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Design Concept of Propulsion System for Nuclear Operated Vessel Adventurer

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1. Introduction

This work centers about advantages of nuclear power propulsion with various naval applications such as military surface ship, submarine, and ice breaker. These applications are required to work for a long periods of time on the ocean, where supply of fuel is complicated and sometimes impracticable. A preliminary design concept is presented of the propulsion system for the Nuclear Operated Vessel Adventurer (NOVA). NOVA employs the Battery Omnibus Reactor Integral System (BORIS), a small fast integral reactor cooled by natural circulation and the Modular Optimized Brayton Integral System (MOBIS), a supercritical carbon dioxide (SCO_2) driven Brayton cycle, as power converter to the Naval Application Vessel Integral System (NAVIS).

2. System Design for NOVA

NOVA is designed to satisfy the requirement of a compact, simple, safe and innovative integral fast reactor system [1, 2]. NOVA is powered by BORIS. BORIS is designed to generate 10 MWe for at least twenty consecutive years without refueling, and to meet the Generation IV Nuclear Energy System goals of sustainability, safety, reliability and economics. NOVA is schematically shown in Fig. 1.

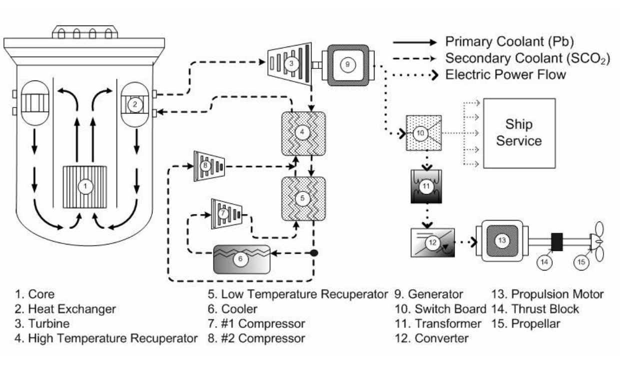

Fig. 1. General arrangement of NOVA

2.1 Primary System

The reactor holds a total of 757 fuel rods without assemblies. The active core height and the core diameter are 0.8 m and 0.9828 m, respectively. In the primary system BORIS adopts an integrated heat exchanger system operated by natural circulation of Pb coolant without pumps to realize a compact reactor. BORIS utilizes proliferation-resistant nitride fuel with a high thermal conductivity and open cartridge type core without individual subassemblies.

2.2 Secondary System

NAVIS has two SCO_2 turbine generators powered by MOBIS. MOBIS consists of a 14.7 MW_{th} turbine, a 31.6 MW_{th} high temperature recuperator (HTR), a 12.6 MW_{th} low temperature recuperator (LTR), a 10.2 MW_{th} cooler, and 2.0 and 2.6 MW_{th} compressors. The MOBIS energy conversion efficiency was calculated to be 45%.

2.3 Propulsion System

NAVIS comprises the generating and distributing system, power electronic converter and the High Temperature Superconductor (HTS) motor as shown in Fig. 2. The power electronic converter consists of two converters, i.e. a rectifier and an inverter. The rectifier functions to convert the alternating current (AC) of output transformer to direct current (DC). The inverter has the opposite function with the rectifier. It converts DC to AC. The rectifier and inverter are shown in Fig. 3.

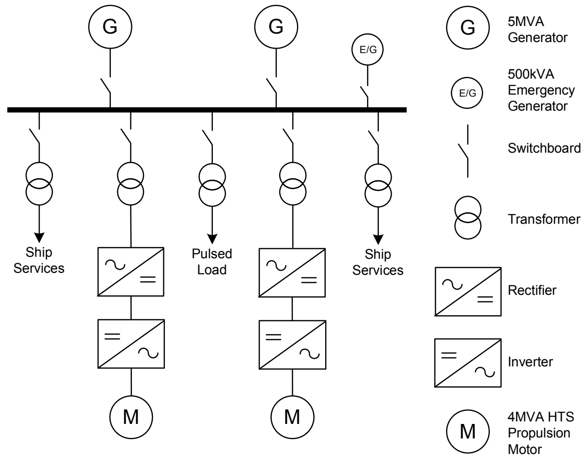

Fig. 2. Single line diagram of NAVIS

As shown in Fig. 3, a load-commutated type rectifier and an auto-sequentially commutated type inverter are chosen as the control component of the propulsion motor. The motor speed is controlled by changing the inverter output current frequency. The correlation of frequency and speed of the motor can be written as

