Mobile Shore Power Supply for Submarines

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Abstract - The Swedish Defence Materiel Administration (FMV) has purchased a mobile shore power supply (MSPS) unit for submarines from Hitzinger GmbH in Linz, Austria. The need for such a unit has grown more and more evident in the past few years as the submariners of the Royal Swedish Navy (RSwN) have found it hard come across good quality electrical shore power during visits to foreign civilian harbours. Enclosed in a 20 ft container, the MSPS can easily be transported anywhere around the world and provide power for charging primary submarine batteries as well as supplying the hotel load and auxiliary equipment, e.g. spare parts containers and liquid oxygen supply.

This paper describes this procurement from start to finish. FMV sheds some light on how the ideas and requests from the submariners together with the experiences gained from procurement and use of similar equipment, delivered to the Royal Swedish Army and Air Force, were transformed into actual requirements in a specification. Hitzinger then gives the technical details on the design of the MSPS.

Key Words – shore power, submarine, genset, container, rotary, UPS

1 Introduction

During the last few years, submarines from the Royal Swedish Navy (RSwN) have taken part in international military exercises around Great Britain and in the Mediterranean as a part of Partnership for Peace (PFP). Valuable experiences have been gained from these as to how the RSwN submarines function outside the waters surrounding Sweden. Originally designed for operating mainly in these waters, the submarines have since been modified with regard to, among other things, saltwater and warmer, more humid climates.

Operations around Sweden give access to reliable shore power at naval bases along the coast.

This implies, for instance, that the final of the three-stage charging process of the submarine’s main batteries, can be carried out using the shore supply and by doing so, relieving the onboard diesel engines for maintenance. But reliable, good quality shore power cannot be guaranteed everywhere along the coasts of Europe. Carrying out maintenance under such circumstances is a tedious and time-consuming task because one of the diesel engines has to be running at all times.

A mobile power source to accompany the submarine when on international exercises would be ideal. The possibility of renting this kind of equipment does exist at some locations in Europe but in the long run this ought to become a costly affair.
And what if this kind of equipment is not available when needed? Furthermore, can this sort of mobile power source be found outside Europe? A rental unit is, in addition, most likely not adapted for military conditions and would therefore not be suitable to bring along on peacekeeping missions around the world. It is therefore more advantageous procuring a mobile shore power supply (MSPS).

Please note that the figures (Fig.1-4) referred to in the following text can be found at the end of this paper.

2 Assessing The Requirements

2.1 General Requirements

2.1.1 Initial Thoughts and Constraints

The fact that the Swedish Armed Forces take part in international exercises and peacekeeping missions around the world implies that the equipment can be used anywhere within a circle with a 4000 km radius originating from Brussels, Belgium. Being of rather small size, compared to other armed forces, the Swedish Armed Forces have to rely on small numbers of equipment to carry out missions. Therefore each piece of equipment has to have multifunction capabilities and be able to execute them in many different kinds of environments. This sets rather tough requirements on the equipment.

The problem with procuring small volumes is that development costs often become a big part of the total procurement costs. There is often little or no room for prototyping and testing. Instead the first, in for instance, a class of ships, has to play the part of the prototype. In the case of the MSPS only one unit was to be ordered, with an option for a second, a rather small volume to say the least.

The functional requirements for the MSPS can be seen below:

- Battery charging (the final of the three-stage charging process)
- Supplying the hotel load
- Supplying auxiliary equipment

Standardized off the shelf products and systems are often desired as they help to reduce overall costs. After a glance at the functional requirements followed by a quick market survey, it is evident that the requirements do not match anything that can be bought off the shelf.

2.1.2 Compatibility

Compatibility is also an important aspect. This is nowadays something a procurer always strives toward for logistical reasons, especially when it comes to spare parts handling; a spare part that is used in several systems, be it a ship or aircraft and regardless of age, is cheap and has high availability.

