Designing a Hybrid Electric Vessel (HEV)

After the recent turn of the century in the year 2000 there has been a significant change in thought regarding global natural resources and the effect of carbon fuels upon the environment, especially with regard to the operational characteristics of marine vessels. Those of us in the business of design and supply of marine power equipment can attest to the variance in convention speeches addressing the multiple choices of proposed hybrid marine propulsion technology.

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I myself was a skeptic when approached by a team of Naval Architects in spring of 2005 and asked to design an efficient electrical hybrid propulsion system. The requested system would ideally be one that customers could afford. I found it very difficult to accomplish the task at hand and at the time did not realize the extensive time needed to "get it right".

Before beginning the design phase the meaning of a marine hybrid propulsion system needed to be defined. After some thought, I was able to isolate 3 distinct areas, or variations, of marine hybrid technology.

- Alternative fuels (Hydrogen fuel cells, CNG, etc...).
- Increased power system and drive line efficiency (elimination of gear boxes, deployment of higher efficiency motors, better use of diesel engines, streamline process', etc...).
- Stored energy (battery storage systems, ultra-capacitors, energy harvesting technology, etc...)

To achieve a reliable and repetitive propulsion system combined with cost efficiency, the design engineer becomes limited with readily obtainable equipment available in today's markets for deployment in a marine hybrid power system. When confronted with this task, I thought it best to place myself into the ship owner's position and review the options. So, if I was the vessel owner I would want as the primary goals a design that is efficient and reduces operating costs, that is affordable and not exponentially expensive and have a short return on investment.

Therefore, by definition, you must first surmise a solid design premise offering reliability, reasonable investment cost weighted against a return with the result of the design not placing limitations upon the global area of operation of the asset (vessel).

At present, the global infrastructures to support alternate fuels, such as hydrogen and CNG, outside of targeted geographical areas are very limited. This would restrict the mobility of the asset to generate revenues in the event the contract changed geographical regions. Therefore, this option was not

considered as a primary source of propulsion energy leaving a combination of item 2 - optimization of system efficiency optimization and item 3 - deployment of a stored energy reserve as the best viable options.
Having stated this, we at Thrustmaster realize that if you wanted a CNG power plant, it would only add to the benefit of the system and is left to our customers to decide.

The design premise I based the HEV upon is as follows;

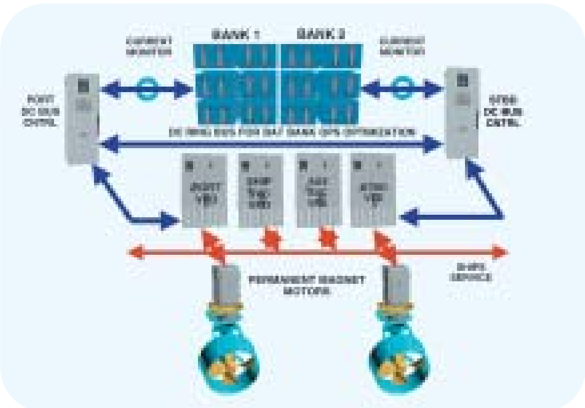
DESIGN PREMISE - "A cost efficient product that will result in reduced fuel consumption, reduced maintenance expenditures, and reduced exhaust emissions by automatically drawing power from the most efficient source.

Maximize system efficiency by streamlining and controlling the current pathways with the ability to harvest all inertial energy when available and provide maximum adaptability of the power sources in the system".

At this point the task appeared to be well in hand.

