Application for KMB

within the area

ENERGY-EFFICIENT ALL ELECTRIC SHIP (EE-AES)

Faculty of Engineering Science and Technology
Department of Marine Technology
and
Faculty of Information Technology, Mathematics and Electrical Engineering
Department of Electrical Power Engineering

in cooperation with

Aker Elektro, ABB Marine, Marintek,
Brunvoll, Smart Motor, Norpropeller

Part 1: The KMB Project

and

Part 2: Exploitation of results

TABLE OF CONTENTS

Part 1: The KMB Project

Part 2: Exploitation of results

1. OBJECTIVES

The vision of the KMB is to supply research institutes and industry with

World-class experts in the design and operation of cost- and energy-efficient all electric ships

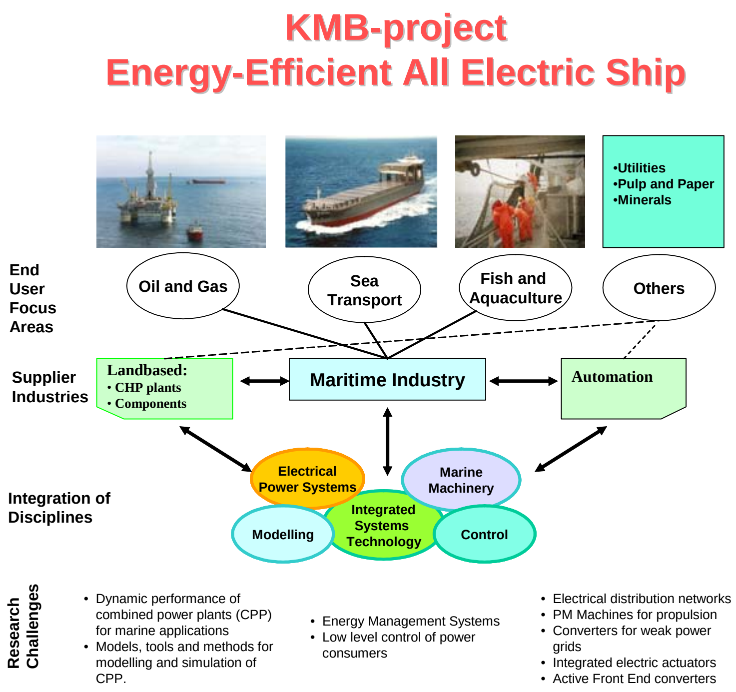
within the areas

- total energy management and control
- system interaction and dynamics
- power electronic converters and new energy sources
- integrated electrical machines and propulsion systems

by

- establishing a multi disciplinary research group to work within the area in cooperation with selected university and industry partners
- educating internationally recognised MSc and PhD candidates
- developing laboratory hardware- and software prototypes for education of this new type of marine engineers and to carry out research projects

The figure below outlines in a nutshell the KMB-project Energy-Efficient All Electric Ship presented in this application and its relations to end-users, supplier industry, the integration of disciplines and research challenges.



1.1 Goals of the KMB

Basis for the application of a KMB is the need to develop and improve the knowledge needed to meet the challenges in the field of research:

Energy-efficient All Electric Ship - EEAES

The need of system as well as component knowledge is common for all such new systems using the electrical form of energy in the energy conversion processes.

Main goals

The subject for the KMB requires good knowledge about the total energy system and its components, as well as knowledge about several technological disciplines.

The main goals of the projects are:

- *Supplying the industry with highly qualified personnel within the area of EEAES.*: A total of 10 PhDs within the area of research will be ready to join the industry when this program is completed.
- *Optimal design/manufacturing and operation of an EEAES*:
  Develop new methods and tools to better to utilize the energy-sources on-board, reduce life-cycle cost and to improve the reliability of the system.
- *Provide technology for cost-competitive products from Norwegian vendors:*
  Combination of electrical-, mechanical- and marine engineering provides knowledge to develop competitive products for marine applications.

KMB funded:

Steady state performance evaluation and optimization

- 1 Dr.-Ing.-student and Prof. Harald Valland

Dynamic performance evaluation of combined power plants for marine applications

- 1 Dr.-Ing.-student and Ass. Prof. Eilif Pedersen

Energy management system

- 1 Dr.-Ing.-student Prof-II. NN/Prof. Asgeir Sørensen

Energy efficient Permanent Magnet Machines for ship propulsion:

- 1 Dr.-Ing.-student and Prof. Robert Nilssen

Multi level converters including harmonic filtering for weak marine power grid.

- 1 Dr.-Ing.-student and Prof. Roy Nilsen

NTNU funded:

Advanced component models for dynamic performance evaluation of combined power plants for marine applications

- 1 Dr.-Ing.-student and Ass. Prof. Eilif Pedersen

Integrated compact electric actuators for marine/offshore applications

- 1 Dr.-Ing.-student and Prof. Robert Nilssen

Modeling and analysis of marine local power grid

- 1 Dr.-Ing.-student Prof. NN/ Prof. Roy Nilsen

Modeling, Analysis and Control of Active Front End (AFE) converter

- 1 Dr.-Ing.-student and Prof. Roy Nilsen

Low level control of power consumers:

- 1 Dr.-Ing.-student and Prof. Asgeir Sørensen

2. FRONTIERS OF KNOWLEDGE AND TECHNOLOGY

2.1 Background

Maritime electric systems include power generation, distribution and control, and consumption of electric power on supply-, service- and fishing vessels as well as offshore installations. Electric propulsion has increased especially for vessels with several large power consumers, for example cruise ships, floating production systems, supply- and service vessels.

Maritime electric systems are autonomous power systems. The prime movers, including diesel engines, gas- and steam turbines, are integral parts of the systems. The power consumers are large compared with the total capacity of the system, as for example thruster and propulsion systems for DP operated vessels, drilling systems, HVAC systems in cruise ships, etc.