Compatibility is also an important issue when it comes to service functions, both domestic and abroad. Things such as fuel handling systems have to be taken into account, as do electrical plugs and sockets as well as transportation aspects (see 2.2.1).

2.1.3 Maintenance and Repair

Due to the vast operational area, it is reasonable to assume that supply of spare parts and tools will be limited. Maintenance, trouble shooting and simple repairs have to be easy to carry out, regardless of environment. Also good values on Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) are desired.

2.1.4 Safety

Personnel safety is something that cannot be overlooked. It is reasonable to assume that the users of MSPS, during an international operation, do not necessarily have to be Swedes, thus their knowledge of the equipment may be far less than what is actually required. Therefore the system safety requirements demand a lot of work from the supplier. In short each risk has to be categorized according to the matrix below (Tab.1).
Tab.1: Risk assessment matrix
The numbers in the matrix determine the criticality of the risk:

1: Death, system loss, loss of property or severe environmental damage
2: Severe injury, severe illness, major damage to property or major environmental damage
3: Minor injury, minor illness or minor damage to property or minor environmental damage
4: Less severe than any of the above.

The probability is categorized as:

A: Continuous
B: Frequent
C: Intermittent
D: Unlikely.

The risks are defined as:

U: Unacceptable
FMV: To be decided by FMV
A: Acceptable.

The unacceptable risks have thereafter to be eliminated or reduced by means of one of the following:

- Change of design
- Incorporating protective devices
- Incorporating warning devices
- Instructions
- Training

2.2 Mechanical Requirements

2.2.1 Transport and Handling
The design of the MSPS has to be such that with a mere months notice be able to deploy. This means that the system has to be rather compact and integrated, with no or little auxiliary equipment stored elsewhere outside the unit itself, in order for personnel to quickly be able to send it off. Also, for increased flexibility and availability, the MSPS has to be able to be transported by air, sea and land. Containers are suitable for housing equipment of this kind and can be transported easily. In the table below are some examples of requirements on the MSPS regarding transport and handling (Tab.2).

<table>
<thead>
<tr>
<th>Shock</th>
<th>Half sine 30 m/s², 50 ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>3 g (in direction of motion)</td>
</tr>
<tr>
<td></td>
<td>3 g (vertical)</td>
</tr>
<tr>
<td>Inclination</td>
<td>30° in any direction without fluid leaking (not in operation)</td>
</tr>
<tr>
<td>Container</td>
<td>20 ft (2438 x 2438 x 6038 mm³)</td>
</tr>
<tr>
<td></td>
<td>15 t maximum</td>
</tr>
<tr>
<td></td>
<td>ISO 668</td>
</tr>
<tr>
<td></td>
<td>ISO 6346 (labels and markings)</td>
</tr>
<tr>
<td>Load Exchange Frame</td>
<td>SS3659</td>
</tr>
</tbody>
</table>

Tab.2: Example of requirements relating to transport and handling

2.2.2 Environment
The vast operational area, as already mentioned, encompasses large climatic variations, e.g. temperature, humidity, rain and snow - a portable roof, with an angle of 15°, can be useful for long-term outdoor storage or stationary use. Also sand and dust have to be taken into account. While writing this paper Hitzinger is preparing a desert-kit with sand and dust filters etc, to accompany the MSPS.

Then there is also the issue of the working environment. Noise has to be minimized as it can make working alongside the MSPS intolerable. Also there is the risk that it can disturb the surroundings, be they ships or perhaps even a residential area. This also sets demands on the exhaust system. An exhaust bend and pipe (minimum 10 m) are required to channel the exhaust away from sensitive spots.

The table below states some of the environmental requirements (Tab.3).

