional performance tests (FPTs) to be clearly specified in the project bid documents, making the construction phase commissioning process more biddable and enforceable.

This paper discusses the need for comprehensive design-phase controls logic and integration, suggests a process for doing so, and provides examples of how the process facilitates project success.

About the Authors

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Introduction

Commissioning guidelines prompted by organizations such as ASHRAE, the United States Green Building Council, and the United States Department of Energy recommend that commissioning begin early in a project's design phase. Based on the positive experiences of commissioning providers, owners, designers and contractors, many building industry professionals are becoming believers in the benefits of early commissioning as promoted by these and other organizations. As a result, there appears to be a growing trend toward design phase commissioning in many segments of the commissioning market.

Among the benefits offered by design phase commissioning is the opportunity to forge a strong designer/Commissioning Authority (CxA) team that can cost-effectively identify and resolve issues in the design phase that frequently have to be mitigated via costly change orders and project delays in the construction phase. Often-times, the CxA can provide the design engineer detailed information regarding issues that repeatedly delay successful commissioning efforts and insight into how these issues are typically resolved. In return, the design engineer can provide the design tools and expertise to address the issues in the construction documents thereby avoiding a potentially costly change order or schedule delay. This collaboration can provide tremendous benefit in addressing the common issue of interoperability between equipment and controls provided by different vendors. Design phase collaboration between the designer and CxA provides a highly cost-effective means of realizing effective and efficient systems operation and interaction in precise accordance with the Owners Project Requirements (OPR) and the Architect/Engineering (AE) design team’s BOD.

Systems are comprised of components. The means by which components are to be controlled to operate as a system are defined by the sequences of operation. The designer develops the sequences of operation and includes them in the construction documents. The sequences are commonly communicated as a written narrative to define how specific components are to be controlled and by what feedback signals, settings and/or operator commands. Our experience has shown that the detail included in the sequences varies dramatically from project to project. These can be a few sentences to describe the control of a simple system to pages upon pages of how a complex system is to operate. Unfortunately, sometimes only a few sentences are provided for complex systems. This then allows the controls contractor great latitude on how the actual programming is written which can have a drastic and often negative result on system operation.

Control systems logic & integration (CLI) is a process that strives to precisely identify the details of how components and systems are to work together to achieve the desired control strategies. Performing this process during design allows this information to be clearly specified in the construction documents. This helps level the playing field for bidders and increases the likelihood the building systems will work correctly going into functional testing. Fully defined control logic and integration also provide the CxA with the information needed to develop accurate and comprehensive Functional Performance Test procedures (FPTs). If this information is known during design, FPTs can be included in the project specifications. This allows the contractors to more accurately bid their commissioning work and facilitates enforcement of the commissioning process for the CxA and owner.

Project History Leading to the Process

CLI processes have been advocated by various individuals and organizations and have even been presented at past National Council on Building Commissioning conferences. For Commissioning providers, the need for a CLI process is rooted in FPT writing. According to the Building Commissioning Association’s Essential Attributes of Building Commissioning: "*The functional testing program objectively verifies that the building systems perform interactively in accordance with the Project Documents. Written, repeatable test procedures, prepared specifically for each project, are used to functionally test components and systems in all modes of operating conditions specified for testing. These tests are documented to clearly describe the individual systematic test procedures, the expected systems response or acceptance criteria for each procedure, the actual response or findings, and any pertinent discussion*." This is commonly interpreted to mean that the test procedures are of sufficient detail that the same results will be obtained when the procedure is performed by different experienced HVAC technicians without specific knowledge of the project.

In order to write such detailed FPTs the CxA has to know the exact control logic used by the control systems' programmers to translate the sequences of operation into Building Automation System code. If the control logic has not been clearly communicated, the CxA often-times must convert the sequences of operation into logic diagrams or statements. Inevitably this leads to questions regarding: 1) the intent of the engineer’s design and; 2) how the contractor interpreted and implemented the control logic. In our experience these two factors were frequently in conflict.

In these cases, we found that when we went through the process of converting the sequences of operation, functional testing and project acceptance went much smoother for everyone than when we didn't. Controls contractors and engineers that initially thought the request for clarity and detail was unreasonable and unnecessary, later went on to comment on how well things went because of this effort. This process seemed to “head off at the pass” a lot of potential issues in the construction phase. Why, we asked, not do it in design?

We frequently encountered two common objections to design phase CLI. The first is a concern that the process will require increased AE time. Although the process may cause a modest increase in effort, some designers believe that the benefit far outweighs the cost. In fact, one of the authors was selected as the CxA for a project because the design engineer, who was on the selection committee, felt strongly about the value added by the process. Other engineers may be initially skeptical, but will most likely become believers after participating in the process.