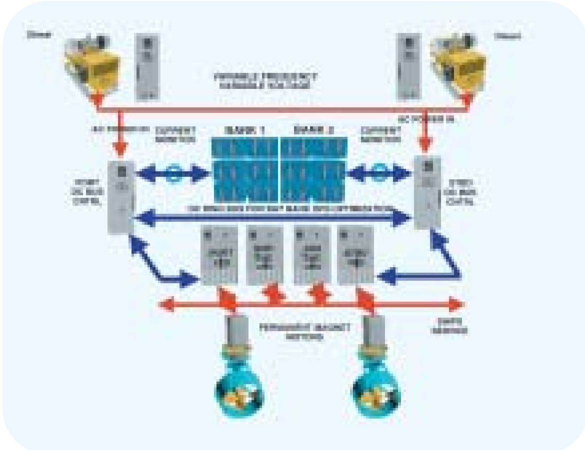
However, what I found, through extensive market research of the stored energy systems offered within the global markets, was a definitive gap in product offering that could be used to develop a repetitive and reliable integrated system with guaranteed years of operation for the stored energy system.
As a result of the market gap in available products, during the R&D and the extensive test phases, new electronic controls and software systems needed to be designed from the ground up and implemented to fill this gap. The result was a system that optimizes the vessel power system efficiency and is able to provide a very rapid refresh rate to the stored energy system, even when loading conditions are severe. We at Thrustmaster firmly believe in the proven product design philosophy. So this product has been fully tested and subjected to severe operating conditions during the past few years to validate the reliability of our system.
The normal operating mode, named Stealth Mode because it allows the vessel to operate without operation of the diesel engines and is very quiet, seamlessly analyses the operating conditions and performs adjustments to the power system. The control system automation is based upon decision making algorithms that monitor every battery cell and automatically adjust the power system based upon variables of the vessel task duty and hull design. The pilot only notices the that when he pushes the throttles forward (or in reverse) the vessel responds promptly.
In stealth mode, the engines and generators are seamlessly controlled to start and come online to provide charging and/or power to the ships service only when needed. Therefore the diesel engines are not required to operate for exceptionally long periods when the vessel is loitering or in a slow transit mode.

Stealth Mode Operation (no engines running)



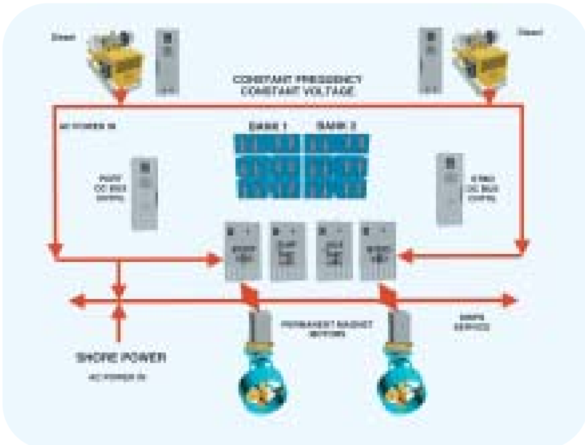
A depiction of stealth mode is shown below. The direction of the arrows indicates bi-directional current flow is possible through all areas of the distributed power. With the application of permanent magnetic motors, energy harvesting is optimized.

When engines are needed, the RPM is controlled (not constant) in coordination with the variable excitation curves of the generator output to ensure the engine is ALWAYS within the optimal load curve. Oddly enough, engineers at GE independently developed a similar concept for their ECOMagination rail transports that optimizes the engine power curve in the same fashion. The variable excitation results not only in KW optimization of the engine but also provides the foundation for a very rapid refresh rate of the stored energy system batteries.
A depiction of charging and/or energy assist mode is shown below. Note that the system design can be variable with addition of engine/generator sets combined with increase (or decrease) in size of the stored energy system and thus easily support a multitude of variations and applications.



System power demand increases or stored energy decreases

Other operating modes can be selected as desired. The modes vary from emergency mode with all available power sources online, bypass mode with all stored energy systems offline and the engine/generators revert to constant speed - constant voltage, to simple maintenance modes where service can be performed upon any portion of the system.
The Maintenance and/or bypass mode is depicted below. Note that the system design is so versatile that it easily reverts back to a standard diesel electric by the simple "flick of a switch".



Stored energy maintenace bypass mode

Power management of the batteries is performed on a cell per cell basis. An intelligent proprietary design was developed allowing the ability to transport energy locally from one cell

with a high charge to another cell with a low charge across the battery monitoring electronics without the use of expensive specialty wound coils. This process is continuous and dramatically minimizes voltage divergence across the power cells during high power draws from the stored energy system.
As each battery cell is monitored on an individual basis, the information gathered is used to predict cell failures "IN THE FUTURE".
One aspect of the design and proving phase is that I was very surprised none of the battery manufactures found globally had a system that I could purchase off the shelf. There were a few available but none for continuous duty above the one megawatt range of operation. Therefore, the system for monitoring the Battery State Of Change (SOC) and strict control of the bus current pathways had to be designed from the ground up, as previously stated.

