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Design

Innovations in Integrated Control Systems

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Introduction

Since the 80's there has been a move in the offshore industry from installing a number of dedicated control systems towards integration of several functions into one overall multi-functional control system. The driver has been to reduce the number of different control and alarm systems /PLCs which creates higher maintenance costs in form of high number of spare parts, obsolete components and a low grade of operational integration. The traditional Integrated Automation System combines functions such as machinery alarms, power management incl. diesel engines controls, machinery auxiliaries, ballast and cargo controls. For Oil&Gas production plants the topside process controls were integrated with marine controls.

The trend was followed by integration of more systems such as DP/joystick systems, propulsion and thrusters controls, and safety systems (fire&gas detection/protection, process shutdown systems, emergency shutdown systems).

The offshore segment has acted as a frontrunner in this development, in particular for Oil&Gas production plants and drilling units. Lately we have noticed the same directions also in more merchant businesses such as transportation of liquefied gas, offshore support vessels and luxury cruise vessels.

Integrated Vessel Management System - IVMS

In Kongsberg Maritime context the Integrated Vessel Management System consists of a functional and operational integration of several subsystems based on a common technology platform. These subsystems may be:

- Navigation systems
- Manual and automatic manoeuvre system
- Marine automation
- Process and/or drilling controls
- Fire & Gas detection and protections
- Emergency shutdown system

The various subsystems are integrated by means of a dual, system-wide communication infrastructure.

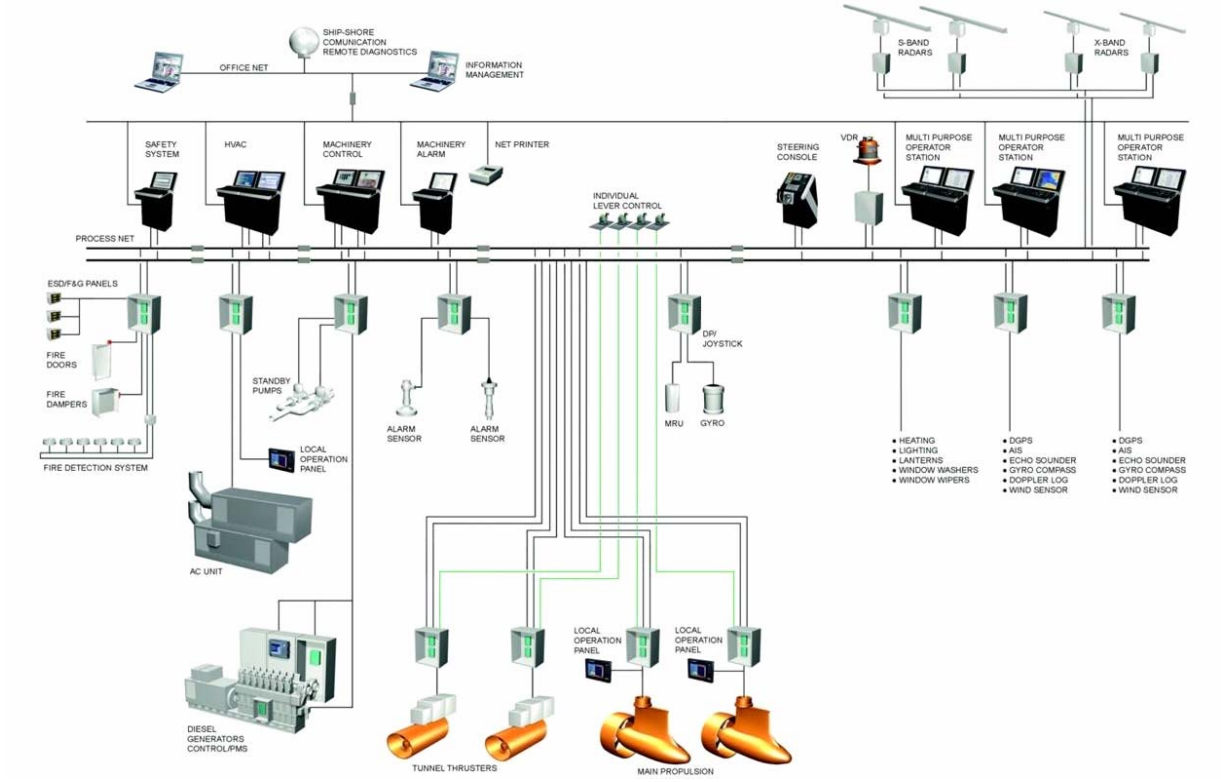

Figure 1 – Integrated Vessel Management

Integrated Navigation and Manoeuvring

In the IVMS concept the Navigation and Manoeuvring systems are fully integrated. Each multifunctional Operator Station may be used to present radar images, electronic chart and track information and conning information. DP controls may be available from any multifunctional operator station.

