Flexibility Demands for Propulsion Systems

Christian Müller (christian.chr.mueller@siemens.com)
Senior Sales Manager Navy Vessels, Siemens Gas & Power GmbH & Co. KG, Hamburg, Germany

Abstract — The Permasyn® Technology, well known for decades, is the most often sold permanent magnet propulsion motor system for submarines to date. This article deals with the development path in the early 80s, it will give an insight into this technology and the design principles and will finally look into the current development efforts for upgrading the technology to meet future demands. In the market a trend is obvious: navies no longer opt for discrete indigenous submarine designs (with the well-known advantages and disadvantages) but partner with other navies to follow the idea of "Pooling and Sharing". Similar submarine designs also used by other partner navies result in new aspects and require extended technical features for the electric systems installed.

1 Development path of the Permasyn®

Beginning in the late 1950s Siemens restarted its efforts within submarine technology and since then has equipped more than 175 submarines with propulsion motors and other equipment such as power distribution, automation and fuel cell modules for AIP. But over the years the requirements for submarine propulsion have grown and so it became time to switch from the proven and mature DC propulsion to a very new and promising technology that is even better especially in terms of signatures, reliability and efficiency. In the early 80s Siemens started to work on permanent magnet technology as the core technology for new submarine propulsion. The first prototype was installed on board a surface vessel called *Schwedeneck* in the mid-80s; though the inverter modules are not installed within the motor, the inverter modules and the motor itself build one physical compartment so that there is no need for a relatively long cable connection between the motor and some external inverter cabinets, as we often find today when we take a look at some other permanent magnet propulsion systems for submarines.

The absence of these cable connections of course goes along with a minimization of the magnetic field and therefore minimizes the magnetic signatures of the propulsion system already by design.

Fig. 1. Production of Permasyn® Motors

This first Permasyn® motor had a power output of around 1 MW and excelled all requirements to such an extent that it was decided to go on and develop an improved motor especially for submarine applications. This motor was even more compact compared to the 1st generation Permasyn® because the inverter modules were now integrated into the motor itself. This second generation of Siemens Permasyn® motors, which has been in operation on ten Class 212A submarines of the German and Italian Navy for nearly 20 years now, is of non-magnetic design and has a power output of around 2 MW which doubles the power output compared to the 1st generation Permasyn® motor. During the time of tests and trials of this new Permasyn® motor Siemens was asked to upscale this motor to the size of around 4 MW but in a ferromagnetic design.

Though there was no field experience with the 2 MW Permasyn® motor on board submarines at that time, to minimize risks in this "upscaling" Siemens relied on the experience gained during the development of the 2 MW

Permasyn® motor and on the structured development process which is mandatory for every new motor or generator development, whether for submarine applications or even for such sensitive areas like (nuclear) power plants. Because of this structured approach Siemens was in a position to deliver the first 4 MW Permasyn® motor of the 3rd generation in 2003 within the allotted time and budget. To date Siemens has received 38 orders in total for this Permasyn® propulsion concept from countries like Greece, Turkey, South Korea, Portugal, Italy, Germany and others.

Since its introduction the 4 MW Permasyn® motor has gone through some major innovation projects. One concerned the innovation of the inverter modules which brought them from a partly analogue design into the full digital world. Innovations like combination of the Speed Monitoring Computer (SMC) with the Automatic Propulsion Controller (APC) reduce system complexity and save space. Many other improvements have been made during recent years to keep the concept up to date. Special requirements by end customers sometimes also led to smaller changes. After almost 20 years of operation Siemens' experience is that owners demand much more flexible answers to their requirements. Changes in boat design for size or speed directly affect the necessary propulsion power. This also applies during the development process of the boat by the yard. Up to now, the two existing Permasyn® designs are specified in relatively tight power ranges close to their nominal power output. An unrivaled technological lead, but with limited flexibility. In the past electrical systems were designed and optimized for one characteristic submarine type without - or only to a very limited extent - considering variants. Most of the existing technologies, such as propulsion and AIP fuel cell systems, have been developed and introduced up to two decades ago based on long-term successful experience.

