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The conception of the use of multi-level inverters in the shipping shaft generator systems of high power

Koncepcja wykorzystania falowników wielopoziomowych w układach z okrętową prądnicą wałową dużej mocy

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Key words: shaft generator, stability of frequency, multi-level inverter

Abstract
The fundamental problem of using the shaft generators of high power in the shipping systems is bound up with the stability of frequency. Electronic systems used nowadays are based on the thyristor inverters which entails vices of such solutions. The article presents the conception of the use of multi-level inverters built on the basis of fully controllable valves (transistors IGBT).This solution eliminates the defects of thyristor inverters.

Słowa kluczowe: prądnica wałowa, stabilizacja częstotliwości, falownik wielopoziomowy

Abstrakt
Zasadniczy problem stosowania w systemach okrętowych prądnic wałowych dużej mocy związany jest ze stabilizacją częstotliwości. Stosowane obecnie układy energoelektroniczne opierają się na wykorzystaniu falowników tyrystorowych, które implikują wady takich rozwiązań. W artykule przedstawiono koncepcję wykorzystania falowników wielopoziomowych, zbudowanych w oparciu o zawory w pełni sterowalne (tranzystory IGBT), które pozbawione są wad falowników tyrystorowych.

Introduction

The development of the marine transport results in increasing ship's saturation with different electrical devices. It effects in the growth of share of the electricity generation costs in the general ship's operating costs. Having that in mind, we should aim at reducing the costs of the electricity generation.

Along with the increase of the high-power receivers number (e.g. thrusters, ballast pumps) in the marine systems, the demand for the power plants of the power ranging from a few to several megawatts raises.

The diesel internal combustion engines or steam turbines are most frequently used as a drive in the power generating systems. Using shaft generators is rare despite of the common belief in the high profitability of such a solution.

In comparison to the traditional methods, applying solutions with the shaft generator provides more benefits:

- reduction of lubricating oil consumption,
- reduction of expenditures on the maintenance and repairs,
- reduction of the noise in the ship power plant.

The main reason for the lack of the common usage of the shaft generator is the problem of stabilizing frequency and voltage at speed change of the shaft bolt, resulting from the ship's manoeuvring or surfacing of the propeller on the wavy sea. Electronic controls of the main engine (SG) revolutions would be able to ensure stability of the bolt revolutions during the stormy weather, but such a possibility is not used for the mechanical reasons (high load of SG).

Maintaining fixed frequency of generated voltage when changing the main engine speed can be obtained in the mechanical and electromechanical systems such as: con speed planetary gear, electromechanical converter [1], hydraulic motor, inductive clutch [2] and in power electronic systems.

Classical power electronics systems in the systems with the shaft generator

Currently, the integrated power electronic systems with the high power shaft generators are built on the basis of the thyristors converters, where the thyristor inverter is controlled by the line voltage (external commutation). Internal commutation inverters are not used because of the technological problems and significant costs. Schematic diagram of the shaft generator with the thyristors converter is shown in figure 1.

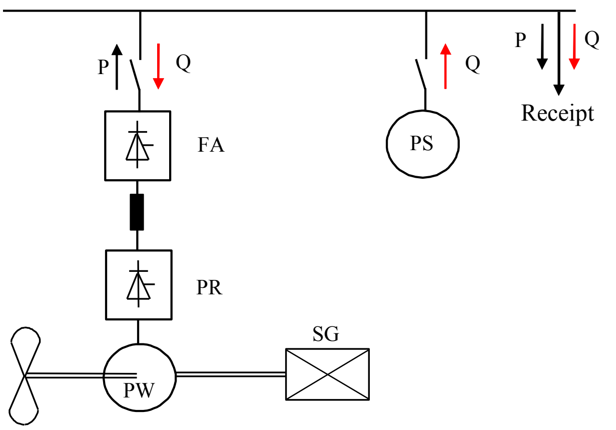

Fig. 1. Scheme of installation of shaft generator and thyristors inverter; FA – inverter, PR – rectifier, PW – shaft generator, PS – synchronic compensator

Rys. 1. Schemat instalacji prądnicy wałowej z przekształtnikiem tyrystorowym; FA – falownik, PR – prostownik, PW – prądnica wałowa, PS – kompensator synchroniczny

Changing the switching angle of the thyristor of the grid inverter (FA) prompts the alteration of the phase shift between the current and the output voltage of the inverter. In practice, the inverter operates at a constant triggering angle (approx. 120°), what is associated with a considerable amount of reactive power taken from the network.

