Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2012, 29(101) pp. 146–150 **2012, 29(101) s. 146–150**

Initial assumption to the mathematical model of the marine elektromagnetic system with the shaft-generator

Założenia wstępne do opisu modelu matematycznego okrętowego systemu elektroenergetycznego z prądnicą wałową

Bogdan Nienartowicz

Maritime University of Szczecin, Institut of Marine Electrical Engineering and Vessel Automation
Akademia Morska w Szczecinie, Instytut Elektrotechniki i Automatyki Okrętowej
70-500 Szczecin, ul. Wały Chrobrego 1/2, e-mail: b.nienartowicz@am.szczecin.pl

Key words: power plant, electric power station, dynamics, mathematical model, electromagnetic system, shaft generator

Abstract
The electromagnetic systems with the shaft-generator are being widely used in marine engineering, nowadays. Simulating investigations of transitory electromagnetic processes in such system require complex mathematical model studies to describe properly the dynamics of the containing objects. The following article is the first part of the final description of the mathematical model of marine electromagnetic system with the shaft-generator. It contains both the discussion about external factors affecting the electromagnetic processes in such system and initial assumptions that should be met by the proposed mathematical model.

Słowa kluczowe: siłownia okrętowa, elektrownia okrętowa, dynamika, model matematyczny, system elektroenergetyczny, prądnica wałowa

Abstrakt
Współczesna technika okrętowa szeroko stosuje systemy elektroenergetyczne z prądnicą wałową. Badania symulacyjne procesów przejściowych elektromagnetycznych w takim systemie wymagają opracowania kompleksowego modelu matematycznego, opisującego dynamikę obiektów w nim zawartych. Poniższy artykuł jest pierwszą częścią docelowego, końcowego opisu matematycznego modelu okrętowego systemu elektroenergetycznego z prądnicą wałową. Omawia się w nim uwarunkowania zewnętrzne, wpływające na przebieg procesów elektromagnetycznych w systemie oraz podaje się przyjęte założenia wyjściowe, które powinny być spełnione przez proponowany model matematyczny.

Introduction

Water transport is considered to be cost-effective. Electric energy takes the considerable part among various factors influencing the cost of the ship's exploitation. There is simply dependence between the quantity of electric receivers and both installed electric power and the quantity of current generators included in the ship's power plant.

Modern ships are characterized by the high stage of installed electric power. The growth in amount of the ship's electrical devices, in turn, affects the range and the automation stage of the power plant [1, 2]. It means sharper requirements for quality and costs of the electro-energy.

Electric energy production cost on modern ships, especially specialist, takes an increasing part of the ship's daily operating costs. That is the reason why the ship-owners are so interested in the electro-energetic systems with the shaft-generator.

Simulation studies of transitory processes in such systems become the necessity [1]. This requires creating a complex mathematical model for the whole electro-energetic system, not only for individual objects. The article presents description of the adopted methodology and requirements, which should be met by the model to obtain reliable results.

Initial assumptions

Assumptions that should be met to create useful model description:

- the structure of model must contain all the important objects that have an impact on the transitory processes in the electro-energetic system;
- model should include the influence of external conditions, i.e.: rolling of the sea, wind and it's direction, ship's transverse and longitudinal swinging, ship's propeller ascending. This results in the change of the rotary speed of the Main Engine (*ME*);
- created model should be useful for ship with the adjusting propeller, as well as non-adjusting propeller;
- adoption of proper description methods of dynamic conditions of the principal components of the system, i.e.: Main Engine, auxiliary engines (*AE*); ship's power station and electric receipts with the division on static and dynamic receiver;
- possibility to analyze working conditions of ship's power station, i.e.: lonely work or parallel work of the ship's generators in various configurations;
- model should have open structure to be able to be expanded with the additional objects or steering systems;
- and mainly it should fulfill the criterion of credibility and liability. This condition imposes the necessity of use widely recognized and proven methodology of description.

Fulfillment of above assumptions will enable the study of electromagnetic transitory processes, which result will let to approach to conditions stepping out in real ship's systems.

Specific of the work of the shaft-generator

Advantages and disadvantages of the generator shafts are well known. However, the mathematical description of the dynamics is complex due to the specific of Main Engine drive and its location in the electro-energetic system. Getting the knowledge about the dynamic processes of shaft-generator and its influence on the work of the fleet by the experiments, is not only inconvenient, but also expensive. It forces us to build:

- laboratory workstation, which research results are greatly doubtful;
- or a prototype to test it on a ship, which is expensive and risky, what it is expensive in the turn and burdened with the risk. After that, knowledge of certain symptoms is most needed at the stage of design work.

Therefore, the most purposeful is computer simulation [1], and this requires mathematical model. The shaft-generator (*SG*) is unit joining two physically different arrangements – electric net and the propulsive complex in the type-matter: Main Engine – main shaft (*MSh*) – adjustable or non-adjustable propeller.