<table>
<thead>
<tr>
<th>Environment</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMC</td>
<td>MIL-STD 461 E</td>
</tr>
<tr>
<td>Noise</td>
<td>80 dBA at 100 % load</td>
</tr>
<tr>
<td>Heat</td>
<td>+ 50 °C</td>
</tr>
<tr>
<td>Cold</td>
<td>- 40 °C</td>
</tr>
<tr>
<td>Humidity</td>
<td>100 % maximum relative humidity</td>
</tr>
<tr>
<td>Rain</td>
<td>50 mm/h</td>
</tr>
<tr>
<td>Snow</td>
<td>500 mm/h</td>
</tr>
</tbody>
</table>

Tab.3: Environmental requirements
2.3 Electrical Requirements

From the functional requirements, mentioned in 2.1.1, it can be deduced that the following electrical outputs are needed (Tab.4).

<table>
<thead>
<tr>
<th>Mode</th>
<th>Output</th>
<th>Voltage</th>
<th>Current</th>
<th>Mode</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>3 x 400 V AC</td>
<td>125 A</td>
<td>Continuous</td>
<td>To the submarine</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>3 x 400 V AC</td>
<td>63 A, 2 x 32 A</td>
<td>Intermittent</td>
<td>Common use on land</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>385 V DC</td>
<td>300 A</td>
<td>Continuous</td>
<td>To the submarine, voltage regulated</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>420 – 470 V DC</td>
<td>0 – 300 A, 0 – 14 h</td>
<td>Continuous</td>
<td>To the submarine, current regulated</td>
</tr>
</tbody>
</table>

Tab.4: MSPS electrical outputs

Output A supplies the submarine’s hotel load, which mainly consumes AC. The hotel load can also be fed from DC-output C, hence the onboard inverters have to be used. Output B is for the auxiliary equipment, which includes for instance spare parts containers and the liquid oxygen pump for refuelling the submarine’s Stirling system. Output D is for the final of the three-stage battery charging.

Estimated power requirements can be seen in Tab.5.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Output</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>50 kVA</td>
</tr>
<tr>
<td>2</td>
<td>A + B</td>
<td>180 kVA</td>
</tr>
<tr>
<td>3</td>
<td>B + C</td>
<td>210 kVA</td>
</tr>
<tr>
<td>4</td>
<td>B + D</td>
<td>230 kVA</td>
</tr>
<tr>
<td>5</td>
<td>B + C + D</td>
<td>350 kVA</td>
</tr>
<tr>
<td>6</td>
<td>C + D</td>
<td>260 kVA</td>
</tr>
</tbody>
</table>

Tab.5: Estimated power requirements

In mode 1 the submarine can be unmanned, relieving the crew for recreation. Mode 6 is the dimensioning criteria for the prime mover of the MSPS, although it will only occur rarely.

3 Realisation

3.1 Background

In spring 2003 Hitzinger GmbH received a tender enquiry regarding MSPS from FMV. This enquiry contained detailed technical and commercial requirements and functional descriptions.

Rotary Uninterruptible Power Supply (UPS) is one of Hitzinger’s core competences and this provides the base for a wide range of products. With Hitzinger’s knowledge and worldwide experience of UPS-systems it seemed that MSPS would be an ideal undertaking.

Combining existing products and solutions, including our state-of-the-art control and monitoring system, Powercon, allowed us to come with an all-in-one design, taking into account the following aspects:

- EMC/ EMP
- Shock and vibration during transport
- High ambient temperatures and humidity
- Cold temperature conditions
- Logistics
- Safety.

3.2 Design

3.2.1 System Overview

Fig.1 depicts a one-line diagram of the electrical system. The MSPS can be operated in two distinct modes.

- **Mains mode**: active power is provided from a power network.
- **Autonomous mode**: no power from the mains or no mains with substantial capability is available.

In both modes, the AC- and the two independent DC-supplies are available simultaneously.

Additionally a bypass circuit is installed in order to route the mains from the container’s input to the AC- load without need of external wiring while the MSPS is switched off.

The system layout is based on a mono- shaft-double- alternator machine. In mains mode it serves as a rotary converter and in autonomous mode as two individual alternators.

