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Control Systems Integration in the All-Electric Ship – The Comprehensive Approach

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Abstract: - When a warship is commissioned, hundreds of sailors on board and thousands of people ashore expect that everything will operate without failure. Commanding Officers who send people into military operations trust that designers and engineers have produced and delivered the best possible material to fulfill their tasks and protect their lives.

The comprehensive use of electrical power in the All-Electric Ship requires a number of design criteria to be considered, regarding redundancy, vulnerability, and safety. Engineering solutions must satisfy the requirements of floatation and stability, habitability, maneuverability, and mission capability, even if the ship is damaged. A high level of systems integration makes modern naval combatants highly effective, yet at the same time vulnerable, if a partial loss of systems affects overall performance. It is therefore important, that with growing system complexity, interactions between integrated systems are taken into consideration early in the design stage. In this paper, a method of identifying and relating integrated systems is introduced and discussed – the comprehensive approach.

Key Words: - Warship Environment, Physical Events, Command Decisions, Simplicity in Design and Operation.

1 Introduction

In any environment, electrical power is a useful thing, which most of us may only notice when it is missing. For many applications, there is no alternative to electricity. Since precautions against the event of a total power loss are limited, the only answer to this problem is not to allow it to happen.

In warship design, strong efforts are made to provide redundant power capacity, resilient power distribution systems, and uninterruptible power supplies. Although this problem appears to be worse in the All-Electric Ship, there are indications that the opposite is true. One reason is, that the electrical power system is a principal design feature of the All-Electric Ship – almost by definition. The general arrangement of prime movers, alternators, converters, and the architecture of distribution networks and control systems are designed to meet the respective power requirements of electric propulsion motors, ship systems, navigation, radio and combat equipment. These advantageous conditions in the All-Electric Ship must be supplemented by a systems integration, where mutual interactions are considered and failure consequences are reduced.

In this paper, a method of identifying and relating integrated control systems is introduced and discussed – the comprehensive approach.

2 Analyzing the Requirements

Modern naval combatants are extremely complex systems. Throughout the ship, more than 10,000 signals are processed almost every second by an increasing number of computers to maintain safe ship operation and mission capability.

Sophisticated computer aided design tools are used to develop these systems. In this process, the balance must be determined between what is considered to be the best possible solution and what is actually required. Many thoughts are spent on operational demands, navy procedures, engineering requirements, and human factors. It is essential that the purpose, the aim, and the boundary conditions be considered. The personnel on board must be able to operate, maintain and repair these systems, even in an unfriendly environment. They must have the knowledge and the experience to understand the behavior of control systems in certain scenarios, and the action to be taken to prevent “misbehavior” of these systems in situations, where the pre-programmed functions do not match the prevailing boundary conditions.

2.1 Functional Requirements

The definition of functional requirements is normally regarded as an important step in the development and design of integrated control systems. Here, the sequence of functions to perform a certain task is described, for example starting and synchronizing a diesel generator, or controlling the pressure in the fire main system. Functions like these are frequently embedded in compound conditions, reflecting the initial situation (e.g. an increasing power demand) and the final state (e.g. stabilized power supply).

From the functional requirements, the technical and operational tasks are specified as discrete steps, which are executed by control systems under the supervision of operators. Their smallest element is a functional sequence (Fig. 1).

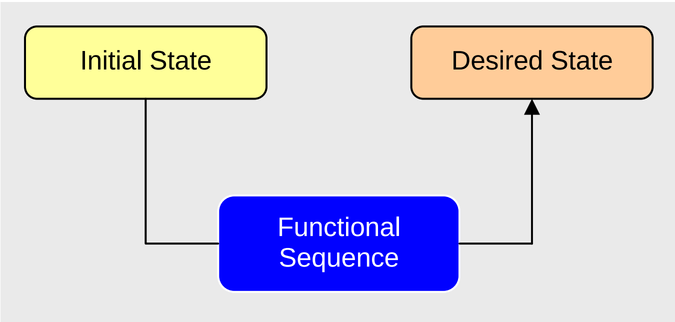

Fig. 1 – Functional Sequence

2.2 Operational Requirements

Whereas the functional requirements describe *what* needs to be done, the operational requirements describe *when* and *how* it needs to be done. This is necessary, because a specific functional sequence may not be applicable in different situations. The operational requirements define the conditions in which a functional sequence is executed. For example, target detection, classification, identification and tracking can be a continuous process without any restrictions. However, weapon assignment and engagement are activated in certain circumstances only.