The auto-pilot and track control algorithms are embedded in the DP controller. Further, the manual remote control system (RCS) of thrusters is fully integrated with the DP and navigation systems, to provide manoeuvring flexibility:

- Manual control
- Auto-pilot
- Track steering
- Joystick operation
- DP modes of operation

Navigation sensor interfacing is redundant and may be segregated in different equipment rooms for maximum fault tolerance.

The concept includes an independent RCS system for each propulsion unit, which may be expanded with full redundancy per unit.

Integrated Automation

The IVMS provides seamless integration of marine automation systems with drilling and process automation systems.

Multifunctional Operator Stations provides information on all subsystems with user interactions as per project specifications.

Typical functionality of marine automation system covers:

- Machinery alarms
- Power management and engine controls
- Auxiliary systems such as: fuel supply, cooling water, compressed air, boiler and steam systems, bilge
- Ballast and cargo control incl. level gauging

Process control systems:

- Oil and gas separation
- Gas treatment (compression for export or re-injection)
- Power generation
- Drilling controls and auxiliary systems

The automation technology supports a high distribution level of the control and monitoring functions. Process controllers normally cover a single process segment in order to minimize consequences of a failure. Enhanced fault tolerance is obtained by redundancy of controllers, communication links, I/O units and power supply.

Utilization of remote I/O units and field bus technology reduces installation cost and enhances information availability within the IVMS.

Integrated Safety Management

The Safety Management System gathers and integrated information from:

- Fire detection system
- Gas detection sensors
- Fire door control & monitoring
- Ventilation and fire dampers
- Fire extinguishing systems (fire pumps, sprinkler, water mist, inergen, etc)
- CCTV cameras
- Water ingress, water tight doors, stability computation

Through the integration information from Navigation and Manoeuvring systems as well as Marine and Process automation systems are available, for display on Multifunctional Operator Stations on request.

The information is presented in GA plan view ("Electronic Safety Desk"), which also contains safety plan information in layers that can be switched on or off. The "electronic plotting table" function facilitates crisis management by showing for instance deployment of personnel, confirmed evacuated areas etc.

The Safety Systems utilize common technology, both hardware and software, and provides high integrity safety solutions that are complying to Safety Integrity Level 1 to 3 in accordance with IEC 61508 (parts 1-7).

Control room arrangement

The multifunctional user interface offered by the IVMS concept provides flexibility with respect to arranging operator friendly working environments.

- Information presented according to the actual situation
- Large overview screens
- Removal of fixed panel mounted equipment (lamps, buttons, indicators, dedicated alarm and control panels, etc)
- Height adjustable control desks
- Removal of computers from console desk (less noise, heat)
- Silent printer networks rather than dedicated printers for each individual system