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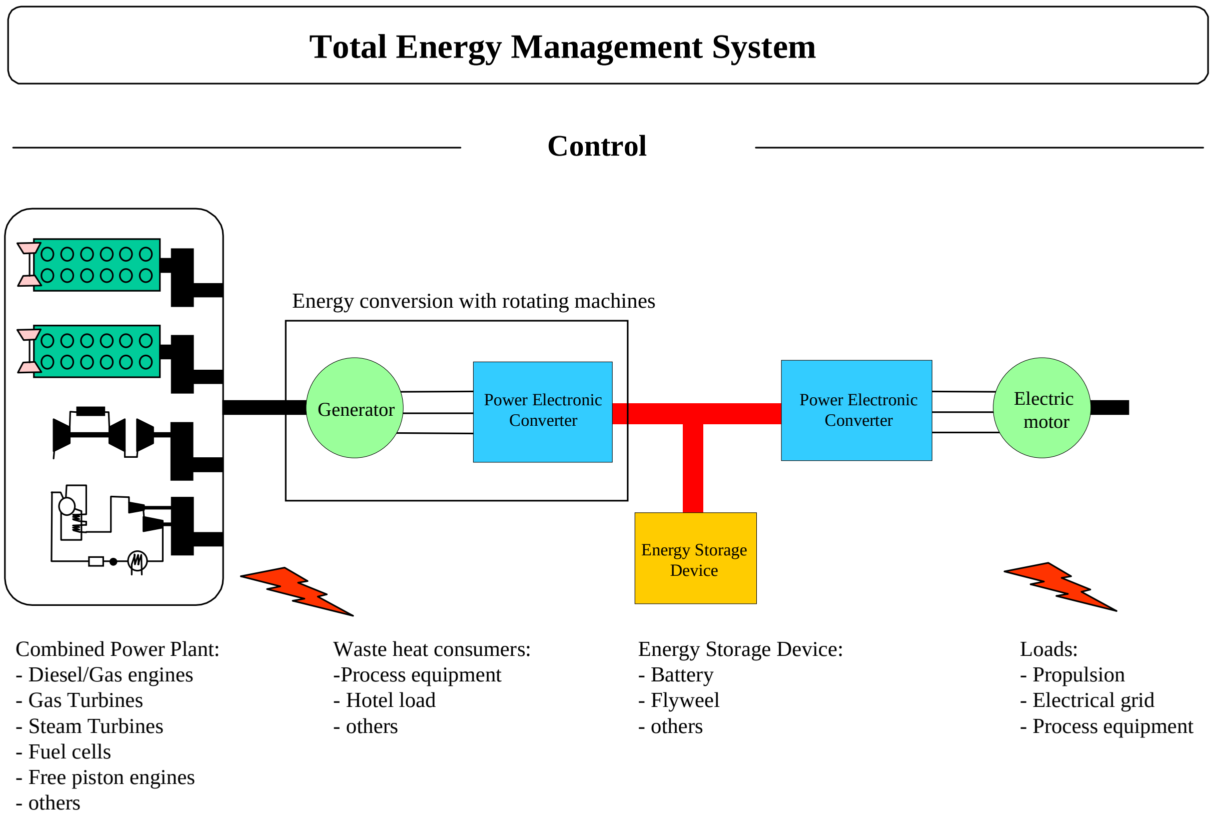

Figure 1 : Typical structure of a combined power plant for ships

A considerable and increasing need for improved competence exists in the field of maritime electrical systems; in system oriented approach for electric power systems on board with heavy impact on vessel and machinery design and operation as well on the component level. Total energy utilization, including waste heat, is usually an important field. Optimum allocation and power control for all subsystems is another field where fuel consumption, regularity and safety are important parameters. Physical and functional integration of power system and automation system is a third field. Use of electrical distribution system of power gives new degrees of freedom in design of ships. One can also see new innovative embedded designs where integration of power electronics, electrical motor and truster gives new cost competitive solutions

The driving forces behind the change towards electric propulsion are mainly:

- Environmental considerations. IMO has issued world wide exhaust emission regulations for ships, and local regulations in certain coastal and harbor areas are even stricter. More restrictive emission regulations have been announced for the future.
- Energy cost reduction is always important. For complex machinery systems this has impact on total system design, operational profile and operational philosophy. Several aspects of optimization will have to be considered.
- Technology development allows new power plants with any combination of diesel engines, gas turbines, steam power plants, sterling engines and fuel cells. In addition a switch from hydrocabons to hydrogen will be seen to have a great impact on the development of new marine power plants within the next 50 years or so. Such combined plants can meet requirements not attainable for each component alone.

Developing new complex machinery systems should be carefully analyzed using relevant theoretical methods for performance, safety and reliability. The types of interesting and in the future required methods for analysis are not only to optimize steady state performance, but also to include analysis of dynamic behavior in extreme operational cases for the total system including low level control and energy management systems. However, the present state of the art type of tools and methods for analyzing such combined systems does only to a limited extent utilize the possibilities for increased knowledge available in the more advanced models and methods developed and used within each of the machinery and electrical engineering disciplines. To be able to analyze increasingly more complex systems of interest, the ability to easily combine models and methods to develop more fundamental insight into the total systems behavior, its characteristics and limitations will be an advantage in design of new systems.

2.2 Strategy of the research groups

The multidisciplinary research team consists of personnel from two different research groups; Marine Machinery Group (MMG) in the Department of Marine Technology at NTNU and the Department of Electric Power Engineering (DEPE) at NTNU. These groups are in close cooperation with MARINTEK and SINTEF Energy Research (SEfAS), respectively.

Strategy of MMG

The strategy of the Marine Machinery Group (MMG) is founded on the following:

- Development of future power production plant for marine applications meeting the requirements for high efficiency, high flexibility and at the same time with low emission levels, can only be met utilizing combined systems consisting of multiple different power generating components such as piston engines, turbines, steam-turbines and in the near future fuel-cells in an optimized energy production system. Knowledge of new systems and methods for design of such systems including topology, optimization, maintenance and lifetime cost has to be established.
- Development and use of numerical tools and methods for both basic and more advanced analysis of such combined systems are necessary for more reliable designs

of such systems. Developing component models at different levels of complexity, methods for assembling these into powerful software simulators, utilization of such simulators for analysis of dynamic and operational behavior and identification of limitations is all important to develop the next generation marine machinery systems.

- In the next generation marine machinery systems the control and management systems are an integrated part of the system to an even higher level than found today. Development and testing of such integrated control and management systems are extremely important for safe and efficient operation of these more complex machinery systems. Knowledge of design and optimization of such control and management systems has to be developed.