Similar situations exist in many other domains of warship operations. They all have in common, that often various options and methods need to be considered prior to executing the action (Fig. 2).

Operational requirements describe these options and methods, but they also limit the number of possibilities to a magnitude that can be handled by control systems and their operators. This cognition is quite important, because it indicates that there are limitations to the performance of any control system. A person relying on fully automatic sequences must be aware that some functions may not operate, or may not produce the desired results, if the actual condition is not covered in the operational requirements specification.

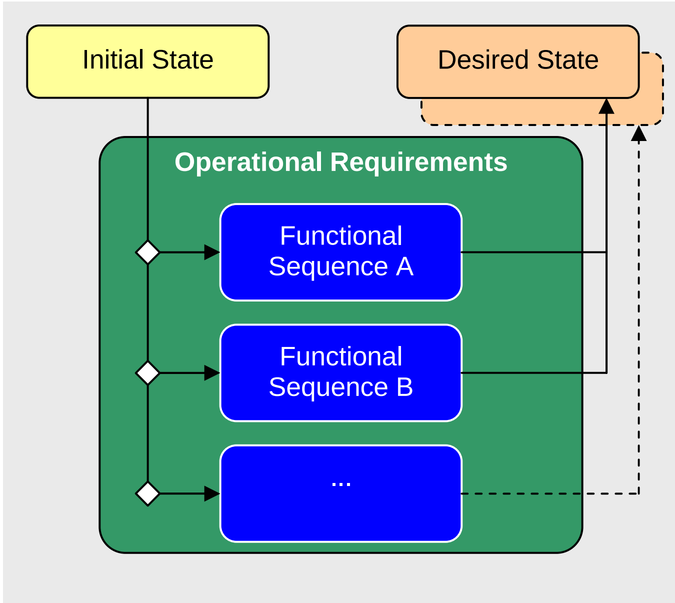

Fig. 2 – Functional Sequences embedded in Operational Requirements

3 System Design and Integration

Usually, the functional and operational requirements are discussed between system designers, engineers, and the navy, and then implemented in the control systems design. Typical points of discussion are scope, risk assessment, and budgeting.

The results usually reflect whatever is affordable. The use of proven technology can help to minimize risk, but essentially this does not imply that system performance is reduced, or that requirements are not met.

The reason for this is, that the applied technology has only moderate influence on the success or failure of automated control systems. More important factors are the extent, the depth, and the quality, at which the operational requirements are reflected in the control systems (design), and at which internal and external links are established among individual systems and sub-systems (integration). Although these issues are influenced by technological standards, many operational functions can be considered within the given technological framework using experience, and imagination.

Integrated control systems show exponential growth of complexity with increasing size. Therefore, efficient methods must be employed of concealing their complexity behind a simplified display of "virtual reality" for the operator without corrupting important information. This is necessary for two reasons: First, the designer using computer aided design tools to develop the increasingly fine dendrite network of system dependencies must never get lost in that network. Secondly, the personnel on board must be able to understand their systems. In critical situations, their knowledge and understanding of system capabilities and limitations may protect their lives, and the designers must be aware of this. Therefore, complex integrated systems must be simple to understand and to operate.