In result, the shaft-generator subject to two principal forces:

- from the side of the electric net, because of the change of active and passive electric power;
- from the side of the drive of shaft-generator, because of the change of the resistory moment on the shipping screw, what causes the labile rotary speed of the main shaft.

The first force influences on the change of voltage of shaft-generator. The second influences both on the tension and the frequency of the electric current. Summing up, it should affirm, that the dynamics of shaft-generator depends on the dynamic properties of the propulsive complex. This in turn, subjects to the influence of the whole sequence of external factors. One can here enumerate principal influences:

- condition of the sea and strength of the wind;
- transverse and longitudinal swing of the ship;
- level of immersion of the ship and its propeller;
- periodical raising out of the propeller of the water;
- the displacement of the ship's gravity center called out by the loading etc.

The situation is being complicated by the fact, that one can't subordinate the work of the Main Engine to the exploration requirements of the shaft-generator. This results from the conditions of the safety of navigation. In effect, labile rotary speed of the main shaft causes labile frequency in the electric net, what is harmful.

Taking into account these circumstances set certain requirements for the mathematical model, which contains the description of the shaft-generator.

The choice of the type of the ship adjustable propeller or steady propeller

It is believed that the adjustable propeller system favors the use of shaft-generator. It is not so obvious. It depends on the specific solution and adopted criterion of propeller control. Propeller type selection is dictated by kind of ship and its destination (scheduled jobs). There is a considerable number of solutions of adjustable propeller systems. Generally adjustable propeller systems can be divided into:

– separate steering of the stroke of the propeller spades (*h*) and rotary speed (*n*);
– adjustment by the stroke of the propeller only ($h \neq$ const), near the stabile rotary speed (n = const);
– simultaneously program control of both parameters ($h \neq$ const; $n \neq$ const);
– automated, self-regulating systems.

While separate steering, operator gives both the parameters separately, with the support of suitable charts and diagrams, with regard to the conditions of navigation and the technical condition of the Main Engine. The last two systems from the principle enter the changes of both parameters. This results in a labile rotary speed of the main shaft. This situation is usually accompanied by a control based on the criteria:

– reaching optimum ship's speed;
– the optimum fuel consumption.

There is no doubt that, the hardest working conditions of shaft-generator take place on ship with steady propeller. This case should be considered and included in the mathematical model.

Only second type of adjustable propeller provides supportive conditions of work for the shaft-generator. This kind of steering the adjustable propeller had been chosen as the object of the description.

Principles of description of the propulsive complex

The propulsive complex contains the main motor, main-shaft and the propeller. As it had been already mentioned, rotational speed of this complex depends on operating conditions – including sea state. Decisive impact has undulation of the sea that often causes periodical propeller's raising out of the water.

It is the most difficult enforcement operating on the shaft generator because in practice it means suddenly changing working conditions of the propulsive complex – from 100% unload to 100% load. This is accompanied by a sudden, wide range change of the rotational speed of the main shaft. There is direct relationship between rotational speed of the main shaft and the frequency (*f*) of the electricity network. Rotational speed also affects the fluctuation of active power produced by the shaft generator.

The above analysis shows an important conclusion. Main engine should be described as main shaft's variable speed control object.

Such an approach avoids taking into account the impact of combustion, supplying of air and discharging exhaust gases on rotational speed of the shaft generator.

The "Woodward" UG – CTL controller had been chosen as the main shaft's rotational speed controller. It is one-parameter controller with rigid feedback. Its choice determines the relative simplicity of operation, reliability, high power of executive and the fact that it is still widely used in fleets of many countries.

Choosing the type of electrical machine as a shaft generator

From the standpoint of the shaft generator, the main engine serves as variable rotational speed's drive [1, 3]. This causes difficulties in maintaining constant voltage (*U*) and frequency (*f*) in electrical network. Voltage problem may be considered as solved because of the widespread use of excellent, electronic, very fast-acting voltage regulators. They are able to maintain constant voltage over a wide change of speed of the generator. The problem of frequency is still valid.

There are many solutions of shaft generator's systems [1, 2, 3, 4, 5, 6]. They differ from each other in the idea of work and in the way of stabilizing the frequency (*f*) current and voltage. One can observe two main trends:

– stabilizing the rotational speed (*n*) between the main shaft and the electric machine;
– stabilization of the frequency (*f*) by electric methods if fluctuations of the main shaft's rotational speed will be allowed.

In light of Classification Societies laws, shaft generator can be only considered as a basic source of ship's electrical power if it is capable to long-term, trouble-free parallel cooperation with the traditional ship's generator [1, 2, 3, 4, 5, 6]. In fact, there is no such a universal solution that can satisfy all the requirements of the law. The possibility of such an investigation must be taken into account in the simulation model.

Synchronous electric machine is the main source of electric power of alternating, three-phase, sinusoidal current on ships all over the world. It is also used in 90% of linear alternators, which are currently in operation. The alternative is to use an asynchronous machine but its commonly known, operating difficulties during working as a generator make that it is used reluctantly and only in a small, experimental solutions of linear alternators [3, 4, 5]. For this reason, described model assumes a synchronous, three-phase machine.