Strategy of DEPE

Electric maritime applications are prioritized in the strategy plans for the Energy conversion group (ENO). These plans are based on the close contact with a wide network of industrial companies. ENO emphasizes the following research topics :

- *Maritime systems and components:* Propulsion of ships by help of standard diesel engines usually gives a non-optimal utilization of the energy. Today an increased use of diesel electrical propulsion of ships can be seen. New power electronics and electrical machines will be developed for propulsion and thrusters, as well as other application on board. Knowledge has to be developed about how such large motor drives will influence the autonomous power systems on-board. Even development of new integrated electrical systems for replacement of hydraulic systems (top-side as well as sub-sea) are important areas of research.
- *Renewable sources of Energy*: Develop cost-optimal power electronics and electrical machines which enable best utilization of the energy sources with respect to energy-efficiency and environmental issues; in a system either connected to existing electrical infrastructure or by conversion to mechanical energy.
- *Modelling and analysis of interconnected and autonomous power systems*

  The maritime power system envisioned in this project will include many new challenges that need to be addressed from a system study point of view.

  A key activity will be to develop and establish a complete power system simulation model for overall system performance verifications. Such a model can, to a large extent, be based on models already available at the various research groups, but there is a need to adapt and combine the various models into one unified system model. A main challenge in this respect is to create a functional and modular system model where all critical components are adequately represented. This means that each type of component in the system, ranging from thermal engines and mechanical drive trains to purely electrical loads and converters, is represented by models with the same level of complexity from an integrated system point of view. The system model will serve a number of purposes, including:

  - General system stability studies.
  - As an aid in development and testing of the overall control system and for tuning of individual controllers

Strategy of MARINTEK:

MARINTEK Division Machinery and Technical operation has a strategy on energy and environment expressed through the target to contribute to development of marine propulsion and power generation systems with increased energy efficiency and reduced environmental impact from use. In order to maintain the position as an attractive research partner for the industry, MARINTEK continuously needs to further enhance and develop own competence in the areas of:

- *Properties of alternative energy carriers*: The fuel matrix for available marine bunker fuels is changing, with increasing focus on emission to air from shipping. Cleaner fuels, either by stricter requirements to sulphur content of present available fuels, or by increased application of alternative fuels such as natural gas and hydrogen creates need for increased knowledge in the industry with respect to consequences of change in choice of fuel.
- *Energy conversion:* Efficiency of energy conversion varies for alternative choices of technology (diesel engine, gas turbine, fuel cells). Further development of alternative technology to the diesel engine, requires in depth studies and benchmarking on component and system efficiency.
- *Conceptual design:* The flexibility in design of propulsion or power generating system solutions is increasing with increasing application of alternatives to the traditional diesel engine. System optimization with utilization of alternative solutions, including hybrid solutions, requires improved analytical models and tools in conceptual ship design processes.

3. RESEARCH TASKS

3.1 Key technologies, market and technology trends

Energy Management Floating installations are characterized as closed loop energy systems, where the vessel has to be self-contained with respect to electrical power. Typical installed power for the installations studied can vary from 10 MW up to 50 MW. Roughly we divide the components and subsystems into two categories: producers and consumers of energy.

The interconnecting point for all installed power equipment is the power distribution system. By starting and inrush transients, load variations, and network disturbances from harmonic effects the load and generators are interacting and influencing each other. Optimum operation and control of the power system is essential for safe operation with a minimum of fuel consumption. As it is the energy control system (energy management system) which monitors and has the overall control functionality of the power system, it will be the integrating element in a totally integrated power, automation and positioning system.

The trend is towards hierarchy-implemented control, monitoring, and protection systems of the power and propulsion plant systems, where physical and functional integration is a vital design philosophy. The system level controllers are implemented in control stations or PLCs. They can be centralized or distributed computers, depending on design philosophy for the vessel. In these one will find the energy management functions, such as power management, blackout prevention functions, start-up and reconfiguration sequence control. Due to the need for separate testing and clear responsibility, there will be a need for low level fast-response control, monitoring, and protection of devices and components. Here are the fast control functions and safety functions implemented. These are linked to the system control level by hard-wired or field-bus signal interface.

Combined power plants*:* The marine power plant must supply mechanical and electrical power for propulsion and several other purposes on the ship. In addition it must also serve the need for heating, cooling etc., which at certain conditions may require more power than propulsion. Exhaust emissions are expected to have an increasing importance for the total integrated power plant design and operation, specially in harbors and certain coastal areas. Reliability is a requirement for safe and economic ship operation.

Conventional power producers in ships are diesel engines, gas turbines and steam power plants. Each type has its own particular operational characteristics concerning power capacity and power range, fuel consumption and fuel quality requirements, exhaust emissions, etc.

Combined power plants however, has the potential for very high performance (power, fuel consumption, exhaust emissions, reliability) over a wide range of operating conditions. However, methods and tools for design and advanced performance evaluation at relevant operating conditions are not readily available.

For power sources the marked trend is to search for more efficient and at the same time environmental friendly solutions for the power production. The interest is moving towards more flexible plants where different power producers are combined to solve different purposes facing different requirements for best possible energy efficiency and low emission. The search for new solutions results in renewed interest for both old and new processes and new combinations of equipment for power production. Of special interest here is fuel cells and hydrogen based systems. To identify cost efficient solutions is a dominating activity

El.Distr. Power grid

It is a *trend in the market* to use a distributed power system based on an electrical distribution network on board. Diesel-electrical systems are introduced. This gives more flexibility in mechanical design of ships as well as in use of different sources of energy. Use of AC- versus DC-distribution system are considered. An AC system is the short-term solution, while a DC-system is looked upon as interesting to investigate on long-term basis. It is a clear trend of more use of power electronics in power distribution systems. It gives, among others, an increased flexibility in energy management.

Key technologies to be handled on system level are control and analysis methods for the weak power grids. Weak power grids with local energy production are also of interest for some islands. A big difference from on-shore power grids is that single consumers, as for instance main propulsion, is in the same power range as total sum of energy sources/producers on board. Harmonics generated by power electronics may influence main generators as well as other equipment on board and should be carefully investigated. The influence of power electronic converters in the grid with respect to control strategies as well as failure modes should be investigated.

Technology trend is that new simulation tools and very fast development of microprocessor technology makes in possible to develop models for simulation of complex power system. Models developed can be used for estimation and prediction in a real control system used on board.