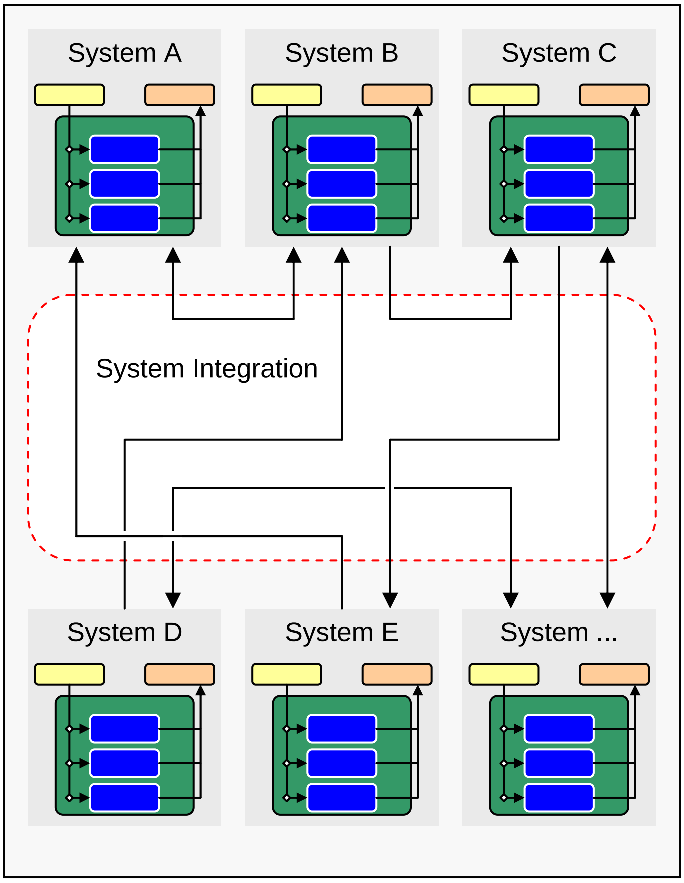

Fig. 3 – Integrated Systems

Fig. 3 illustrates the growing complexity with increasing integration. Implementation of the dependencies between the systems yields an increasing number of possibilities to carry out specific functions (e.g. "if A, then do B, but only if C is not true"). The problem is to identify those relations and to account for their influence on system behavior.

4 The Comprehensive Approach

From the previous explanations, the design and operation of integrated control systems is characterized as follows:

- Any component, which is included in a control system, can be transformed from its initial state to the desired state by a functional sequence.
- A functional sequence can be made resilient to different scenarios by the influence of operational requirements.
- A control system can be integrated with other systems by defining the relationships and interface requirements, and by responding to operational boundary conditions.
- Integrated control systems are complex, which should be concealed.

In this section, a method is introduced that enables the various aspects of control system design and integration to be considered comprehensively. It is helpful when specifying the relationships between components, systems, operators, and operational scenarios.

4.1 Real and Virtual Components

The starting point of the following discussion is the simple fact, that the number of components, which can be managed by a control system, is limited. This statement is always true, irrespective of the justification of any limitation. Because the number is limited, all components can be fully listed in a finite database. Next, any relations between components can be determined.
A component can be regarded as "real" or "virtual". If a component is physically installed in the ship, it is "real" (diesel engines, pumps, ammunition, radars, missile launchers, etc.). If it is an internal or external event, or an external object, interacting with the ship, it is a "virtual" component. (electrical power demand, ship speed, course and heading, radar contacts, geographical and hydrographical data, etc.). Control systems represent real and virtual components as a piece of digital information, therefore this distinction apparently is of little use. But at the design stage, this terminology is quite convenient, because it allows to describe all relevant information, irrespective of its physical nature, using the same notion, including those "components" that are not physically a piece of the ship.

