THE INTEGRATION OF NEW WEAPON SYSTEMS INTO IN-SERVICE WARSHIPS

BY

DAN GARDNER, BENG, CENG, MIEE
COMMANDER Chris SAXBY, BENG, MSC, CENG, MCGI, FIMAREST, RN
(both formerly of the Marine Electrical Systems IPT, WSA)

This is an edited version of the paper that was presented at the two day International Symposium Engine as a Weapon. *Organized by the Institute of Marine Engineering Science and Technology and held at Abbey Wood, 9 - 10 June 2004.*

ABSTRACT

This article discusses the integration of new weapon systems into in-service platforms, from the marine engineering point of view. The integration of new weapon systems poses some significant questions regarding who has what responsibility for the integration into the ship's systems, the standards used and implications for the ship design. This article is not intended to cover all of the integration aspects of weapon systems but is focused on the integration of systems into the ship's electrical power system. What came to light during the Sonar 2087 project was that it was absolutely critical that all of the right people are involved in the project at the right time. Further more, that it is unwise to assume that the a weapon system supplier will have all the necessary technical expertise or understanding of the whole platform design to completely integrate a weapon system with out assistance from the MoD. This may seem like common sense; however, the weapon system project team may not carry any in-depth marine engineering expertise, so some of the potential problems may not be recognized until late in the project.

Introduction

Warships such as frigates and destroyers are usually designed with a service life of 25-30 years, this is often extended to 30-35 years. During a ship's life many changes are made to the ship's systems including weapon systems. There are two main reasons for changing the weapon systems on a ship: the first is the fact that rapidly advancing technology will often render equipment obsolete; the second, that changing military requirements will require changes to weapons fit. The latter can have a profound effect on the modus operandi of military platforms. The Royal Navy's cold war deep ocean fighting platforms now spend a significant time in the littoral environment in support of land operations.

To overcome obsolescence from both an equipment and military point of view it has become common to undertake mid-life updates of warships. During mid-life updates it is common to refit the ship with new equipment that requires integration with the ship. Mid-life updates are not the only time major equipment installation takes place, the concept of incremental acquisition ensures that ships will undergo a series of improvements to the ship's weapon and marine plant systems, both in and out of fleet time.

Integration of systems is an everyday aspect of engineering. There are many levels of integration and differing interfaces to consider when fitting a new system to a ship; chilled water, power, combat management etc. In this article we shall look solely at the aspects of electrical integration since future weapon system developments are leading to more power, or energy, hungry systems with the primary power requirement placed upon the ship's electrical supply system.

Such future weapon systems are being developed all the time; they all have high electrical power requirements and are expected to be available for military use in the next five to fifteen years. These systems include high power microwave, high-energy laser, electric armour, electric guns and electromagnetic launch. They all have very different power supply requirements.

Sonar 2087

Sonar 2087 (S2087) is a new towed array sonar that is being fitted to Type 23 (Duke Class) Frigates. The S2087 replaces the system currently fitted to the Type 23 and provides an improved military capability to the platform. As the sonar has significantly higher power requirements than its predecessor a decision was made early on in the project to supply the power directly from the ship's propulsion bus. Flywheel energy storage was also considered, but a direct supply was selected.

The Type 23 Frigate has a CODLAG propulsion system, that is to say a combined diesel electric and gas turbine propulsion system. The propulsion system consists of two DC electric motors on separate shafts powered from the main power bus. The power bus is energized to 600V. Ship's service power at 450V is provided via two motor-generators, (FIG.1).

Authority and Responsibility

Early in any project it is important to identify who has authority to set policy and make decisions and furthermore who carries the responsibility for those decisions. It is preferable that these are the same people, however, it is important to recognize that this will not always be the case, this could be due to the use of Classification Societies or other third party design assessors. On very large projects such a major system upgrades conducted in mid-life updates it is usual that most of the authority and responsibility for the integration and management of overall platform design will be vested in a prime contractor. The overall responsibility for the ship design for most in-service ships rests with the MoD.

For smaller projects that are undertaken during a ship's normal operational programme the MoD retain the responsibility for the overall ship design. A dockyard would conduct the installation, with commissioning possibly by another contractor that will not always the Original Equipment Manufacturer (OEM). Both of these situations require vigilance on the part of the ship owner. It is during the time-pressured operational activity periods, that there is the most danger of crucial decisions either not being recognized, going unmade or being made with responsibility divorced from the decision making process with the focus being on maintaining a ship's readiness and not necessarily upgrade.

