Management Systems
in
Production Engineering

2013, No 3 (11), pp 9-13

SYNCHRONIZATION OF NATIONAL GRID NETWORK WITH THE ELECTRICITY SHIPS NETWORK IN THE "SHORE TO SHIP" SYSTEM

Dariusz TARNAPOWICZ
Maritime University of Szczecin

Abstract:
'Shore to ship' system – ships' power supply from the local electrical substations – is one of the effective ways to limit the negative impact of the ships lying in ports on the environment. Energy infrastructure of the port installation necessary to provide ships with power supply has to be designed so that different types of ships can use it.
The important issue concerning 'shore to ship' system is the quality of power supply. This can be achieved via sustaining continuity of power supply while switching from the ships' electrical network over to the national grid.
In this article the author presents the way of synchronizing the national grid with the ships' electrical network during ship's lying in port. Such synchronization would allow for uninterruptible work of the ship's electrical devices.

Key words: *'shore to ship' system, synchronization, phase-locked loop PLL*

INTRODUCTION

Ships are like floating businesses. Production and distribution of power is performed in the environment in which obtaining power from the external sources is impossible. Ships' electrical installations are indispensible for the main motor operation, navigation, communication, as well as for the supporting systems that provide basic facilities such as lighting, water supply systems and hotel services.

In the majority of cases power is supplied by autonomous auxiliary engines (AE) that consists of internal-combustion piston engine and synchronous generator.

When a ship lies in the port main motors are usually switched off so the main source of air pollution are ship's power generators and heating boilers. The studies of pollution emission carried out in ports and their surrounding reveal that sea ships are the main source of pollutants such as nitrogen oxide (NO_x), sulphur dioxide (SO_2) and particulate matter (PM) [1]. Pollution emission from the land sources (industrial plants, cars, trains) has been drastically decreased within the last two decades thanks to the implementation of strict norms of the pollution emission, using clean fuels and installing the devices limiting the pollution emission. The pollution generated by the ships lying in ports is not to be accepted.

Connecting ships' electrical network with the national grid contributes to limitation of negative impact of auxiliary engines on the environment. The technical problem of such solution is that different ships use different nominal parameters of the electrical networks and the normalization of national grids' electrical power parameters worldwide does not exist [2].

Figure 1 presents vessel electrical power supply system configuration (STS) in the port according to EU regulations [3].

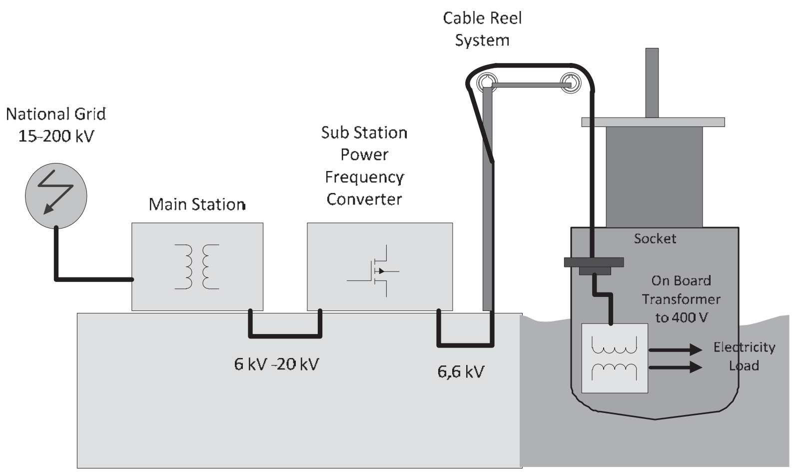

Fig. 1 The scheme of vessel electric power supply system configuration (STS) in the port according to EU regulations

SYNCHRONIZATION IN THE VESSEL SYSTEMS

Sustaining continuity of the important vessel devices' supply is the basic condition of the ship's safety understood in the broad sense. Electrical power vessel system is designed so that involving subsequent autonomous auxiliary engines in parallel work is synchronized. Disconnecting vessel auxiliary engines and connecting the ship to the on-land national grid has to be performed uninterruptedly and automatically. Correct and quickly-performed synchronization of the systems affects proper functioning of the majority of vessel devices.