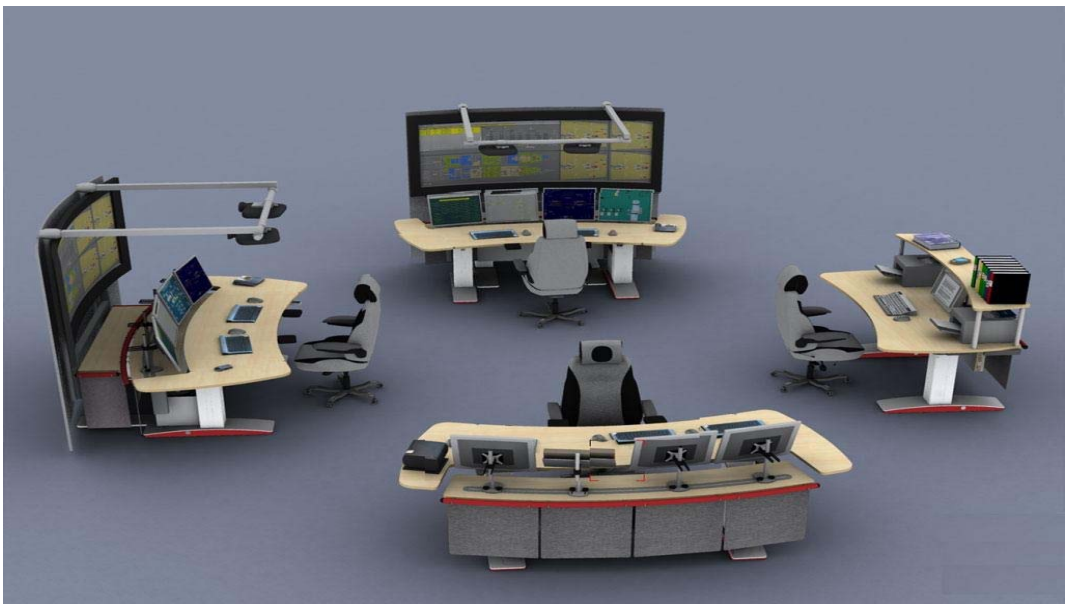

Figure 2 – Control room arrangement using multifunctional operator stations and overhead projectors

Common Technology

The Integrated Vessel Management System is based on a common technology platform. This means that the individual subsystems are utilizing common hardware units such as process controllers, input/output units, network components and operator station computers. Also basic software layers are common for all subsystems including operating systems, component firmware, I/O drivers, communication, alarm system, graphic presentation systems, and so on.

Some benefits of common technology:

- Multifunctional Operator Stations providing consistent working environments. Important details such as consistent usage of colour and symbols, common alarm presentation and operational menus/dialogues is reducing the likeliness of misinterpretation which in turn reduces operator failures
- The system wide communication network enables information sharing between subsystems
- Identical hardware components significantly reduce the number of different HW modules. This is even further enhanced by using multifunctional input/output units where software configuration defines whether a signal is input or output, analogue or digital, resistor, RTD etc. Spare part components are reduced.
- Common and synchronised data logging and analysis tools
- The Remote Diagnostic function enables onshore assistance and troubleshooting

Operational Advantages

The concept of integrating several subsystems using common basic technology leads to a number of advantages for the users. The most important advantages are described.

Integrated Navigation and Manoeuvring

In a traditional concept there are (at least) three separate systems: Navigation, DP/joystick and Remote Control System for thrusters and propulsion units. These systems have very different user interfaces and responses. Transitions between different modes of operation is by hard switching between systems (manual control, DP/joystick, auto-pilot/auto-track).

In the IVMS concept, the Navigation and Manoeuvring systems are fully integrated and provide a consistent user interface. Each multifunctional Operator Station may be used to present radar images, electronic chart and track information and conning information. DP controls may be available from any multifunctional operator station.

When combined with the ECDIS route planning system, the integrated navigation and manoeuvring system will also provide low speed track steering with zero crab angle, which today only can be achieved by using DP control.

The manual remote control of thrusters are fully integrated with the navigation and manoeuvring system, providing bump-less transfer between manual and automatic controls as well as when changing command location. Electric shaft control of levers is available, ensuring smooth take-over to manual control or between control locations.

Auxiliary bridge control such as deck/navigation lights, window wipers, heaters etc. may be built into the system providing easy access for the mate and reduces console space requirements.

Power generation and consumer control

The integration of control systems for power generation as well as main consumers ensures safe power situation.

Fast acting load reduction system

The purpose of the load reduction system is to avoid overload of the power generation plant by reducing power consumption of large speed controlled drives, rather than tripping the consumers. Typically this is applicable for thrusters and drilling systems.

The load reduction system is normally controlled by the DP system which is monitoring the power generating capacity in order to avoid overload. However should an overload situation occur, for instance following a generator trip, the Power Management System will quickly reduce the load of individual consumers as required to re-establish a safe power situation. The standby generator(s) will be started and connected to the net to increase capacity.

As a third level, frequency monitoring facilities within each frequency converters will phase back converter output when net frequency drops below normal operating conditions.

When electric power is limited the “Power Optimal Thruster Allocation” is enabled in the DP system ensuring that the available power is used in the most optimal way for vessel positioning.

Improved speed control

Both the traditional droop speed control and the more modern isochronous control methods have limitations and weak points. Droop control has a rather slow response which may be a problem during situations with big power fluctuations. Isochronous systems have experienced problems in case of failure of the loadsharing links.