When assigning responsibilities it is important that all of the stakeholders are involved as early on as possible and that every one is aware of where authority and responsibility rests for the various aspects of the project. When technical advice is being brought into a project from outside it is important that the advisors understand their level of responsibility and the overall context of their advice. The S2087 project practised this with the result that the technical aspects of the power system integration were addressed and resolved.

It perhaps goes without saying that decisions should be recorded for accuracy and audit. Equally it is just as important to record the rational behind decisions so that in the future should decisions be questioned, and the original members of staff have moved on, the incumbent staff can respond in a positive and knowledgeable way.

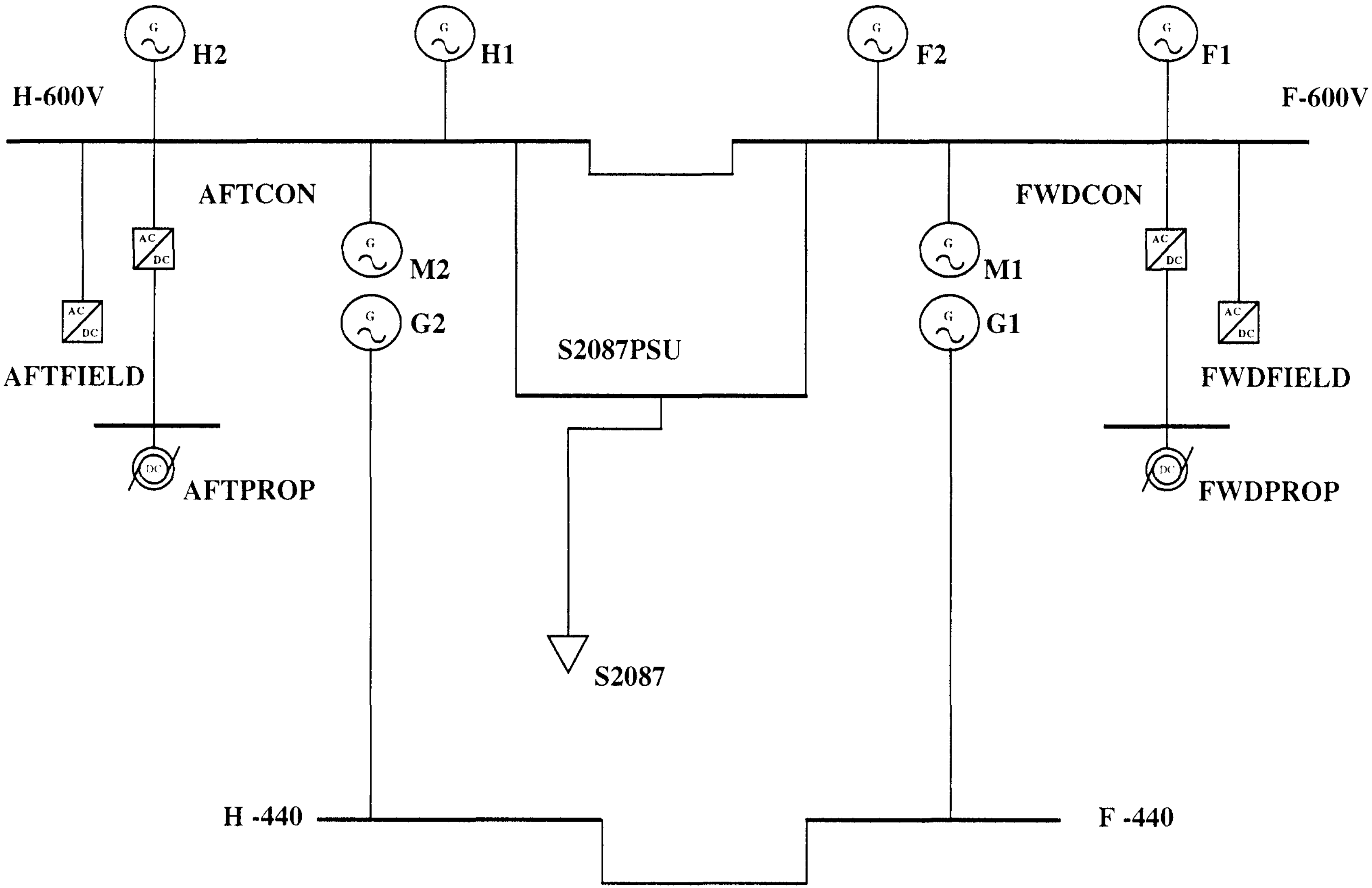

FIG.1 – TYPE 23 FRIGATE POWER SYSTEM

Implications of Integration

As mentioned above there are many levels of integration and many interfaces to consider. Generally the costs of integration are out weighed by the benefits of embedding weapon systems into the ship's system. Although it is of course possible to have a weapon system fitted with little embedding into the ship. The level of integration required will be dependant on the project, a machine-gun mounting will require little real integration, an air defence missile system will be deeply embedded into many of the ship's systems. Identifying, then managing the many interfaces and ensuring the compatibility of interacting systems is of paramount importance.

A weapon system may require electric power, hydraulic power, chilled water, air etc from the ship as well as physical space. The weapon system being integrated may well place a large load onto the ship's services with subsequent demands having a significant effect on the dynamics and performance of the original ship's services. This is where integration management becomes crucial in ensuring that the desired capability is achieved. For example it may be possible to integrate a high power electric weapon system into a ship with integrated full electric propulsion, however without strict management there may not be sufficient power available for propulsion when it is required.

Although system integration is the stock and trade of engineers to date, marine engineers have mainly been involved in integrating marine plant and weapon engineers with weapons equipment. There have been few recent examples of weapon systems being integrated into the ship's power system to a level beyond that of a normal ship's load.

The implications of the S2087 fit are significant on the ship, new winches, new sonar systems and S2087 was the first, of perhaps many, weapon systems to be integrated into the ship's power system. The implications to the ship's power system as well as the sonar although reasonably straight forward are not trivial. The sonar has to be able to cope with a power supply that has no standard governing its quality, the 600V supply on the Type 23 is subject to levels of harmonic distortion much higher than one would normally want to connect a piece of weapons equipment to. A harmonic distribution study was conducted and it was determined that the sonar and the propulsion converters were compatible.