PE and machines

For the field “Maritime systems and components” technologies of vital importance are:

- Design and control of power electronic converters
- Design and control of energy efficient electrical machines

Power electronics and electrical machines are very important components in most of the new environmental friendly marine energy systems, due to the increased flexibility obtained in operation of the system. To be able to achieve optimal control of the total system, it is very important to have knowledge about the primary energy source and how the system is utilized in the actual application. Such knowledge has to be acquired in cooperation with the departments/companies where the primary energy source is a part of the core competence. Technologies such as cooling technology have to be included in the project.

A clear *market trend* is increased pressure on price and the need of reduced cost and reduced losses. Cost-reduction will be very important for new energy resources where cost pr. kWh is high. Some trends are:

- Yearly price erosion of 5-10 % for power electronic converters.
- Price reduction is compensated by that reduced prices gives increased application of power electronics; number of units sold is doubled the last 4 years and the same increase is predicted in the future (ca. 15% pr. year at world market).
- Increased efficiency has impact on life cycle cost, but so far purchase price seem to be most important.
- Increased focus on energy-efficient electrical motors and generators.
- Large gear-less motor drives are required to increase the reliability; i.e. direct-driven machines needed. An example of application is thrusters for electrical propulsion of ships up to several MW of power.
- Integration of power electronics and machines to obtain cost-effective solutions and to reduce space requirements.
- The market wants to buy functionality (a complete system) and not components.

Developments of the technologies, t*echnology trends,* are usually based on market needs. However, in some cases new technologies, or evolution of already existing technologies, enabling new product developments. Trends within power electronics and electrical machines are:

- Increased current densities in power electronic devices, but with the same losses pr. footprint area of the device. This means reduced volume for the power rating. A yearly price erosion of 5-10 % is the driver.
- IGBTs (Insulated Gate Bipolar Transistors) for increased current and voltage ratings are available. Devices for 4.5 kV and 6 kV are available.
- Technology development within power electronics makes it possible for small companies with high technological competence, within some markets, to compete successfully with large converter manufacturers.
- New materials and magnetic concepts are developed.
- By using permanent magnet materials new types of machines with high efficiency and reduced volume can be developed. Direct driven machines with substantial reduced volume and weight are possible to achieve. This is important in marine applications.

Low level control of consumers*:* If the various consumers (thrusters, pumps, compressors etc.) of power act separately and uncoordinated from each other, the power generation system must be dimensioned and operated with larger safety margins to account for the corresponding larger mean power demands and unintentionally power peaks. For ships the thruster system normally represents one of the main consumers of energy, and is regarded as a critical system with respect to safety. However, the thrusting controlled by e.g. a dynamic positioning system is only an auxiliary system for the vessel to do a profitable operation of one kind or another, such as drilling, oil production, loading, and so on. Hence, the thruster usage should not cause a load shedding of those productive consumers, or in worst case cause a total power black-out because of unintended power consumption. In order to improve overall energy/power management operating with less additional power margins on the power network it is essential that local control of the various consumers ensure predictable power outtake. This research task will address the importance of focusing on low level actuator control exemplified on thruster control in order to achieve a thorough successful control result, which does not have negative impact on the other systems on the ship. It is also believed that improved local control strategies may reduce mechanical fatigue.

3.2 Research challenges

In this section the research challenges for system- as well as component level will be pointed out.

System level

On system level modelling, analysis and control are key issues. The rapid development of information technology should be utilized in the control of the local power system on board. In analyzing the system good models are needed for the components in the system. This has to be provided by those responsible for the components, but only at a level suitable for system level investigations. These models can be used for prediction and estimation in the Energy Management System as well.

Energy Management System: The purpose of the Power Management System (PMS) is to ensure that there is sufficient available power for the actual operating condition. This is obtained by monitoring the load and status of the generator sets and the power system. If the available power becomes too small, either due to increased load or fault in a running generator set, the PMS will automatically start the next generator set in the start sequence. While the PMS only consider the power flow, the Energy Management System (EMS) monitors and controls the energy flow in a way that utilizes the installed and running equipment with optimum fuel efficiency. The energy management system's main functions can be grouped in:

- Power generation management
- Load management
- Distribution management

The new generation production vessels and also drill ships/rigs have a complex power system configuration with advanced protection and relaying philosophies. There are close connections between the functional design and performance of the energy control system (power management system) and the power protection system functions. It is a challenge for involved parties to obtain an optimal and functional solution with several suppliers involved.

A combined power plant will challenge the conventional power management function. Varying topologies with completely different type of energy suppliers (producers) enabled will define new requirements to incorporate operational requirements into the power allocation and the scheduling of consumers. In order to operate the power plant with the optimal numbers of energy producers and consumers enabled to the power network, the requirement to predictability in the power out-take of the different consumers (thrusters, pumps, compressors, etc.) will increase without violating the safety margins. Hence, the energy management system should also incorporate new principles for low-level control with reduced need for power reserve to handle unintentional sudden power demands. Knowledge of the primary energy source as well as components for energy storage is required.

Energy sources The main challenge for power production systems is to simultaneously supply sufficient power with low fuel consumption and low exhaust emissions, and sufficient high level of system safety and availability. The research challenge is to develop analytical means that allow combined system performance evaluation at steady state and at transient operation.

Tools and methodology*:* To be able to analyze the total energy-efficient all electric ship system performance and behavior in advance, the most promising method available is system simulation. However, to efficiently use simulation methods for different purposes such as steady-state and transient performance, control- and management system design and evaluation to name a few, combining methods from different energy domains and engineering disciplines are important. To efficiently "produce" numerical models of components and total systems for different purposes, both modern efficient tools and capable methods and methodologies are important.

Local control of consumers**:** Until recently, less attention has been paid on the thruster allocation and the low-level control of the local thruster devices with some few exceptions. Conventionally, the propeller and thruster devices can be controllable pitch propeller (CPP) with fixed speed, controllable speed with fixed pitch propeller (FPP), or controllable pitch and speed in combination. Since normally no sensors are available for measuring the actual force developed by the propeller, there are no guarantee for fulfilling the high-level thrust commands from e.g. DP system, and the mapping from commanded thruster force to actual propeller force can be viewed as an open-loop system. Conventionally, the resulting pitch or speed set-point signals are determined from stationary propeller force-to-speed/pitch relations based on information about thruster characteristics found from model tests and bollard pull tests provided by the thruster manufacturer. However, they are strongly influenced by the local water flow around the propeller blades, hull design, operational philosophy, vessel motion, waves and water current. In conventional positioning systems, variations in these relations are not accounted for in the control system resulting in reduced positioning performance with respect to accuracy and response time. In addition, the variations may lead to deterioration of performance and stability in the electrical power plant network due to unintentionally peaks or power drops caused by load fluctuations on the propeller shafts. The unpredictable load variations force the operator to have more available power than necessary. This motivates finding of improved methods for local thruster control based on combined speed, torque and power control. Electrically driven thrusters with variable speed drives allow such control designs without any additional instrumentation. The control principles exemplified for thrust control will also be valid for local control of other consumers exposed to time varying disturbances.