The systems shown above have over 6,832.8 of charge and discharge cycles on the battery banks. Those of us in Houston vividly remember the first and second week of September of 2008 when hurricane Ike finally made land fall in Galveston and Houston. Fortunately we happened to be in the process of depletion testing of one 1,000 KW stored energy unit and were in a rapid refresh cycle at the time the hurricane hit. This system provided valuable data when we were forced to use it as the only source of power for over 3 full days due to county wide power outages. We operated all of the office loads, all the shop loads inclusive of overhead cranes and welding machines plus provided power to some of our industrial neighbors. The information gathered led to many new developments. One of the new developments is an intelligent battery controller with the following features;

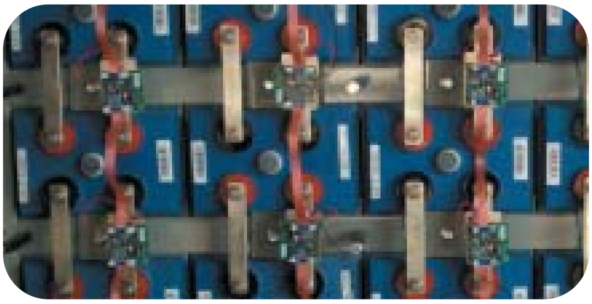
An intelligent circuit board is mounted on each battery cell

- Monitors cell voltage
- Monitors cell temperature
- Shifts charge from cell to cell to balance SOC
- Has onboard memory and serial communications

Central controller coordinates actions

- Gather, analyze, record, report data
- Identify strong and weak cells
- Issue commands for charge balancing
- Flag cells needing maintenance
- Provides and records total current flow to management system
- Provides and records total output voltage of battery array

The technology described above allows us to ensure the stored energy batteries can be guaranteed for a minimum of 5 years under warranty. The boards are physically mounted to a heat sink and measure not only the battery operating temperature but the power bus temperature well. The photo below shows the design installed onto a 2.0 MW reserve power unit.



Most people I talk to always say "This thing sounds expensive!", but remember, one of the initial design criteria is that the result needed to be cost efficient. The Thrustmaster hybrid propulsion systems detailed above are only 12-15 percent more in real cost than a standard diesel electric power system to deploy. Depending upon the application, these systems can deliver between 17% and 42% fuel savings in a 24 hour cycle of operation. The system is designed around a breakeven point on investment cycle time between 18 to 38 months.

Harbor tug operations, Ferry operations and loitering operations of the OSV or a standby vessel are ideally suited to this design. Offshore towing vessels would not have a great benefit in reduced operating costs unless they have extended loitering periods.

Thrustmaster is uniquely positioned to offer a complete vessel package, from the thrusters, power plant, drives and switchgear, stored energy and energy management system, station keeping system all the way through to oversight of shipyard installation and operational support. The HEV designs have many benefits for the vessel operator. A few of these are;

THRUSTMASTER HEV POWER CONTROL SYSTEM BENEFITS

- Fault tolerant KW-KVAR load share lines
- Fully integrated Power Bus overload control technology
- DP system interface designed into the system
- Vessel piloting is seamless to the operator where the power originates.
- In the event of problems, the system records and displays the exact nature of the fault and directs the personnel to the affected component.
- The system records all events for up to 3 years
- Constant Bus, Variable Bus Optimizing control of the main engines and generators ensures the prime movers are always in the optimized area of the loading curve.
- Optimized stored energy system that monitors every cell and provides theoretical fault analysis for events IN THE FUTURE.
- Fuel savings
- Reductions of emissions
- Increased time for maintenance interval on main engines
- Remote system monitoring options (if the vessel has internet)
- Complete integration and supply from a single source.

The Thrustmaster hybrid power systems provide flexibility in design to fit most vessel deployment strategies. The initial design premise that I originally used provides a great benefit to the vessel owner and is easily deployed by us, therefore a win - win scenario.

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