The source of the reactive power is the synchronous machine PS, which provides the reactive power needed for the commutation processes of the inverter, as well as for the inductive load (cage motors).

The line voltage is regulated by a voltage compensator regulator PS [1]. When the voltage drops, the compensator's excitation current increases, and thereby the output reactive power and the line voltage increase as well. The network frequency is adjusted using the voltage regulator of the generator shaft.

Increasing the excitation current of the shaft generator raises the active power given back to the network by the inverter, resulting in an growth in the turnover of the synchronous compensator. The network frequency increases in proportion to the frequency of the compensator.

The system of the shaft generator described is currently being produced by the most prestigious world companies producing marine generating sets (ABB, SAM Electronics and others). Such a solution that makes it possible to keep the desired frequency and voltage is not flawless because:

- it is necessary to work in a synchronous compensator system, which increases the operating costs (the cost of synchronous machine, maintenance and repairs) and because of its size it takes a lot of space in the ship power plant;
- high line voltage distortion caused by the work of the thyristors converter [3] (determined by the THD rate, whose value, according to PRS, cannot exceed 10%).

Multi-level inverters in the systems with a ship's high-power shaft generator

In the power systems not bigger than 2 MW, the flaws of the thyristor converters listed above are largely eliminated by means of the fully controllable transistor semiconductor devices (IGBT transistors).

The rapid development of semiconductor technology is related to the fact that the capacity of the transistor-based circuits will only increase. Currently, in the high-powered systems (over 2 MW) there are SCR thyristors used for the technological reasons. Inverters built on the basis of thyristors have virtually no restrictions as for the voltage class. The producers of the power electronic technologies create the thyristors for the voltage of 30 kV and intensity up to 5 kA.

In the solution for the high-powered systems proposed in this paper, the thyristors have been replaced by the IGBT transistors due to the suitable topology of the converter.

The power of the classical two-level transistor converters built on the basis of IGBT transistors is limited by the technological considerations. IGBT transistors protect the currents' commutation up to 1.8 kA and are built for the maximum voltage to 4.5 kV at a much higher thyristors' parameters (current commutation < 5 kA, voltage commutation < 30 kV).

The application of the topology of three or multi-level inverters for the transistors' systems reduces the requirements for the connectors' voltage class. First solutions consisted in adding up the voltage of several inverters by means of special summarizing transformers [4]. Such systems had significant drawbacks: a very large size and high cost of the system. Recently, the summarizing transformers have been eliminated in the multi-level inverter systems, and the neutral-point-clamped inverter is the most popular one.

NPC inverter topology is based on the separation of the intermediate circuit voltage into three or more steps using a capacitive divider. Zero-voltage power feed 'N' is the point of reference for the output phase voltages. Figure 2 presents the topology of the single-phase, five-level NPC inverter.