The diesel engine is equipped with a clutch allowing the electrical machines to run at synchronous speed while the diesel engine is at stand still. An additional start up choke facilitates while in mains mode in order to speed up the converter to synchronous speed without the aid of the diesel engine.
3.2.2 Mains Mode
In mains mode the first synchronous machine (M/G) serves as a motor driving the second synchronous machine (G-YY), which feeds the two controlled rectifiers. Together with the choke the M/G also functions as a power conditioner.

G-YY is equipped with two three-phase stator windings at different voltage levels isolated from each other. These windings supply the DC-outputs C and D via the controlled rectifiers. The active power for the DC- units is provided from the mains via M/G and G-YY generates the reactive power. No harmonics, surges or other interferences caused by the DC- units are inducted to the mains network.

3.2.3 Autonomous Mode
In autonomous operation the clutch engages cranking the diesel engine, which accelerates the electrical machines to nominal speed. The output voltages of M/G and G-YY are controlled independently, taking into account their respective loads.

3.2.4 Integration
The entire system is integrated in a 20 ft container designed according to ISO 668 (Fig.2). It functions as both mechanical protection and climatic shelter for the equipment. It is thermally insulated and can contain internal leakage of fuel, water and other liquids.

Some key features incorporated in the design are:

- Fuel tank for 15h operation at full load
- Cable drum for storing relevant cables
- Cable gangway that can manage up to 10 m tide
- Access ladder
- Remote indication panel for monitoring in the submarine
- Powercon
- Compartments for accessories and spare parts
- Portable roof that can easily be mounted on the MSPS for long-term storage
- Load Exchange frame to enable easy transport.

3.3 Key Components

3.3.1 Diesel Engine
The diesel engine used in the MSPS is a four-cylinder, in line four-stroke, turbo charged, air-to-air intercooled, direct injection Volvo TAD 1634 GE. The water-cooled engine is equipped a starter motor powered by batteries, 24 V DC, charged by an alternator. Speed control is done electronically and the engine is protected against over speed as well as low oil pressure and high water temperature.

3.3.2 Motor/Alternator (M/G)
M/G is a brushless, self-excited, stationary-field, three phase synchronous machine and when running as an alternator it generates a voltage of 400/231 V AC, 50Hz.

Stator and rotor cores are made of laminated magnetic sheet steel. The rotor is shrunk onto the shaft and is equipped with a damper winding for unbalanced loads. The rotor coils are secured against centrifugal forces by wound supports.

The winding insulation is made of non-hygroscopic, non-tracking material and can withstand severe thermal stressing. All windings are vacuum pressure impregnated with single-component resin.

3.3.3 Converters (G-YY)
One of the windings produces 286/165 V AC 75 Hz that is rectified to 350 V DC (output C) whereas the other gives a voltage of 362/209 V AC 75 Hz that in turn is rectified to 420-470 V DC. The thyristor rectifiers are mounted on the shaft end. This double-winding converter is in all other respects of the same design as the motor/alternator.

3.3.4 Clutch
An electrically actuated single-disc clutch transmits torque through friction between the rotor and armature, both equipped with special linings to enhance contact. If the clutch is de-energized, the armature disc is pushed towards the driving disc by the force of the diaphragm, releasing the clutch.
4 Conclusions

The Factory Acceptance Test (FAT) has been successfully concluded (Fig.3 and 4) and the MSPS is now at Muskö Naval Base outside Stockholm, Sweden, where it awaits commissioning before becoming operational.

This Austrian-Swedish cooperation between Hitzinger and FMV has resulted in a fine product that should prove to be useful for the submariners of the RSwN. The compact integrated design makes it easy to transport anywhere in the world - be it by road, land or sea – in order to accommodate the electrical needs of the submarine while in port.

Fig.1: One-line diagram of the MSPS
Fig. 2: Drawings of the MSPS
Fig. 3 and 4: Photographs taken during the FAT