4.2 Component State

Components have an actual or initial state, which may need to be changed in response to technical or operational parameters (e.g. control of ship speed, fire main pressure, bus bar voltage, etc). The transition into the desired state is invoked automatically, or on operator's demand, and executed according to a sequence of control functions.
In a real warship, the cause of any action is a physical event. The result of any action is another physical event. According to the definition given in the previous paragraph, even a piece of information ("virtual component") is a physical event. Therefore, it is possible to relate components with physical events and to give a full description of control sequences in terms of physical events, which define the initial and desired component states.
The definition of each component in terms of a physical event can be simple, for example in case of a fire: Initial state – "fire in a compartment". Desired state – "fire extinguished". Or it can be more complex like in the case of a radar contact: Initial state – "target detected". Desired state A – "friendly, no further action". Desired

state B – "hostile, await command decision". Desired state C – "hostile, target destroyed".
The action required to proceed from one state to another is, in principle, the functional sequence as described in section 2.1.
Two things are evident:

- The initial and the desired states can be defined in terms of physical events for both real and virtual components.
- The functional sequence, as defined by the required action, contains elements that may be beyond the scope of the control system. At this point, external links to other systems or the human operator are required. Hence, an integrated control system must be open to other systems.

Any form of "input" and "output" of the numerous integrated control systems on board of a warship is a physical event, mapped into the process charts of these systems. Although the information is stored and processed in digital form by software, these digital data represent the "real life" environment of the ship and its personnel.
By enforcing this method of considering physical events and going through the entire sequence of steps necessary to produce the desired result, boundary conditions and mutual relations between other physical events are established. This is illustrated using an example in the All-Electric Ship.

4.3 Example

Assume that the ship is damaged in a combat scenario. To reduce the risk of fire, fuel pumps are shut down and the fuel system is de-pressurized. The diesel generators are supplied from their gravity tanks, which contain enough fuel for about two hours. Eventually, two of the four generators trip from lack of fuel, the remaining two can be kept running for approximately 30 minutes.
With respect to the automatic power control system, this situation can be described as a series of physical events. The actual component state is "low electrical power", the desired state is "normal electrical power", and the action to be taken is "restore electrical power".
Normally, the power control system would monitor the electrical load, and disconnect non-vital consumers when the threshold level is reached. It would then attempt to restore the electrical power supply by pressurizing the fuel system, and by starting the remaining generators. After synchronization, the non-vital consumers would be re-connected, and the total blackout would be avoided.
This sequence is logical. As a stand-alone sequence, only relying on electrical load and power data, it would have prevented the generator failure in the first place. But it is unable to respond to the reason of the power failure, and it is in conflict with the physical event "fuel system depressurized", which could have been initiated by another control sequence or manual operator input due to standing procedures, or on command decision.
In the case of the All-Electric Ship, electrical power can also be made available by reducing the ship speed. Provided that a suitable converter and distribution network is installed, the remaining generators could produce sufficient power for weapon engagement and damage control systems, if speed and maneuverability are not vital in the given scenario. The physical events would then enclose "speed restriction", and the physical action would be "reduce ship speed" to increase the running time of diesel generators until it is safe to re-pressurize the fuel system.