New algorithms to control fuel governors by means of an analogue speed order rather than the conventional "speed up/down" signals from PMS and/or manual load control buttons will:

- Improve frequency/load control response – "semi isochronous" operation - maintaining et frequency almost constant also during heavy load shifts
- Improve safety as the fuel governor will monitor the PMS order signal (4-20 mA) and go to safe position in case of signal failure

Monitoring of active and reactive load sharing systems

The Power Management System will monitor the load sharing situation both with respect to active and re-active load. Faulty load sharing may follow failures in PMS, fuel governors or actuators or, for re-active loads, failures in AVRs or excitation equipment.

If a generator moves outside its set operational condition (as a function of load vs. net frequency) the PMS will issue an alarm. In the event that the situation escalates into a situation where a generator is driven into overload or reverse power, the system may trip bus-tie breakers to isolate power systems and eventually trip the faulty generator.

Similar functions are available for re-active load sharing, monitoring and comparing generator electric parameters (voltage, kVAr, cos φ).

Integrated Safety Management

The Integrated Safety Management System combines functions which today are operated from several independent systems:

1. information gathering and presentation
2. decision support functions
3. initiating safety actions

Level 1

The Safety Management System gathers information from:

- Fire detection system
- Gas detection sensors
- Fire door control & monitoring
- Ventilation and fire dampers
- Fire extinguishing systems (fire pumps, sprinkler, water mist, inergen, etc)
- CCTV cameras

- Water ingress, water tight doors, stability computation
- Navigation and manoeuvring system
- Marine and process automation system

Safety information (detector status, smoke / heat values, etc.) is presented on top of General Arrangement views which show safety related information such as fixed fire fighting equipment, escape routes, lifesaving/medical equipment, hazardous equipment location, high voltage equipment and cables. CCTV cameras are shown as icons on the GA views and are displayed either on request or automatically in case of fire. Different types of equipment can be switched on or off by layer control.

The Safety Management system features an Electronic Plotting function which allows the duty officer to drag and drop safety symbols representing for instance deployment of personnel (fire teams etc.) into the GA views, in order to have full overview in the event of an emergency situation. Further interactive emergency procedures are available, assisting the master in taking the right decisions. All safety related information is logged for incident analysis.

The Integrated Safety Management System enables large wall screen overview facilities (such as plasma/LCD screens or projector solutions) in Safety Centre with full flexibility in viewing safety related information as well as "normal" process information, CCTV views etc. The information presented on the large wall screen overview may be selected by the user or automatically (in case of an emergency situation) and is adapted to the current situation.

Level 2

Decision support tools as "kill cards" (detailed safety instructions per area) are available and will together with the built-in interactive emergency check lists guide the crew through an emergency situation (or a safety drill). However, the master takes the final decision of what to do at any stage.

Level 3

The Master/Officer on Duty may initiate safety actions directly from the Safety Management System either manually, or from the interactive emergency procedures. Such actions are activation of fire extinguishing systems and low location lightning, PA announcements, shutdown of ventilation or machinery equipment, operation of fire doors and water tight doors. Automatic actions are pre-programmed in the system as required according to the vessel's safety philosophy and Cause+Effect diagrams.

Training, data logging

The IVMS Safety Management System features built-in facilities for onboard training and safety drills. Various emergency scenarios may be implemented and may be further adapted by the system super-users. Automatic logging and reporting of all safety incidents and safety drills are included.

Vessel mode control and assessment

The IVMS comprises a system-wide mode control function for selecting predefined operational condition for the vessel. The mode control functional will cover:

- power generation plant
- manoeuvring plant (propulsion, thrusters, steering)
- navigation system
- auxiliary ship technical equipment

The IVMS includes a vessel state assessment tool that will provide the user with complete overview of the situation of the machinery systems such as power and propulsion plants, navigation and manoeuvring systems as well as safety systems. The automatic and online assessment program will verify that all equipment are set up and working according to the mode of operation, and check whether any relevant alarm condition exists. Also the status of the standby equipment shall be analysed. Any irregularities with respect to the actual operational mode shall be immediately detected and announced.

Information Management

The IVMS enables common data recording mechanisms where process variables, alarms and events from the various sub-systems are collected in the same database structure. All recorded data are using the same clock and are synchronised with milliseconds accuracy.