By description of electromagnetic phenomena in three-phase, synchronous machine should contain Gorewa–Park's equations [2] with the following assumptions:

- synchronous machine should be treated as a two-phase machine in the coordinate of (q, d);
- coordinate of (q, d) spins with a frequency of the rotor of shaft generator;
- equations should be written using relative units.

Then the number of differential equations will be limited this way, what will facilitate analysis of the results. Usage of relative units will allow to compare changes of different physical parameters.

Description of the generator in the ship's power plant

Standard three-phase generator of alternating current that is used in ship's power plants consists of:

- two machines, auxiliary Diesel's engine as drive and three-phase synchronous machine as a generator;
- two regulators: rotational speed regulator of the auxiliary engines (*AE*) and synchronous machine's voltage regulator.

In this case, the task of the auxiliary motor (*AE*) is completely different from the task of main engine (*ME*). Its work is entirely subordinated to the needs of the generator. The only task is to maintain a constant rotational speed (n = const) of the complex during widely balancing load of electric power. Constancy of the rotational speed is equivalent to the constancy of frequency in ship's electrical network.

This task is being fulfilled by Diesel's rotational speed regulator. The UG-8 Woodward's controller had been selected for this model because of its widespread use. In general, both the frequency of electric current and the amount of produced active electric power (P) depend on rotational speed regulator's work.

When operating with a single unit in ship's network, it affects only the frequency (f). When operating in "rigid" net, it affects only active electric This task is being fulfilled by Diesel's rotational speed regulator. The UG-8 Woodward's controller had power (P). With the parallel cooperation of two units of the same power, it affects both of these factors, depending on the circumstances. Description of the controller's dynamics will be equivalent to a description of dynamics of the auxiliary motor (*AE*).

Voltage regulator maintains voltage stability (U) in the network, but also affects the reactive power (Q). Adequate interaction depends-as noted above--on whether the unit is working alone or it is in parallel work with another unit. Electromagnetic processes in this generator, similarly like in the shaft-generator should be also described by Gorewa–Park's equations.

Description of ship's network load by electric power

A mathematical model of electric energy receivers [3] should contain a description of:

- static load, which determines the level of demand for electric power;
- the dynamic load, which affects the transient electromagnetic processes in the marine system.

Three-phase asynchronous machine working as a motor's is expected to create dynamic load. It fulfills this task very well. Asynchronous machine fulfills this task very well. It is difficult to use, fast and sensitive to the quality parameters of electric power. Changing the conditions of its power supply, immediately calls electric network disturbances in electric network and affects work of other receivers and regulators in the generator's units.

Electromagnetic processes in an asynchronous machine can be also described by system of Gorewa–Park's differential equations. This method is widely recognized and takes into account the impact of magnetic saturation in the three-phase *AC* machine with overload.

Conclusions

The development of computer technology had allowed developing of a new research method – simulation of technical facilities. The benefits of simulation studies do not require comment. The aim of every simulation is to create an accurate mathematical model of testing object, or system. However, like any research method, this technique has its limitations.

They are associated with the problem of the credibility of results. Therefore, it is very important to use the mathematical description of various parts of the system commonly recognized methodology. Then a new quality – a comprehensive and reliable model of the whole system will be received.

References

1. GERMAN-GAŁKIN S., NIENARTOWICZ B.: Perspectives of ships' electric power sources development. I International Congress Seas and Oceans, 18–22 IX 2001 r., Szczecin–Międzyzdroje.
2. GERMAN-GAŁKIN S., NIENARTOWICZ B.: Kompiuternyje technołogii projektirowania i nadiożność sudowych elektroenergeticzeskich sistem. I Konferencja Naukowo-Techniczna „Bezpieczeństwo Żeglugi", WSM, Szczecin 2002, s. 45–57.
3. NIENARTOWICZ B.: Okrętowe systemy odbioru mocy od wału o zmiennej prędkości obrotowej. Seminarium naukowe Zachodniopomorskiego Zespołu Środowiskowego Sekcji Podstaw Eksploatacji Komitetu Budowy Maszyn PAN, WSM, Szczecin, marzec 1997 r.
4. GERMAN-GAŁKIN S., NIENARTOWICZ B.: O pewnej koncepcji sterowania asynchroniczną prądnicą wałową. Konferencja krajowa "Explo-Ship '99", Międzyzdroje 11–14.05. 1999 r.
5. GERMAN-GAŁKIN S., NIENARTOWICZ B.: Sudowaja energosistema s asinchronnym korotkozamknutym wałogieneratorom. Konferencja międzynarodowa „SÈÈ̕2000", Ukraina, 25–29.09.2000 r.
6. NIENARTOWICZ B., WIERZEJSKI M.: Control problem in double-feed induction machine working as a shaft generator. Konferencja międzynarodowa UEES̕99, Sankt Petersburg, 20–27.06.1999 r.