In the modern energy systems the synchronization process is performed automatically. The necessary condition for two energy systems' connection is the difference in their instantaneous voltage in the subsequent phases. In order to meet this general condition, four special conditions (called synchronization requirements) have to be met [4, 5]:

Frequency requirement – equation of voltage frequency of the energy systems working in parallel:

$$f_1 = f_2 \quad (1)$$

Phase requirement – equation of the initial phases of the energy systems working in parallel:

$$\varphi_1 = \varphi_2 \quad (2)$$

Voltage requirement – effective (root-mean-square) voltages of the energy systems working in parallel:

$$U_1 = U_2 \quad (3)$$

Phase coincidence requirement – the same phase sequence in the phase star of the energy systems working in parallel:

$$RST_1 = RST_2 \quad (4)$$

Figure 2 shows meeting the synchronization requirements for one phase of two electrical systems. Once the aforementioned requirements are met, two power systems are connected.

In the vessel power systems the synchronization automation system has to keep up with the changes in the vessel network. As mentioned before, vessel network is a 'soft' network that is characterized by frequent voltage and frequency changes (connecting and disconnecting of receivers of high power comparable to the power of a power generating system). Synchronization among autonomous auxiliary engines in vessel systems is performed automatically and is realized by synchronisers. More or less technologically advanced synchronizers used in shipbuilding guarantee automatic synchronization in minimal time. Synchronizer T4500 by SELCO (a company well-known in shipbuilding) can serve as an example of such synchroniser [6].

To meet the synchronization requirements, the synchronizer sends command signals to power-generating speed governors and optionally, and not frequently, to generators' voltage regulators which are set to work in parallel. Meeting the requirement of the phase order while turning on two power-generating systems to perform parallel work is realized in generators' assembly, and is not checked during synchronization. Voltage requirement is realized by generators' voltage regulators and the synchronizer usually does not influence the effective (root-mean-square) voltages' adjustment. The main task of the synchronizer is to meet the frequency requirement and, what is even more important, the phase requirement. Meeting both is done mechanically via the slight change in the generator's driving motor revolutions. High rotational mass inertia of the driving motor as well as its rotational speed control system inertia extend time of the synchronization process up to a few minutes.

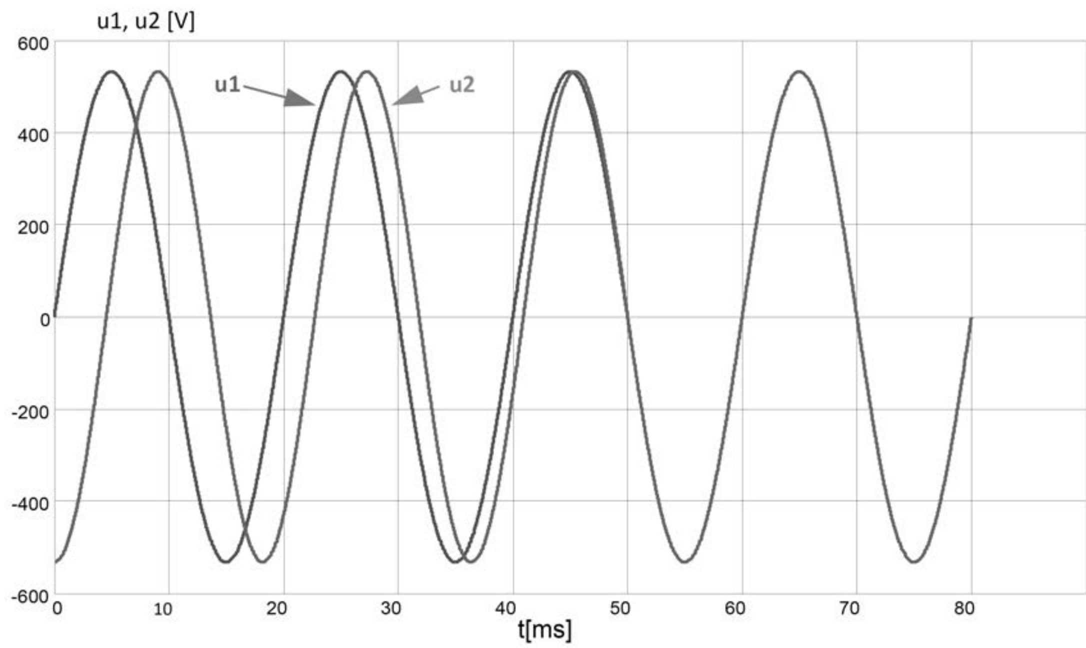

Fig. 2 The requirements for synchronization of two energy systems
u1 - voltage waveform for one phase of I energy systems
u2 - voltage waveform for one phase of II energy systems