Modeling and analyzing of a marine local power grids.: An AC system is the short-term solution, while a DC-system is looked upon as interesting on long-term basis. Stability analysis is important for such weak power system. Development of models, which even can be used on-line to predict unstability in the grid or to limit loads are needed. It can be integrated into the energy management system. Power electronic converters are important components in such a system and should be utilized in system control as well. Harmonics generated by power electronics should be carefully investigated. Different level for models should be developed; for detailed analysis of harmonics, as well as for more high level models for analysis for power flow analysis and power management control. Models for Failure Mode analysis should also be investigated.

Component level

On this level detailed investigation, design and testing of components are to be performed.

Energy sources Reasonably good general performance models exists for diesel engines, but it is not a trivial job to apply these models for a particular engine make and type. The situation is even more difficult for turbo machinery. For new types of machinery components interesting in the future such as free-piston-engines or fuel cells and combinations, a set of models has to be developed. Steady state performance may be computed from first principles, or may eventually be described by empirical data. Dynamic performance evaluation requires development of dynamic system models.

PE and machines Three different main areas of research are important to have success in this market:

Multi level converters including harmonic filtering for weak marine power grid Compact converters, which produce low harmonic voltage and currrents, are a competitive advantage in marine applications. This favors liquid cooled converters. Key scope is thus to reduce harmonics and losses. An important issue is thus to investigate new converter topologies, as multi-level converters. It is then important to take into consideration filters as a part of the converter, which are needed at the input to reduce the harmonics feeded into the local power grid. Modulation methods for the converters, which minimize the harmonics, have to be developed. It is also important that the modulation method for the converter can control the converter when some of the power electronics components are out of operation. This is in the automobile industry called “limp home” feature. Availability is thus of high importance.

Design of energy efficient Permanent Magnet (PM)Machines: The new commercially permanent magnets make it possible to design electrical machines with a very high efficiency and high power ratio (kW/kg). Furthermore, for marine propulsion direct driven (without gear) systems are often requested. Such low speed high torque motors can be made relatively compact with permanent magnets. Classical design will in such cases become bulky with relatively large diameters. Relatively large permanent magnet machines can be manufactured (say up to 50 MW), and are then possible to control with variable speed with high efficiency. The research in this field focus on magnetic concepts (such as transversal flux machines) best suited for the specific application. Some concepts make very short machines while other may result in very high torque pr kg.

Replacement of hydraulic and pneumatic actuators: A part of the “All electric ship” is the replacement of a large number of traditional components. The modern computerized overall control system are likely to communicate “by wire” with a large number of Smart components – electric actuators. Such actuators are of interest also in other industrial areas.

Compact flexible PM-machines are now used extensively in such automated electrified ships. Electric valve actuators and electric winches are examples where hydraulic and pneumatics are replaced by special purpose electric motors. New actuator systems are developed in Norway and competence in both actuator design and system design of such actuators are often requested.

Modeling, Analysis and Control of Active Front End (AFE) converter : An AFE converter has to be modeled at different level of complexity. Relatively complex models have to be modeled when analyzing the converter with control in the power grid. This may be important when analyzing harmonics and failure mode analysis. For more top-level control analysis, more simplified models can be used. Due to the weak power grid it is important to have a control system for the AFE, which is very robust and can “ride-through” large disturbances in the power grid.

Dr.ing research:

The major research issues identified for dr.ing thesis research are:

- Steady state performance evaluation and optimization
- Dynamic performance evaluation of combined power plants for marine applications
- Energy management systems
- Energy efficient Permanent Magnet Machines for ship propulsion

- Multi level converters including harmonic filtering for weak marine power grid
- Advanced component models for dynamic performance evaluation of combined power plants for marine applications
- Integrated compact electric actuators for marine/offshore applications
- Modeling and analysis of marine local power grid
- Modeling, Analysis and Control of Active Front End (AFE) converter
- Local control of consumers.

4. RESEARCH APPROACH, METHODS

In the project it will be developed mathematical models of integrated power and automation systems consisting of machinery systems (diesel engines, turbines, fuel cells etc.), power plant, distribution network and consumers including all relevant control and management systems. This is a novel approach to design and analysis of combined power plants and control systems. In addition hardware prototype designs of electrical motors and converters for marine applications will be build up and tested.

Verification of theoretical models and simulation results will take place in cooperation with ABB Marine, Aker Elektro and Brunvoll and possibly other partners. Full scale experiments will be carried out at the sites of these .

Multilevel converters with filters will be analyzed, designed and tested. Test will be performed both in laboratories at NTNU and Aker, as well at test sites provided by Aker.

Permanent Magnet Motors for ship propulsion will also be tested at a test site, as well as on board a ship.

Results from the project will be published according to the plan expressed in Chapter 14 and in the activity description in Chapter 7.

5. PROJECT ORGANISATION AND MANAGEMENT

A program-committee will be appointed consisting of:

Prof.	Roy Nilsen
Prof.	Robert Nilssen
Assoc. Prof.	Eilif Pedersen
Prof.	Asgeir Sørensen

Prof.	Harald Valland
Dr.ing	Atle Minsaas, Marintek
Dr.ing.	Alf Kåre Ådnanes, ABB Marine
CTO	Ingve Sørfonn, Aker Elektro
	NN, Brunvoll

The program manger will be:

Prof. Harald Valland

The program-committee members will act as a management-group in all matters of importance to the program. However, Prof. H. Valland will be the contact towards NFR.

6. INTERNATIONAL CO-OPERATION

Student exhange and scholar visits are initiated with recognized universities in Europe or elsewhere.

Scientific staff will participate as scientific advisors and senior research personell within the project and towards the industry partners national and international branches.

Cooperation will be sought within the projects:

- FCSHIP – Fuel Cell Technology for SHIP. Proposal number GRD2-2001-50022, EU-project withing the GROWTH programme.

and other upcoming EU-projects within the same area..