The following quote is from an initially skeptical design engineer that has been through design CLI process on two projects. "*I think that the greatest value to the projects in both cases was early involvement by the commissioning agent in the design process. This allowed a couple of things. First, it allowed the CxA to offer suggestions based on his filed experience that could be incorporated into the design at the appropriate time. Second, it allowed him to have input into the wording and structure of the documents, specifically the control diagrams, so that they were in a form that was beneficial to the commissioning documents. The result was that we as the designers, and the commissioning agent, both understood and agreed with the documents produces and we both took ownership. I believe that not only made the process better, but it allowed us to present a more closely knit team to the Contractor during construction phase. The best suggestion I can make is to have the commissioning agent on board at the beginning of design development so that you can make the most f the commissioning process.*" CLI takes more time for the AE and the CxA during design, but we believe that it saves time overall because it minimizes time consuming and potentially contentious confusion during startup testing and closeout. In our experience, design engineers that have been through the process tend to agree.

The second objection we sometimes here comes from the common belief that control logic is proprietary, and that specifying precise control logic and integration might eliminate some suppliers from being able to bid the project. We don't understand the basis for this. We agree that programming languages and the capabilities of system architecture vary from vendor to vendor. However, we've yet to encounter control logic that isn't universal on a basic level. The following anecdote tends to support this: Two major controls vendors were asked to participate in a panel discussion at a recent meeting of the Northwest Chapter of the Building Commissioning Association (BCA). Each company sent two very experienced representatives, one that has worked extensively for a vendor that wasn't present. The subject of specifying control logic came up and the controls engineers were asked directly if specifying fundamental control logic in the form of diagrams of If-Then-Else statements presented difficulty in bidding or implementing a design. All of them indicated that well designed logic statements and diagrams improved bid-ability and implementation over more traditional concept/narrative sequences of operation.

A Design Phase CLI Approach

The AE and CxA share a common fundamental goal of providing a project that satisfies the owner's functional needs. It stands to reason then that a truly effective design process is based on a common understanding of what those needs are; which is of course the purpose for the development and evolution of the OPR and BOD documentation promoted in ASHRAE Guideline 0 and required by the USGBC LEED program. The most effective design development processes we've encountered include developing concept sequences of operation in the early drafts of the BOD. When it is clear which concepts of operation best address the OPR, system schematics are developed that best accomplish the sequences of operation. Only then are components and equipment types chosen that best support the systems and implementation of the sequences of operation.

As soon as the systems are selected and the narrative sequences of operation are known, defining the controls logic and integration should begin. We advocate that Design Team and the CxA participate in a control systems logic and integration process. The electrical and mechanical engineers, owner's representative, and the Commissioning Authority resolve integration issues between equipment, systems and disciplines such that integration, procedures and responsibilities are clearly specified. The CxA brings to this collaboration detailed information regarding issues that repeatedly delay succesful commissioning, and insight into how these issues are must often be resolved. The design engineers bring the design tools to address the issues before they make it into the field. One effective approach to CLI coordination is for the CxA, as a part of their design submittal review, to begin outlining the functional testing plan. This outline includes the following information:

1) A list of all the FPTs anticipated by the CxA
2) For each FPT, a list of the objectives, the acceptance criteria, and the minimum participants (typically contractors and suppliers)
3) An outline of the various steps of the procedure required to confirm the acceptance criteria

We use the outline as a working document that evolves into the completed Functional Testing Plan, which contains the functional performance test (FPT) procedures. We find it highly cost-effective to begin considering the test procedures as a part of the design review, when the CxA's head is wrapped around the entire "design forest", with a focused eye on the details of the trees. Beginning the FPTs early on enhances the design review because, more often than not, if we can't figure out how to test the operation of a system the contractor can't figure out how program the controls or integrate the operation of interactive systems. Along with our outline, we generate a list of issues for clarification, which we believe effect the functional performance of the systems. The Design Team and owner's representatives respond to the comments in writing. These parties meet and discuss the written responses in order to clearly document the control logic and integration procedures and responsibilities. Examples of the types of issues we often encounter are described further in the following paragraphs:

Control Logic

Control logic issues are related to how the concepts described in the narrative sequences of operation are to be implemented through control system programming and installed components. In our experience, systems are most likely to operate as the designer intended when the designer's sequences of operation are presented in a series of logic diagrams or statements. One reason for this is that the success of a systems' design depends on specific cause and effect relationships, which may not be fully apparent to readers of narrative sequences of operation, or even to the designer, until the logic is fully developed. Another reason is that control system programmers must translate narrative sequences of operation into a programming language that is understood by a binary-based processor. By using logic diagrams or If-Then-Else statements, the precise methodology of how the components are to be controlled can be communicated in a manner that can be clearly understood by the reader. It is not the intent of this paper to discuss the merits of logic statements versus logic diagrams. We find both methods have their advantages depending on the situation. We have however, found that designers that have not specified control logic in the past may adapt to using logic statements more readily than logic diagrams.