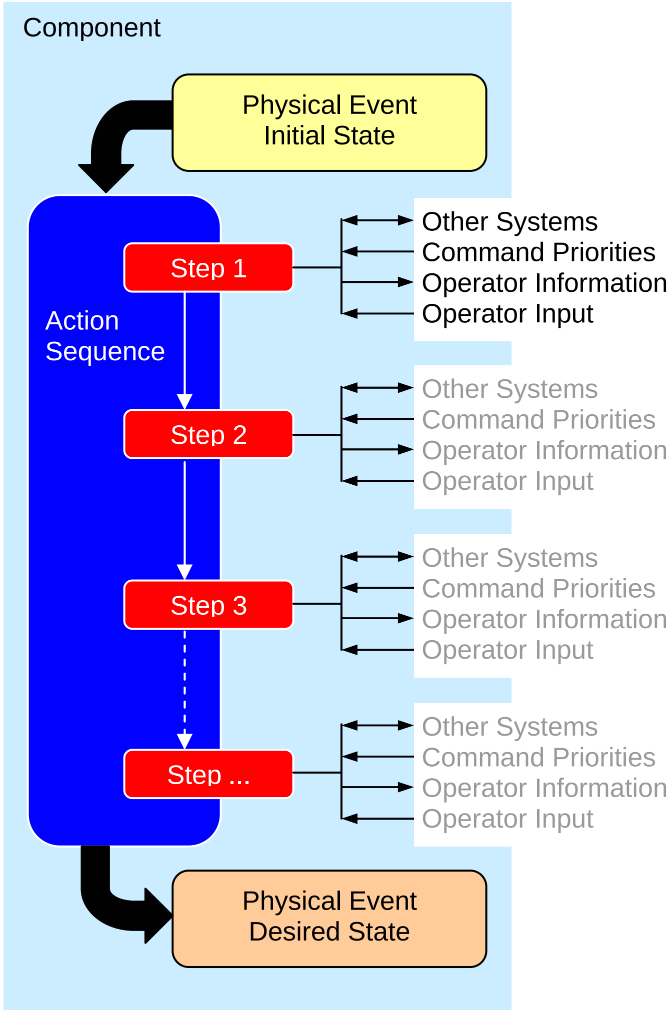

Fig. 4 – The Comprehensive Approach

4.4 Systems Integration

This example shows that a "static" control sequence will not perform adequately in complex scenarios. But this is the real world of warships.
The question remains, how an image of the "real world" can be imprinted into automatic ship and weapon control systems. Apparently, any control system must have the "knowledge" of any other control system and "know" how to combine this information and to derive the

correct procedures. At present, it seems extraordinarily difficult to achieve this to the full extent. Decisions are also based on command priorities and operator experience. How can automation systems obtain their experience?

The answer is, not to attempt the impossible. Operator experience and command decisions are the essence of warship operations. Control systems must be designed for their support, not for their substitution. This can be achieved using the comprehensive approach and establishing the physical events necessary for a full description of a given scenario. This procedure will automatically include the operator, command decisions, and information exchange with other systems. At this stage, the information necessary for a context sensitive performance of a control system is defined, and the integration requirements can be determined.

Fig. 4 shows the basic structure of this method. The real and virtual components are the objects under consideration. Any process acting on a component has a physical event at the starting point (initial state) and at the end point (desired state). The transformation process from the initial state to the desired state contains one or more successive steps. At this level, the relations to other systems, naval procedures, or command decisions are investigated, identified, and defined for each individual step. Hence, all relevant interactions can be specified in the system design.

During this investigation, it may occur that a certain step in the automatic sequence is regarded unsafe, if executed without consulting the operator. This is usually the case, when a piece of information that is required to determine a correct and safe system operation is not available within that system or any other system, or can only be retrieved from any other system by the operator.

In such a case, the requirement must include the operator in the sequence – the “man is designed into the loop”. In turn, this imposes the requirement of presenting the relevant information to the operator in a perceptible way.

Since the relations with other systems under various boundary conditions are established for each step in the sequence, a comprehensive picture of associations can be obtained.

5 Conclusions

The comprehensive approach in systems integration offers a solution to the problem, how the integration requirements of complex control systems can be determined. Relationships, dependencies, and interactions among various control systems, procedures, and human activities on a warship are investigated and accounted for in a very early design stage. If a certain information or action requires human decisions or manual action, the operator becomes part of the sequence.

Although the capabilities of control systems are finite, their response to many aspects of the “real world” in a warship is resilient and precise.

Using the comprehensive approach in systems design and integration does not generate fully automatic systems providing correct control action under any circumstances. However, this method permits all relevant associations with other ship systems to be established on component level, including processes related to ship operations (virtual components). Hence the information processed in the systems and presented to the operator is comprehensive, and reflects all known parameters that are relevant in any given scenario.

Such integrated control systems will allow the ship personnel to manage the complex All-Electric Ship environment with the required simplicity.

References:

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