7. PROGRESS PLAN - MILESTONES

Time schedule for main activities/tasks																				
Period : From date: 01.01.2003 To date: 31.12.2007	2003				2004				2005				2006				2007			
Main activities/tasks	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
KMB_1: Steady state performance evaluation and opt.	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/				
KMB_2: Dynamic performance evaluation of combined	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/				
KMB_3: Energy management system					/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
KMB_4: Energy efficient PMM for ship propulsion					/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
KMB_5: Multi level converters including harmonic filtering..					/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
NTNU_1: Advanced component models for dynamic perform..	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/				
NTNU_2: Integrated compact electric actuators for marine..	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/				
NTNU_3: Modelling and analysis of marine local power grid					/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
NTNU_4: Modelling, analysis and control of Active Front End..	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/				
NTNU_5: Low level control of power consumers.					/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/

Table 1: Time schedule for the main activities

The time schedules for the main activities are presented in table 1. Description of sub activities or tasks are presented below. Important milestones and deliverables are included..

KMB-funded activities are indicated with numbers starting with KMB_n, and NTNU-funded activities area starting with NTNU_n.

The exact time schedule of the different activities has to be fixed in cooperation with industry partners.

KMB-funded activities:

Activity KMB_1: The activity "*Steady state performance evaluation and optimization*" has the following sub-tasks:

- *System performance evaluation (SSPE):* Development of models for steady-state performance of combined machinery components like diesel engines, gas turbines, steam turbines, etc. Development of methods for building components into a system, and computation of over-all performance characteristics of combined systems at steady state. System capacity such as power and heat/steam production, fuel consumption and exhaust emissions will be included together with measures for thermal and mechanical loads on the components.
- *System optimization (SSPO):* Relevant object functions will be developed and methods for optimization (structural- and parameter-) will be employed for system improvement at system design stage.
- *System design:* Application of methods for SSPE and SSPO will be demonstrated for some cases selected in co-operation with KMB_2.

Milestones:	*Time:*	*Deliverables:*
M 1: Start dr. ing. study	01.01.2003	
M 2: SSPE specification completed	31.12.2004	Report

M 3: SSPO specification completed	30.04.2005	Report
M 4: SSPE/SSPO software completed	31.12.2005	Report and software
M 5: Design study	31.12.2006	Report
M 6: Dr.ing thesis delivered	31.12.2006	Thesis

Activity KMB_2 *Dynamic performance evaluation of combined power plants for marine applications*

This activity can be divided into the following sub-tasks:

- *Total energy production system simulation and optimization.* Development of a prototype total system simulator will be carried out, using or based on the component models developed for both the power production plant and waste heat consumers, and for electric conversion and consumer systems. Advanced optimization algorithms will be used for optimizing the total system for energy efficiency and at the same time low emissions.
- System evaluation of combined power plants during extreme dynamic loads using system simulation. Utilizing different levels of component models developed the behavior of selected interesting new systems at extreme dynamic loads will be investigated. The necessary refinement of basic models to be valid in such cases will be specified and implemented.

Milestones:	Time:	Deliverables:
M 1: Start dr.ing study	01.01.2003	
M 2: Simulator specification completed	31:12:2004	Report
M 3: Software simulator completed	31:12:2005	Report and software
M 4 CPP system evaluation	31:12:2006	Report
M 5: Dr.ing thesis delivered	31.12:2006	Thesis

Activity KMB_3 *Energy Management System*:

This activity can be divided into the following subtasks:

- *Modeling* Development of models of important consumers and producers and simulation of power and energy consumption.
- *Control system design:* Design of control algorithms.
- *Simulation:* Development of appropriate simulator.
- *Prototyping:* Development of prototype Energy Management System for experimental testing on Lab and later in full scale. The last in close cooperation with industry partner.

Milestones:	*Time:*	*Deliverables:*
M 1: Start dr. ing. study	01.01.2003	
M 2: Modelling	01.06.2004	Report and tested models.
M 3: Simulation	01.06.2004	SW+Report of test results.
M 4: Control system designs	01.06.2004	SW+Report of test results.

M 5: Experiments	01.06.2005	SW+Report of test results.
M 6: Dr. ing thesis	31.12.2006	SW+Reports.

Refinement of models and controller designs are subject for later delivery dates

Activity KMB_4 "Design of permanent magnet machines for direct driven propulsion". Permanent magnet electrical machines have proven to be energy efficient and compact. In ship propulsion such motors can be used in integrated designs where gears and complex mechanical systems can be eliminated. In future designs the motor and propeller (turbine) is likely to be integrated in one efficient compact unit.

- *Analysis*: Development of general technical (magnetic, electric etc) and economical models for permanent magnet machines in propulsion application. The goal of this part is be able make an overall technical/economical optimization of the motor also taking in to consideration corresponding power electronics.
- *Design.* A demonstration model (prototype) of an integrated modern PM- motor for ship propulsion is to be made. This may be a thruster where the water is flowing through the motor. This part will focus on modern design with use of new materials and concepts suitable for integrated motors and propellers. The power electronics and control units are to be developed in parallel.
- *Testing* .The motor is to be tested to verify the prototype design. Typical results from the test are output power, efficiency, noise level, vibrations, etc.

Milestones :	*Time:*	*Deliverables:*
M 1: Start dr. ing. study	01.01.2004	
M 2: Modeling	01.06.2005	Report and tested models.
M 3: Simulation	01.06.2005	SW+Report of test results.
M 4: Control system designs	01.06.2005	SW+Report of test results.
M 5: Experiments	01.06.2007	SW+Report of test results.
M 6: Dr. ing thesis	31.12.2007	SW+Reports.

Activity KMB_5 *Multi level converters including harmonic filtering for weak marine power grid.*

In marine power grids the total sum of converter ratings can be in the same range as the installed generator ratings. Thus, in such weak power grids harmonics produced by the converters should be minimised. Two approaches to this challenge is to install filters and to chose converter topologies that produces little harmonics as possible. Such topologies will in additon reduce the required filter ratings. Volume of converter, including filters, should be as low as possible. Thus, Multilevel converter including filters will be investigated.