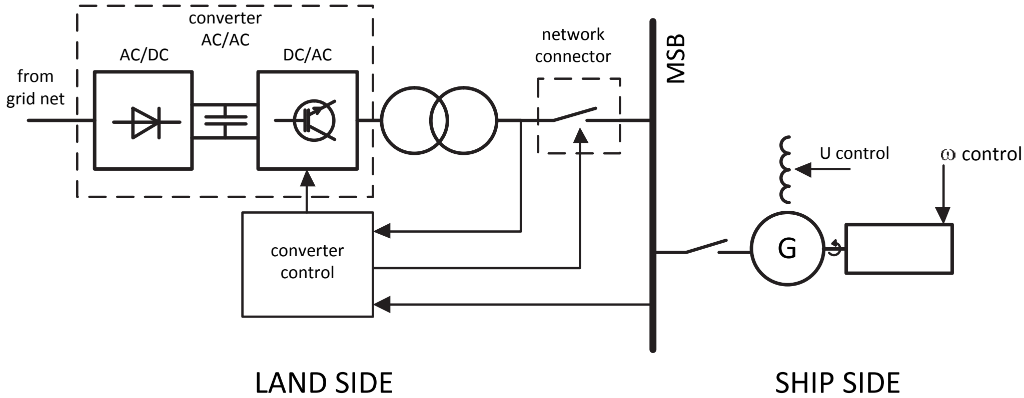

Fig. 3 STS system synchronization

Using the aforementioned synchronizers in STS system results in significant drawbacks:

– Assuming that the synchronizer adjusts ship's network parameters to the national grid parameters, motors' revolution adjustment of auxiliary engines will cause the frequency changes of the power receivers currently supplied. This is not beneficial for the receivers whose rotary mechanisms are associated with the frequency of supplying voltage. Asynchronous squirrel-cage motors are the main receiver in the vessel systems. Rotational speed is proportional to supplying frequency:

$$n = \frac{60*f}{p} \quad (5)$$

where:

f - supplying voltage frequency

p - number of synchronous field pole

– Low dynamics of the synchronization system – long synchronization process (especially at high powers of auxiliary engines)

In order to eliminate the drawbacks of the synchronization system realized with the use of classic synchronizers the most appropriate way of synchronization is to control the frequency inverter accordingly (Fig. 3).

As mentioned before, the phase requirement is the main requirement for the synchronization to be performed. There are many methods that allow for determining network's phase and its voltage frequency. As an example can serve a network's phase determining method that is detection of moment at which voltage goes through zero point. During the voltage course there are only two such moments at which the voltage goes through zero point. The risk of voltage distortion (caused by connecting high power receivers in case of 'soft' network, for instance) that introduces errors to the controlling system cannot be disregarded. This method is characterized by low dynamics and precision [7].

Over the recent years, there has been a great development of semiconductor technology and controlling based on CPU and digital techniques. Thanks to this development a PPL (Phase-Locked-Loops) synchronization system, well-known in electronics, found application in electrical power systems. PPL system is used in electronic systems of frequency division and multiplication, frequency synthesis, demodulation and synchronization. Phase synchronization system based on PLL consists of three main functional blocks (Fig. 4):

– PF – phase detector compares different phase angles of the input signal X(t) and output signal Y(t) from voltage-controlled oscillator VCO and produces voltage error signal ΔX(t) that depends on the difference in phases and frequency.
– LF – lowpass filter, in which the filtration of the error signal high frequency takes place, and then the filtered signal ΔXF(t) is sent to the voltage-controlled oscillator VCO.
– Error signal ΔXF(t) voltage-controlled oscillator VCO.