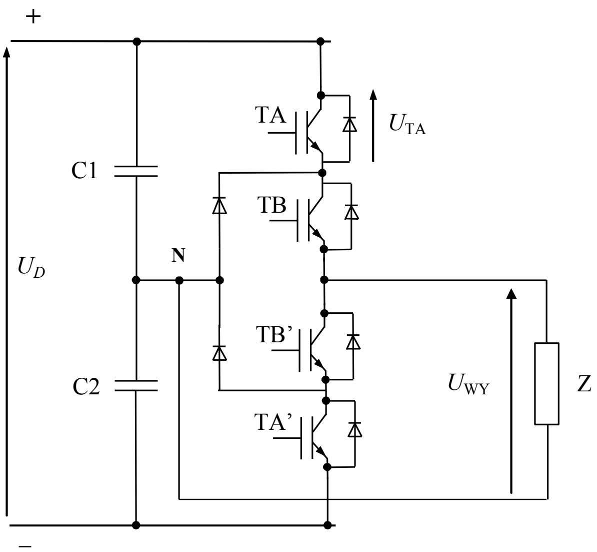

Fig. 2. The topology of the single-phase five-level inverter NPC

Rys. 2. Topologia falownika jednofazowego pięciopoziomowego NPC

The output voltage can be shaped by means of five voltages of the constant circuit:

$$\pm U_D,\ \ \pm\frac{1}{2}U_D \text{ and } 0.$$

Figures 3a and b present the waveforms of the output voltages and the loads in the seven-level and classical (two-level) inverter system obtained in the simulation studies. At the same DC circuit voltage, the voltage of a single valve is smaller for a seven-level inverter than for a classical one.

The three-phase three-wire inverter consists of three single-phase branches linked to each other in parallel (Fig. 4). The proposed inverter topology allows for doubling the voltage class of the inverter

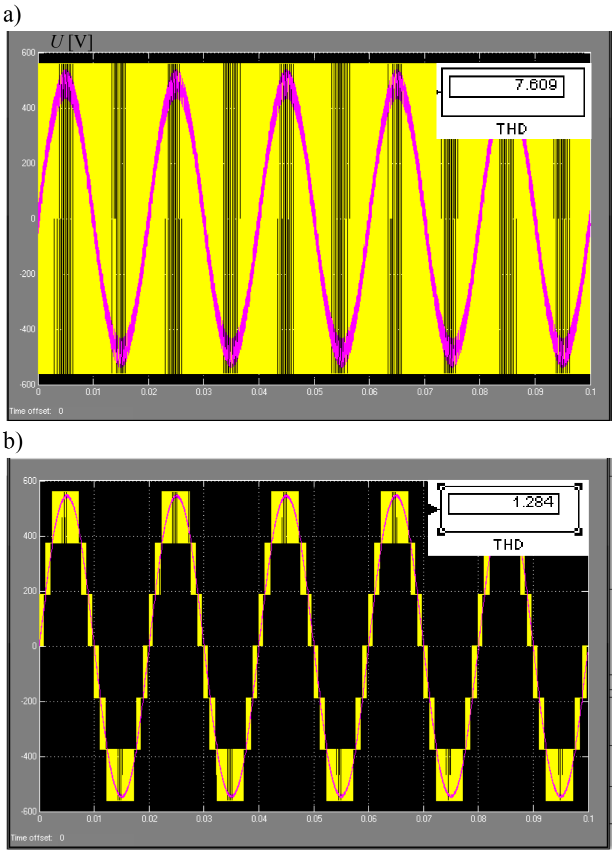

Fig. 3. The courses of voltage outputs (obtain in simulations) of; a) single-phase two-level classical inverter, b) single-phase seven-level inverter

Rys. 3. Przebiegi napięcia (uzyskane symulacyjnie); a) klasycznego falownika jednofazowego dwupoziomowego, b) falownika jednofazowego siedmiopoziomowego

valves, and thus the use of inverter to work with the high power shaft generators. This inverter (built on a fully controllable valves – IGBT transistors) is both a source of active and reactive power. This feature allows us to eliminate a synchronous compensator from the shaft generator system (Fig. 5).