The load of the sonar is a typical cyclic pulsed load. Careful consideration needed to be made to determine the effect that this would have on the stability of the power system. This is an aspect that ought to be highlighted, it is easy to assume that because a load is trivial in comparison to the overall capability of the power system then it will be compatible. In the case of cyclic or pulsed loads attention needs to be made to the transient stability of the system as the pulsed load could excite an inherent instability in one, or more often a combination, of the system loads or generators.

The S2087 project conducted a power train compatibility trial at sea to ensure stability of the power system under sonar loading. However, no preliminary transient stability study was undertaken that could have saved some of this work; the MoD held no suitable model for this purpose.

The propulsion system on the Type 23 uses a simple algorithm to calculate how much power is available for propulsion. Each converter determines how many diesel generators are on line and subtracts the load of the two motor-generator sets feeding the hotel load from the over all generation capacity. This gives the power available for propulsion, the converters then load share this power according to their individual demand settings. A modification was proposed by the propulsion system OEM to reduce the power available signal when the Sonar is in operation.

The power trail compatibility trial was designed to yield sufficient data to determine the necessity of such a modification.

Should an extra diesel generator be required to be run in order to satisfy the operating conditions of the propulsion system brings implications beyond the immediate. Generator running hours will increase overall and, especially if they are running at low load, consequential increases in through life maintenance and so cost may result.

Standards

When conducting the preliminary designs the definition of standards to be applied to the project requires attention. Design, installation and interface standards all need to be selected. If these are to be the same as used in the design and build of the ship then care should be taken to use an appropriate issue. The standards used may have been up-issued several times since build and it should be made clear whether it is the current or the build standard that is to be used and the reasons why.

Where standards are to be used that were not applicable during the build of a vessel, a clear rational for the choice needs to be laid down and external experts may need to be consulted. The overarching consideration in the selection of appropriate standards is pragmatism. To a certain extent the choice should be made in order to ensure that the systems work rather than based on history or a or autocratic policy of using predefined standards.