Tools for reporting and analyses are available, onboard as well as onshore. Combination of time series (trends) and alarms/events in histograms further the understanding of causes and effects in a post-incident analysis. Reports may be signed digitally in Adobe PDF format to guarantee report authenticity.

The IVMS historic data server offers high data integrity incl. hot standby equipment and redundant data servers. Data backup and restore facilities are included.

Data may be exported for instance to MS Excel, and for usage in playback environments.

For usage in shore office(s) data replication function is available.

Network Integrity

The total integrated concept may sound overwhelming. Questions that are often raised are:

- What if one network drops out?
- What if both networks drop out?
- What happens in the event of a network storm?
- Will we loose control of the vessel?

We all need to be concerned about safe operation of the vessel in the event that parts of – or the complete – network infrastructure should fail. In this respect, there are some basic features with the IVMS network configuration that need to be underlined:

- Network segregation
- Usage of managed (intelligent) switches

Network segregation

In the IVMS concept there are different network segments for each main sub-system:

- Navigation and Manoeuvring
- Safety systems
- Process and/or drilling automation
- Marine automation

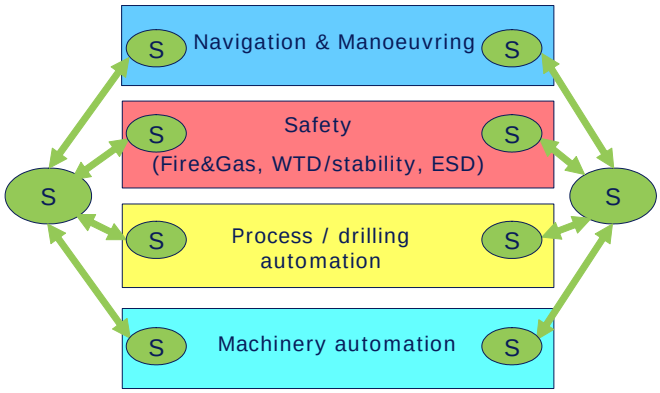

Figure 3: Network segregation and integration

Each network segment forms an autonomous redundant local area network. There are two network switches in each segment (network A/B). All operator station and process controllers are connected to both switches in a "dual star" configuration. A failure in one network branch or a switch will cause alarms but the system will continue to operate without downgrading system performance.

To enable information to pass from one network segment to another there are two "master switches" which interconnects the switches in each individual subsystem. Now process data for instance in the power management system is allowed to pass on to the DP system. And the navigator may call up a ballast display on his normal ECDIS screen (if he should wish to do so).

However, only requested information is transferred between network segments.

Managed Switches

By using managed ("intelligent") switches the traffic on each network segment is automatically reduced since the switch will detect which computer is connected to each of its ports. It will only transfer the relevant information to each computer. Compared to traditional transparent hubs this means a significant reduction of bandwidth utilisation. High speed networks are used; 100 Mbit/s communication to each computer and with 1 Gbit/s between switches. The design criterion is to use max 10% of available bandwidth in normal condition, although tests show that communication works properly even in case of much higher utilisation.

One "fear" for network communication is "net storm" situations where a component starts to jam the network thus blocking communication. An important feature with the managed switches is the ability to limit traffic from a single computer to e.g. 3% of the available bandwidth. In this case the computer cannot jam a single network segment. The "master switches" will also work as second barriers protecting against network overload spreading from one segment to another.

There is also protection mechanisms built into each process controller and operator station in order to reject messages that are not intended for the respective computer, faulty messages or just plain rubbish. Should traffic on one network connection become very high, the computer will stop listening to that connection.

Backup mechanisms

Even it may be considered as a dual failure the consequences of a total network breakdown must be taken into consideration. Backup mechanisms must be in line for essential systems and functions, such as:

- Navigation (heading and position info to radar and ECDIS)
- Propulsion and steering control (non-follow up or follow-up backup system)
- DP (independent joystick system)
- Fire detection system (independent alarm display)
- Emergency shutdown system (direct wired from ESD panel to ESD controllers)
- Local controls of machinery systems, ballast systems etc.

Experience

Since introduction of managed switch technology, Kongsberg has not registered critical network failures (total loss of one or both networks). This is based on observations from more than 150 integrated systems over more than 4 years.