Using the same submarine design in different navies does not necessarily imply waiving operational, geographical or national specific demands. A basic submarine type might have different peculiarities considering these specific demands resulting in models / versions differentiating in propulsion performance, operational and technical features. With the above-mentioned trend an increased demand for adaptability of essential components seems to be essential to avoid costly and time-consuming developments. Hence several innovations addressing different fields of applications were initiated during recent years. Flexibility in layout and design of a drive system will allow easy adaptation to varying performance demands in underwater propulsion. Uniform components are the basis for drive platforms covering a wide power range. Pre-defined elements will allow rapid construction and faster project execution. Changing demand during final design stages will not lead to a drawback in the timeline. Lifecycle costs are another driver for further development. Submarines are usually in operation for 40+ years. Phase out cycles for electronic equipment are shrinking year by year. As the Permasyn® technology incorporates several semiconductor parts, the effort to limit obsolescence costs will rise as the concept becomes older. With the flexible Permasyn® concept, Siemens follows the idea of limiting the amount of different parts by increasing flexibility of the system. By limiting the total amount of parts incorporated in the system the future logistic efforts (and therefore costs) will be limited as well. Further upgrades within the Permasyn® evo design due to new technological developments can be much more easily implemented into all different sizes in later motor systems. This will reduce the time to market for future motor systems.

2 Improved Flexibility with consistently proven technology

The design principles for a Permasyn® propulsion system have basically not changed since the first generation. The new flexible Permasyn® (with the extension "evo" for evolutionary) is designed in such a way that the increasing requirements concerning

- Signatures
- Reliability and availability
- High efficiency
- Maintainability
- Modularity

are clearly fulfilled. Reliability and availability of the Permasyn® motor is achieved by a very high degree of redundancy at multiple levels (e.g. cooling, control and feeding). The extremely low signatures in acoustics, thermals and magnetics are achieved by the special design incorporating the inverter modules in the motor housing or a closed cooling water circuit. The technology has always been improved now in more than 60 years of research and innovation. When designing the Permasyn® motor high emphasis was put on minimizing losses, especially within the rotor, the windings and the inverter modules. By doing this very high efficiency was achieved especially in partial load conditions because this is essential for a maximized stay in the operation area. Along with this approach towards a flexible drive design the development of a new converter concept as well as predefined motor designs has been initiated to fulfill challenging demands in a wide range of power and speed. The conceptual challenge is to improve all relevant parameters at the same time, like for example to increase power output by increasing silent mode acoustic noise performance and limiting the weight. To find the utmost possible balance of all requirements, Siemens uses its Quality Function Deployment evaluation process (QFD), where advantages and disadvantages of many different electrical and mechanical topologies are weighed against each other. In addition, relevant parameters like switching frequencies, stator currents or system voltages are being evaluated in parallel. As a result, a decision matrix is the starting point for further detailed R&D activities. This process ensures a superior technical

solution upgrade by keeping the well-established level of quality.
Result of all these activities is a series of 3 different basic motor diameters with three to four different lengths each. With some overlapping between the different diameters, nearly all necessary speed / power configurations with variation in torque of 10% between the individual machines can be achieved.

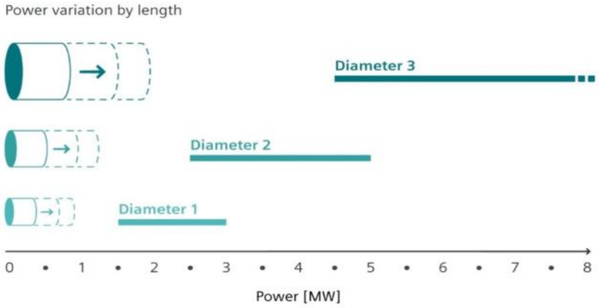

Fig. 2. Overlapping power ranges in the Permasyn® evo design

The core element in the Permasyn® concept is the inverter integrated into the motor housing. Optimized for operation with the stator winding it is the limiting element in the total construction. The focus was put on equality of structure enabling similar basic components, arranged in a modular way according to the necessary current needs of the stator winding. The nominal current within the scope can be nearly constant. In addition, the required DC voltage for the individual machines does not depend on the power demand. This fact allows the use of one standardized inverter for this wide range of different power outputs. In the case of the largest diameter, the mechanical construction allows a higher amount of inverter modules of the same type to be used, creating a higher number of strings within the machine.

Fig. 3. Similar inverter module for different machines

3 Conclusion

During recent years it became obvious that new projects usually require upgrades to the existing motor concepts, which usually created a severe impact in construction. These facts have an impact on time, resources, additional efforts in obsolescence management and in the end lead to additional costs. A more flexible concept will help us all to offer solutions that meet the individual demands of different customers while limiting future costs.
This new approach will again extend the Permasyn® family.