Modelling

Modelling and simulation has developed to a level that can make it an extremely useful integration tool. In the field of electrical design there are a number of well-proven products on the market. The UK MoD uses a dual approach for modelling electrical power systems. For general electrical design the MoD has traditionally used IPSA, however after commissioning a study to examine the market it was decided to replace IPSA with EDSA. EDSA is an all encompassing electrical design tool that is both usable and very powerful.

For detailed analysis the MoD's electrical modelling strategy is to use Simulink. As EDSA is an electrical tool, Simulink is a multi-environment tool. This is used where detailed analysis of a particular system or item of equipment is required, be it mechanical, electrical, electrochemical or control. It is not always useful to examine a whole ship's system in such a way, but for detailed work Simulink is a very powerful tool.

Where can modelling be used in a project? To answer this question we must examine the electrical integration requirements of a project. Although all projects are different there is a degree of commonality to the electrical design process. Firstly one must determine if there is sufficient capacity within the system to provide power to the weapon system whilst still maintaining an expected level of ship's service load and propulsion. A load flow study is utilized for this purpose, this study can also be used for sizing cables.

A fault level study should be conducted to determine the rupturing capacity of the cables, protective devices and equipment installed on the system. This is done to ensure that under fault conditions the fault can be contained until the protective devices clear the fault. This is essential for system safety. Following a fault level study the main equipment selections can be finalized. It is then appropriate to study protective device co-ordination to ensure that satisfactory discrimination is achieved.

The distribution and extent of harmonic distortion around a power system can be examined using harmonic analysis tools. The level of harmonic distortion can have a fundamental effect on the operability of sensitive weapons equipment as well as other equipment installed on the system. It is perhaps the issue of harmonics that has caused most concerns with the operation of weapons equipment in integrated full electric propulsion ships.

Load flow, fault level, protection co-ordination and harmonic analysis are static studies. Dynamic studies should be used to determine how the system would operate under actual conditions; such work is needed to predict the stability and operability of the system. The process of static and dynamic analysis is an iterative and concurrent one, as the project develops so does the modelling. EDSA is an excellent tool for static analysis, it is also good for high level dynamic analysis. Simulink is an excellent tool for detailed dynamic analysis.

The S2087 project used modelling to a limited degree, mainly for harmonic analysis. As mentioned above no dynamic analysis was conducted. If a dynamic analysis were conducted the power train compatibility trial could have been de-risked to a considerable degree. Although modelling cannot replace the requirement to run trials it can greatly reduce the risk of trials producing unfavourable results and lead to trials that are very directed and focused on the design solution. In short modelling is an essential tool for systems integration that will reduce design time, risks and costs.

Summary

The rapid advance of technology and high procurement costs have led to the principle of incremental acquisition. A platform may be put into service without its full military capability enabled at build. The integration of new and potentially more powerful weapons means that the subject of this article will become an increasingly high profile one.

The definitions and delegation of authority and responsibility and the involvement of stakeholders is, as always, the subject of good project management. It is imperative that for technical advice the stakeholders are identified and involved as early as possible in order to head off any potential 'show stoppers' before they come to fruition.

Careful design is required when integrating systems and a holistic approach is required. The integration may result in trade-offs between platform performance and military capability, with careful management reasonable compromise may be reached. However, this will not always be possible and major changes to the future ship's systems should not be ruled out in the early stages of design.

The choice of applicable standards requires co-operation of all the stakeholders and careful consideration by the project team. Choosing the wrong standard, one that is either too lax or too stringent, will result in design difficulties and greater project costs. It may also render what seemed a sound concept inoperable in a ship's systems.

Modelling is a tool that should be used throughout a project. Modelling has the potential to ease the design burden and to reduce the risks through the life of the project. Dynamic modelling can reduce the requirement for expensive trials and to examine alternative installation or operating arrangements. Modelling is a software tool and follows the adage; garbage in, garbage out. The information required to build a model is usually the most labour intensive part of a modelling project. Investment in data gathering does pay dividends though in terms of the validity and usefulness of modelling activity. Having said all that, modelling is only a tool, it requires skill, knowledge, competence and an understanding of the whole system to deliver the required results.

Conclusions

- Authority and responsibility for aspects of the project should be defined and promulgated to all of the stakeholders as early as possible.
- Technical advice should be sought as soon as possible so as to avoid surprises late in the project.
- Standards should be carefully selected.
- Modelling is a powerful tool and should be used appropriately to de-risk the project.
- There is no substitute for clear communication across the stakeholder community.