- *Analysis:* Different mulitilevel converter topologies will be investigated with respect to harmonics at the output and losses in the converter. Different filters will be analysed. Modulation methods will be developed. Cost of the converter is an important optimization criterion. Control strategies and models have to be developed.
- *Design:* A laboratory model will be build. This will include different type of filters, as well of a total control system for the converter.

- *Testing/Experiments:* The converter with filter will be tested inlaboratory as well on at test site . Harmonics will be measured. This will be in cooperation with Aker.

Milestones :	*Time:*	*Deliverables:*
M 1: Start dr. ing. study	01.01.2003	
M 2: Modeling	01.06.2004	Report and tested models.
M 3: Simulation	31.12.2004	SW+Report of test results.
M 4 Design basis	31.12.2004	SW+ Report
M 4: Designs	01.06.2005	HW+Report of test results.
M 5: Experiments	01.06.2006	SW/HW+Reports
M 6: Dr. ing thesis	31.12.2006	SW+Reports.

Activity NTNU_1 *Advanced component models for dynamic performance evaluation of combined power plants for marine applications*

The activity can be divided into the following sub-tasks:

- *Development of component models:* The main objective is to develop advanced dynamic component models for combined power plant performance simulations. The outcome of this sub-task will be a model library of basic and specific component models for efficient generation of total system models in multiple complexity levels for both steady state and transient performance evaluation.
- *Model documentation*: Review of requirements and development of prototype tools and methods for model documentation.
- *Model reduction/production:* Development of methods and techniques for model reduction for generation of simplified component and system models for specific applications and for use in specific external/industry simulators.

Milestones :	Time:	Deliverables:
M .1: Start dr.ing study	01.01.2003	
M 2: Comp. models review/requirements	31.12.2004	Report
M 3: Comp. model development completed	31.12.2005	Rep& comp.lib.
M 4: Model interfacing techniques	31.12.2006	Rep& comp.lib.
M 5: Dr.ing thesis delivered	31.12:2006	Thesis

Activity NTNU_2 *Design of permanent magnet actuators for marine and offshore applications*.

Permanent magnet actuators have proven to be compact and flexible. In ship applications such actuators can be used in integrated designs where hydraulic and pneumatic devices can be replaced. Furthermore older electric actuators with expencive gears replaced by direct driven device with more advanced control. In the future the “all elecric ship” is extensively automised. In the future such electric actuator will characterise the all electric ship.

- *Analysis*: Study of general technical (magnetic, electric etc) and economical requirement for actuators used as a system component. Development of models for compact low cost permanent magnet based. The goal of this part is be able make an overall technical/economical optimization of the device also taking in to consideration corresponding power electronics.
- *Design.* A demonstration model (prototype) of an integrated modern PM- based actuator for ship applications is to be made. This may be a valve actuator . This part will focus on modern design with use of new materials and concepts suitable for integrated actuators. The power electronics and control units are to be developed in parallel.
- *Testing* .The actuator is to be tested to verify the prototype design. Typical results from the test are torque.

Milestones :	*Time:*	*Deliverables:*
M 1: Start dr. ing. study	01.01.2003	
M 2: Modeling	01.06.2005	Report and tested models.
M 3: Simulation	01.06.2005	SW+Report of test results.
M 4: Control system designs	01.06.2005	SW+Report of test results.
M 5: Experiments	01.06.2006	SW+Report of test results.
M.6: Dr. ing thesis	31.12.2006	SW+Reports.

Activity NTNU_3 *Modeling and analysis of marine local power grid.*

An AC system is the short-term solution, while a DC-system is looked upon as interesting on long-term basis. Stability analysis is important for such weak power system. Development of models, which even can be used on-line to predict instability in the grid or to limit loads are needed. It can be integrated into the energy management system. Power electronic converters are important components in such a system and should be utilized in system control as well. Harmonics generated by power electronics should be carefully investigated. Different level for models should be developed; for detailed analysis of harmonics, as well as for more high level models for analysis for power flow analysis and power management control. Models for Failure Mode analysis should also be investigated.

- *Modeling:* Models at different level of complexity will be developed. The most complex models will include converters with their switches modeled as ideal switches. Harmonics and ripple components of voltages and currents will be included. Controllers for the converters will also be taken into consideration. More high level component models will be developed and tested. It should be pointed out in which type of simulation these models are valid.
- *Analysis:* A numerical simulation program should be agreed upon. The models should be included in this program,. A model of a typical power grid in a ship should be analyzed.
- *Testing/Experiments:* The simulation of a case study should be verified by help of measurements on board of a real ship.

Milestones : *Time:* *Deliverables:*

M 1: Start dr. ing. study	01.01.2004	
M 2: Modeling	01.06.2005	Report and tested models.
M 3: Analysis	31.12.2005	SW+Report of test results.
M 4: Experiments	01.06.2007	SW+Reports
M 5: Dr. ing thesis	31.12.2007	SW+Reports.

Activity NTNU_4 *Modeling, Analysis and Control of Active Front End (AFE) converter*

An AFE converter has to be modelled at different level of complexity. Relatively complex models have to be modeled when analysing the converter with control in the power grid. This may be important when analysing harmonics and failure mode analysis. For more top-level control analysis more simplified models have to be devloped. The converter can be a multilevel converter or an ordinary 2-level converter.

- *Analysis:* Different models for Active Front End converters should be developed and analysed. Control strategies should be investigated. Filters have to be included in controller-design. Models of the filters can be included in the controller. Required complexity of models for systems analysis have to be investigated.
- *Design:* A laboratory model will be build. This model can be based on a 2-level or multilevel converter. Filters have to be a part of the laboratory model.
- *Testing/Experiments:* The converter with filter will be tested in the laboratory, as well on at test site. This could on board of a ship. This will be made in cooperation with Aker).

Milestones :	*Time:*	*Deliverables:*
M 1: Start dr. ing. study	01.01.2003	
M 2: Modeling	01.06.2004	Report and tested models.
M 3: Simulation	31.12.2004	SW+Report of test results.
M 4: Designs	01.06.2005	HW+Report of test results.
M 5: Experiments	01.06.2006	SW/HW+Reports
M 6: Dr. ing thesis	31.12.2006	SW+Reports.

Activity NTNU_5 *Low level control of power consumers*:

- *Modeling* of electrical propulsion system for ships, dynamic thrust loss models, thruster drives and motors.
- *Control system design:* Design of local thruster control strategies based on combined speed/Pitch, torque and power control.
- *Simulation:* Development of appropriate simulator.
- *Prototyping:* Experimental testing of thruster control on Lab and later in full scale in cooperation with ABB.