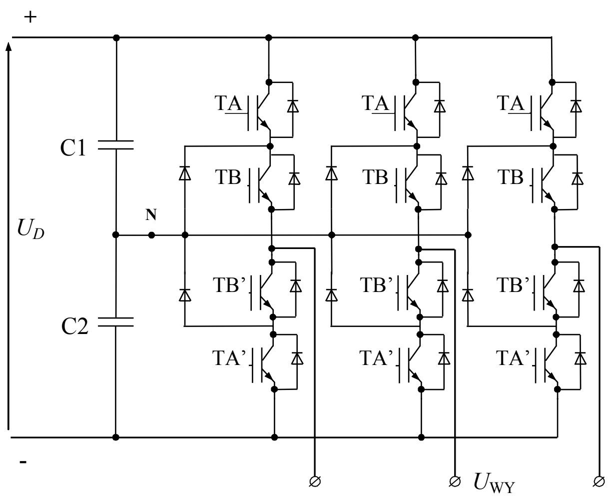

Fig. 4. The topology of three-phase five-level inverter NPC

Rys.4. Topologia falownika trójfazowego pięciopoziomowego NPC

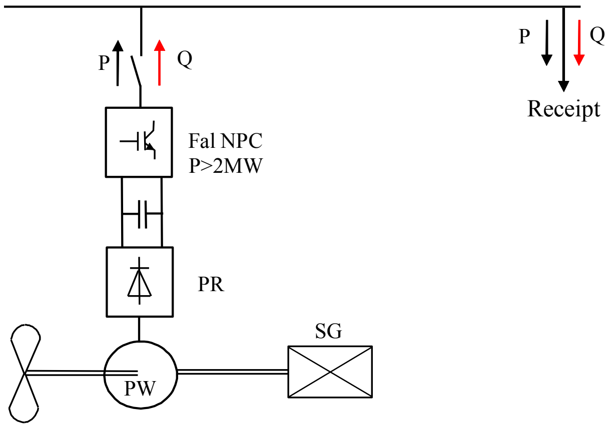

Fig. 5. Scheme of installation of shaft generator and multi--level transistor inverter; FalNPC – multi-level inverter, PR – rectifier, PW – shaft generator, PS – synchronic compensator
Rys. 5. Schemat instalacji prądnicy wałowej z falownikiem wielopoziomowym tranzystorowym; Fal NPC – falownik wielopoziomowy NPC, PR – prostownik, PW – prądnica wałowa, PS – kompensator synchroniczny

An important advantage of the multi-level inverters, comparing with the classical inverters (two-level), is reducing the derivative of the output current of the inverter, and thereby improving the quality of output waveforms (voltages and currents of the network). THD factor (Fig. 3a and b), which with the use of the thyristor inverters was close to an acceptable (by PRS < 10%), is being reduced now.

Along with the emergence of the fully controllable power elements (IGBT transistors), a major expansion of electronic control systems has taken place. Developing techniques for the microprocessors (DSP) have allowed for the realization of more complex algorithms. Design possibilities have also increased by using FPGA programmable devices.

The modern microprocessor technologies allow for the choice of the steering algorithms that clearly improve the quality of the voltages and currents generated by the inverter [5, 6].

There are many methods of controlling the three-phase NPC inverter (Fig. 4) that can be used in the shaft generator system. The most frequently used method of control is SVM (Space Vector Modulation) which is commonly used for the conventional two-level inverters. The number of combinations of the transistors' switches for the three-phase five-level NPC inverter is 27, and it can provide 27 output voltage vectors. The control lies in choosing the proper output voltage vector of the inverter in a given time to obtain the required voltage vector.

The multi-level inverters' topologies are characterized by a large number of the output voltages vectors (a combination of the transistors' switches), and thus there are many algorithms for the selection of these vectors [4].

Conclusions

The main difficulty in the application of the linear generators in the marine systems is to keep a constant frequency and voltage when the shaft speed changes.

One way to stabilize the voltage and frequency in the currently used high-powered shaft generators systems are the thyristor-based power electronic systems, which are not devoid of the drawbacks.

The proposed concept of using multi-level inverters made up of the fully controllable elements in the high-powered shaft generators' systems lets us eliminate the shortcomings of the currently used solutions.

The continuous development of the power electronic technology will contribute to the fact that, because of its advantages, the use of the shaft generator will become more common in the shipbuilding.

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