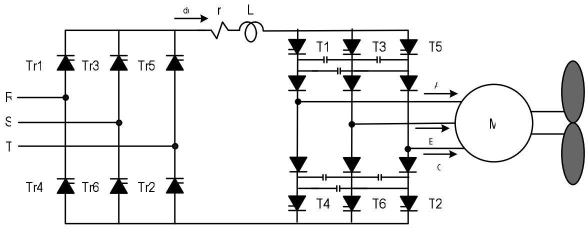

Fig. 3. Power electronic converter of NAVIS

$$\text{revolution per minute (rpm)} = \frac{120f}{p} \tag{1}$$

where *f* is frequency and *p* is number of motor poles. To generate a variable frequency, the inverter is controlled by using gate signals that are based upon the cosine comparator firing control strategy [3]. Particularly, they are defined as

$$\begin{aligned} c_a(\theta) &= \cos(\theta) \\ c_b(\theta) &= \cos(\theta - 2\pi/3) \\ c_c(\theta) &= \cos(\theta + 2\pi/3) \end{aligned} \tag{2}$$

The switching control strategy for the inverter is

$$\begin{aligned} T_1 &: (c_c(\theta) < c_a(\theta)) \,\&\, (c_c(\theta) < c_b(\theta)) \\ T_2 &: (c_a(\theta) > c_b(\theta)) \,\&\, (c_a(\theta) > c_c(\theta)) \\ T_3 &: (c_b(\theta) < c_a(\theta)) \,\&\, (c_b(\theta) < c_c(\theta)) \\ T_4 &: (c_c(\theta) > c_a(\theta)) \,\&\, (c_c(\theta) > c_b(\theta)) \\ T_5 &: (c_a(\theta) < c_b(\theta)) \,\&\, (c_a(\theta) < c_c(\theta)) \\ T_6 &: (c_b(\theta) > c_a(\theta)) \,\&\, (c_b(\theta) > c_c(\theta)) \end{aligned} \tag{3}$$

where θ is the rotor position of motor. By using this control strategy, the Matlab simulation results of the rectifier output current and inverter output currents are shown in Fig. 4.

The HTS motor is chosen as the propulsion motor of NAVIS because it allows a significant size reduction and efficiency improvement, so that a great deal of costs can be recouped. The high magnetic field produced by the superconducting field windings enables an air core construction without core losses, replacing the conventional iron core and cooper field winding [4].

3. Conclusion

A design concept of the propulsion system for NOVA has been presented. NOVA employs BORIS, the small fast integral reactor cooled by natural circulation, and MOBIS, the SCO_2 Brayton cycle, as power converter for NAVIS.

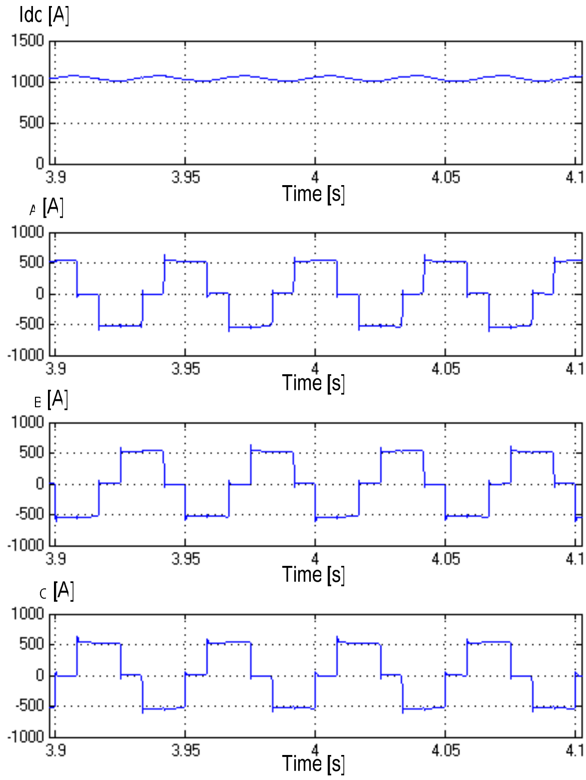

Fig. 4. Simulation results

ACKNOWLEDGEMENTS

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