For example, a sequence of operation we often see for air handling units (AHUs) serving multiple temperature control zones might state as part of the sequence for discharge air temperature control, "*The discharge air temperature shall be reset based on cooling demand"*. We've seen this sequence interpreted in many ways, from resetting of the DAT setpoint based on outside air, to resetting based on the average of the VAV terminal unit (TU) cooling outputs to, to resetting based on the TU with the greatest cooling output. Each of these approaches will have a different affect on occupant comfort and energy savings. The following sequence of operation limits interpretation.

Reset the DAT setpoint as follows:

- *Every 30 minutes (adjustable) poll the cooling output for the terminal units serving each of the labs.*
- *If the greatest cooling output is greater than 95% (adjustable), and the DAT setpoint is greater than the lower limit of the DAT reset range (adjustable); then decrease the DAT setpoint by 1F (adjustable).*
- *If the greatest cooling output is less than 85% (adjustable), and the DAT setpoint is less than the upper limit of the DAT reset range (adjustable); then increase the DAT setpoint by 1F (adjustable).*
- *Adjustable setpoints and rates shall be adjustable from the operator's graphic.*

An example of how such an issue might be written up in a CLI report appears in Table 1 in Appendix1: Sample CL&I Report as item# 1. Using constructive collaboration oriented language promotes team unity and effective dialog. We find that the responses from the design team are more favorable and the goal of developing comprehensive and accurate sequences of operation are more likely to be achieved. Providing specific examples of sequences utilizing control logic may aid designers that have not specified control logic in the past.

Integration

Integration issues pertain to the interaction between controls, equipment, systems and disciplines. For example, major equipment, such as chillers and boilers, may be provided with sophisticated programmable logic controllers. Typically the owner's functional requirements and the engineer's basis of design require some level of interaction between these controllers and the building automations system. As the need for increased interoperability has become more prevalent, manufacturers have responded with products that claim the ability to operate per public or proprietary protocols. Often, however, the project team does not fully understand the type or level of interaction between control systems, and the capabilities of the controllers and interface devices. The design phase CLI process focuses on how various systems and components are envisioned to operate together, and what information must be communicated in order to obtain the intended performance.

Consider as an example, a central plant with two chillers utilizing primary-secondary pumping. Chilled water flow is not monitored. The chiller specification requires the chillers to be provided with a programmable logic controller. The specification does not include a controller model, however, it does include an exhaustive list of information required to be available at the PLC display. Included in this list are supply and return temperatures, and amps. The following sequence of operation is included in the chiller and building automation system (BAS) specifications. "*Upon a call for cooling the chiller plant shall be enabled. A PID loop shall modulate chiller output to maintain the chilled water temperature setpoint, which shall be determined by the BAS. The chillers and their associated pumps shall be staged based on the cooling load of the building".* This sequence of operation could be interpreted and implemented in a variety of ways by the providers of the chiller and the BAS. Each supplier might assume the other is providing critical equipment and programming, which could result in change orders and scheduling delays during construction; or both suppliers might provide the same equipment and programming, unnecessarily increasing the project cost and complicating commissioning.

An example of how such an issue might be written up in a CLI report appears in Table 1 in Appendix1: Sample CLI Report as Item #s 2 and 3. In addition to the integration issue, this sequence of operation raises a number of control logic issues, which have not been included in the examples.

Conclusion

The benefits of design phase commissioning can be greatly enhanced when the CxA and AE collaborate as a truly functional team. One of the greatest benefits this team effort can yield is to specify critical control logic and integration requirements during design; thereby minimizing the potential for these common issues to have an expensive impact to the project both from a change order and scheduling perspective near the critical closeout phase. A design phase CLI process that has been effective on a number of projects includes the following key elements:

- Well documented OPR developed at project conception and maintained throughout the project
- BOD developed early in schematic design including:
    - Concept sequences of operation
    - System schematics based on the sequences of operation
    - Systems and equipment types chosen to best support the schematic design and implementation of the sequences
- CLI process performed as outlined in this paper
- Sequences of operation developed into logic diagrams or statements based on CLI
- FPTs developed based on CLI

Specifying the fully developed details as a result of a control logic and integration process provides the following benefits to the project and members of the project team:

- A/EProject is more likely to be installed in accordance with the AE's original BOD.
- Minimizes time consuming involvement in potentially contentious resolution during construction
- Minimizes the potential for having to reverse engineer solutions for the wrong equipment of control systems.