Milestones:	*Time:*	*Deliverables:*
M 1: Start dr. ing. study	01.01.2003	

M 2: Modelling	01.06.2004	Report and tested models.
M 3: Simulation	01.06.2004	SW+Report of test results.
M 4: Control system designs	01.06.2004	SW+Report of test results.
M 5: Experiments	01.06.2005	SW+Report of test results.
M 6: Dr. ing thesis	31.12.2006	SW+Reports.

Refinement of models and controller designs are subject for later delivery dates

8. COST INCURRED BY EACH RESEARCH PERFORMING PARTNER

Post.Doc/Research Scolarship are dependent on Norwegian Research Council contributes directly with 50% and Marintek with 50%.

9. FINANCIAL CONTRIBUTION BY PARTNER

Part 2: Exploitation of results

10. RELEVANCE FOR KNOWLEDGE-BUILDING AREAS

The topics of this KMB project is of major relevance for the following knowledge-building areas:

- *Marine Technology:*

  The project will contribute significantly to fullfill the R&D objectives of this area within design and operation of novel integrated power plants and propulsion systems, including the all-electric ship and advanced control.

  Direct references to the description of the Marine Technology knowledge-building which can be made are:

  - Marine Systems - [Marine Technology, Chap. 1, 2nd bullet]
  - Marine Control - [Marine Technology, Chap. 1, 5th bullet]
  - “Maritim” - [Marine Technology, Chap. 2, 2nd t paragraph]
  - Marine operation - [Marine Technology, Chap. 2, last paragraph]

- *Energy and petroleum:*

  The project will also contribute to this knowledge-building area regarding especially marine energy utilization and transport, energy system technology and energy producers, including environmental friendly use of energy. [Energy and Petroleum, Chap. 1 & 2]

The most important contribution is to develop world-class expert engineers within the area for the industry and research institutes by supporting 5 Dr.ing-students (10 totally).

Importance for development of university programs:

The Department of Marine Technology has in cooperation with the Department of Electrical Power Engineering started a research based education program to bring out MSc candidates with a spesialisation in design and operation of diesel-electric propulsion systems. The KMB applied for here will contribute significantly to research by supporting PhD candidates in this field, thus enhancing the quality and standing of this education program.

11. IMPORTANCE TO NORWEGIAN INDUSTRY

The table below outlines the importance of this KMB to norwegian industry in some detail. Listed are the main R&D results, type of results, the main beneficiary and type of application at industry partner or others.

R&D results :	Type of results :	Benefit for :	Applications:
Methods for system evaluation and optimisation	Data programs for steady state performance analysis	ABB , Aker and consult-ants	Design of power system and used on-line in Energy Management Systems
Dynamic system models	Simulation models tested and verified by measurements	ABB , Aker and consult-ants	Analysis of on-board power systems. Failure Mode Analysis.
New principles for Power generation-, load- and distribution management	Prototype for Energy Management Systems	ABB	Energy Mangement system to be used in local power system; Ships, oil platforms and remote islands.
Methods for optimal design of compact Permanent Magnet Motors for direct driven propulsion and for PM machines integrated in actuators.	Prototypes of integrated trusters and for an actuator.	Nor-propeller, Brunvoll, Smart Motor and Aker	Ship propulsion, pumps, fans and actuators
Methods for evaluation and design of compact converters not poluting the electrical grid.	Prototype of multi-level converter installed at test site	Aker	Line-side (AFE) converter in local power systems. Converters for connecting new energy-sources as fuel cells, etc. As inverter for motor control.

To be at the technological forfront it is of vital important to have high qualified personell in the companies; both designing systems as well as components. As output of this KMB, together with the NTNU-funded part, 10 PhD will be graduated and ready to join this industry.

To be and/or remain as a major player in the market, new products has to be developed almost continuously. The increased market share due to this KMB is not easy to quantify. This have to be estimated by the industry partners. It is however clear that increased knowledge of the integrated power system is needed, as well that integrated products as PM-machine based truster will be introduced in the market. Power electronic based converter becomes an important element in local power grids with different energy-sources.

12. RELEVANCE FOR IE INNOVATION PROGRAMMES

This KMB-project positions itself within the “Marin virksomhet og offshore operation” – MAROFF innovation programme.

The KMB-projects most important contribution to the objective of the program is:

- To develop new competence within the knowledge-building area Marine Technology related to the **next generation ship** and **ship systems**.
- To develop knowledge ragarding design, analysis and control of **new energy carriers**, new engine and propulsion systems, including the all-electric ship and advanced control.

In addition this KMB-project has several resemblances to the “Energi, Miljø, Bygg og anlegg” – EMBa programme, regarding energy systems, new energy sources, use of natural gas and small scale power plants [EMBa, Chap. 1].

13. ENVIRONMENTAL IMPACT

Environmental issues are a main topic in the project.

- The main goal is to develop energy-efficient systems for electrical propulsion with a primary objective to reduce emissions
- Proper design and operation of combined power plants may reduce emissions considerably compared with conventional power plants.

Developing such systems will contribute significantly to reduce the emissions from the Norwegian ships all over the world and especially the Norwegian costal fleet, inluding supply vessels and fishing boats which contribute to the Norwegian green-house gas emissions according to the Kyoto protocol.

14. INFORMATION AND DISSIMINATION OF RESULTS

Industry
The industry will be involved in the projects in supplying some prototypes of machines as well as devices. Also cooperation on system aspects will be initiated. Actual partners are: ABB Marine, Aker Elektro, Marintek, Brunvoll, Smart Motor and Norpropeller,.

Know-how transfer
Know-how developed in the KMB will be transferred to the industrial partners for application in projects during the period of the KMB; as early as possible. Post-doc’s and dr.-ing. student will join the industry or research institutions after the project. The results from the KMB will be included in course-material at NTNU and via ordinary students be transferred to the industry.

Publications
First of all the dr.ing.-thesis of dr.ing.-students will publish results from the KMB. A target number for conference or article publications from each of the dr.ing studentsis is 3. It is however a goal to publish 2-3 papers each year at international well established conferences during the period of the KMB. At least the same number of papers will be published in Norwegian magazines.

Customer value
The technology is of fundamental importance for industry partners can be the technology base for new products and increased market share.