CxA

- Makes it easier to determine CxA fees by reducing the potential for unpredictable and time consuming issues resolution during construction
- Makes commissioning more enforceable during construction by allowing better specifications to be written

Contractors

- Levels the bidding field by minimizing the number of ways that critical portions of the CDs can be interpreted.
- Makes commissioning more biddable by knowing what the FPTs are in advance
- Minimizes the potential project delays caused by discovering complex issues near project closeout

Owner

- For all of the reasons described for other commissioning team members, the owner benefits by getting a better more cost effective building that works and on time.

Appendix A Table 1: Sample Control Logic & Integration Review Questions/Issues

Project: Science Building: Whatsamatter U. November 3, 2006 Review by: Kent Barber, Doug Chamberlin

Item	*Reference*	*Question / Issue*	*To **	*Resolution / Response:*	*Check*
1.	Section 15970, Building Automatons System, Part 4, Automatic Control Sequences: 4.2.C AHU 1	The sequence of operation states: "*The discharge air temperature shall be reset based on cooling demand*". We've seen this sequence be interpreted in varying ways, giving differing priorities to occupant comfort and energy savings. Examples of these interpretations include reset of the DAT setpoint based on outside air, to reset based on the average of the VAV terminal unit (TU) cooling outputs to, to reset based on the TU with the greatest cooling output. We suggest the control logic be specified in more detail in order to obtain operation in accordance with the OPR priority for saving reheat energy to the extent possible while maintaining room temperature setpoints in all labs. The following sequence offers an example of the kind of detail we've seen work well: *Reset the DAT setpoint as follows:* • *Every 30 minutes (adjustable) poll the cooling output for the terminal units serving each of the labs.* • *If the greatest cooling output is greater than 95% (adjustable), and the DAT setpoint is greater than the lower limit of the DAT reset range (adjustable); then decrease the DAT setpoint by 1F (adjustable).* • *If the greatest cooling output is less than 85% (adjustable), and the DAT setpoint is less than the upper limit of the DAT reset range (adjustable); then increase the DAT setpoint by 1F (adjustable).* • *Adjustable setpoints and rates shall be adjustable from the operator's graphic*	ME		

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Item	*Reference*	*Question / Issue*	*To **	*Resolution / Response:*	*Check*
2.	15681 Water Chillers and 15970, Building Automatons System, Part 4, Automatic Control Sequences: 4.5 Chillers	The following sequence of operation is included in the chiller and building automation system (BAS) specifications. "*Upon a call for cooling the chiller plant shall be enabled. A PID loop shall modulate chiller output to maintain the chilled water temperature setpoint, which shall be determined by the BAS. The chillers and their associated pumps shall be staged based on the cooling load of the building"*. The CxA is not able to determine, which portions of the sequence of operation are to be implemented by the chiller controllers, and which portions by the BAS. It appears to us that the potential exists for each supplier to assume the other is providing critical equipment and programming, which might require change orders and scheduling delays during construction; or for both suppliers to provide the same equipment and programming, which might increase project costs and complicate commissioning. We suggest clarifying which portions of the sequence are to be implemented by the BAS and which portions by the chiller controller.	ME		

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Item	*Reference*	*Question / Issue*	*To **	*Resolution / Response:*	*Check*
3.	15681 Water Chillers and 15970, Building Automatons System, Part 4, Automatic Control Sequences: 4.5 Chillers	The CxA is not able to determine, what information is to be exchanged between the BAS and the controllers provided with the chillers. In order to obtain operation in accordance with the owner's project requirements and the engineer's basis of design, and facilitate functional test writing, we suggest clarifying the following: 1. What information is to be provided to the chiller controller from the BAS. Examples might be the chilled water supply setpoint, and enabling and shutdown of the lead and lag equipment. 2. What information displayed at the chiller controller is to be displayed on the BAS operator's graphic. 3. What is the intended means of communication and is it to be provided with the chiller or the BAS. For example, is the chiller panel to be provided with dry contacts or does the exchange of information require open protocol such as a BACnet interface.			