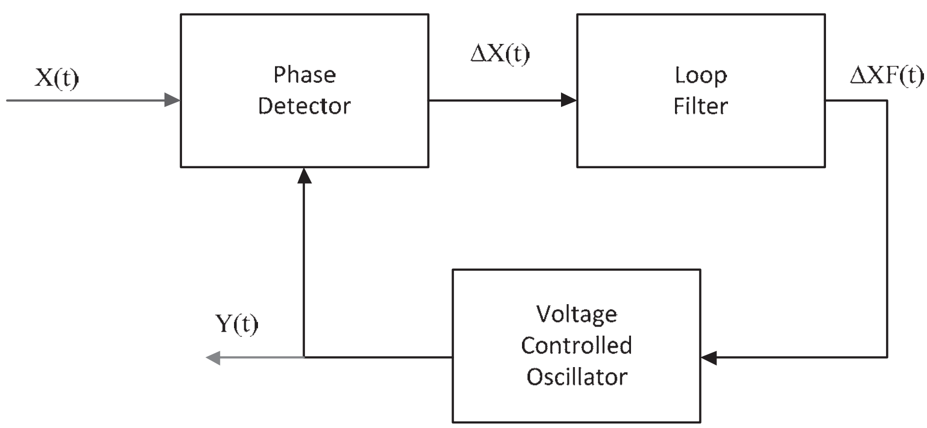

Fig. 4 Basic conceptual models of PLL

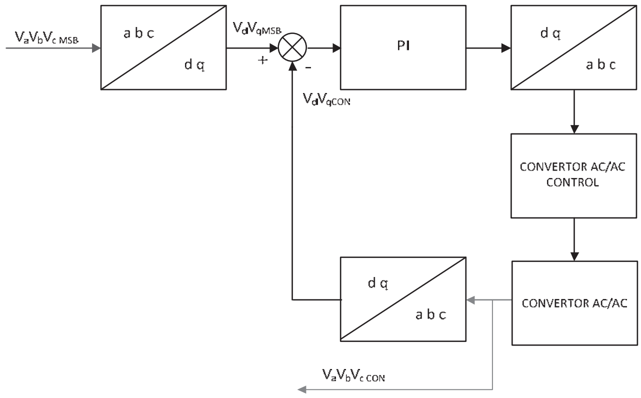

Fig. 5 Block diagram of the PLL to synchronize national grid's converter with the ship's network
$V_aV_bV_{cMSB}$- three-phase voltage vectors on Main Switch Board – MNS
$V_aV_bV_{cCON}$- three-phase voltage vectors of AC/AC converter

Abovementioned conceptual model of PLL can be used in the process of synchronization between national grid and ship's electrical network. Figure 5 presents a block diagram of the PLL where PLL synchronizes national grid's converter with the ship's network. PLL's task is to keep the phase compatibility of the vessel network voltage ($V_aV_bV_{cMSB}$ – three-phase voltage vectors on Main Switch Board – MNS) with the output voltage of STS system converter (– three-phase voltage vectors of AC/AC converter).

There are some limits to the system analysis of the instantaneous values of voltages [8]. Thus, for the purpose of description, analysis and control of the converter the notion 'space vector' is used. Three-phase instantaneous values of voltages are transformed to the two-phase equivalent rotating Cartesian coordinate system (Park's transformation) [9] (6) on the basis of symmetrical component vectors' theory.

$$\begin{pmatrix} V_d \\ V_q \end{pmatrix} = \frac{2}{3} \cdot \begin{pmatrix} \sin(\theta) & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) \\ \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \end{pmatrix} \cdot \begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} \quad (6)$$

SYNCHRONIZATION SYSTEM ANALYSIS

A simulation analysis of the synchronization system of national grid with autonomous ship's network employing PLL system was performed with the use of MATLAB-SIMULINK package. The system presented in the Figure 6 has been modelled.

For the correct control of the converter in order to convert abc coordinate system to dq coordinate system and the other way round (Park's transformation) sine-cosine generator has to be used. Sine-cosine signal has to be precisely synchronised with the 'soft' vessel network. To achieve this the phase voltages of the phase ($U_{a\ MSB}$) and line-to-line voltage between the phases ($U_{ab\ MSB}$) have been used. The voltages mentioned are orthogonal.

Figure 7 and 8 present the results of the simulation analysis of the STS synchronization system employing PLL. Figure 7 presents phase voltages' time courses of both ship's network and national grid during synchronization. Figure 8 shows synchronization error time course.

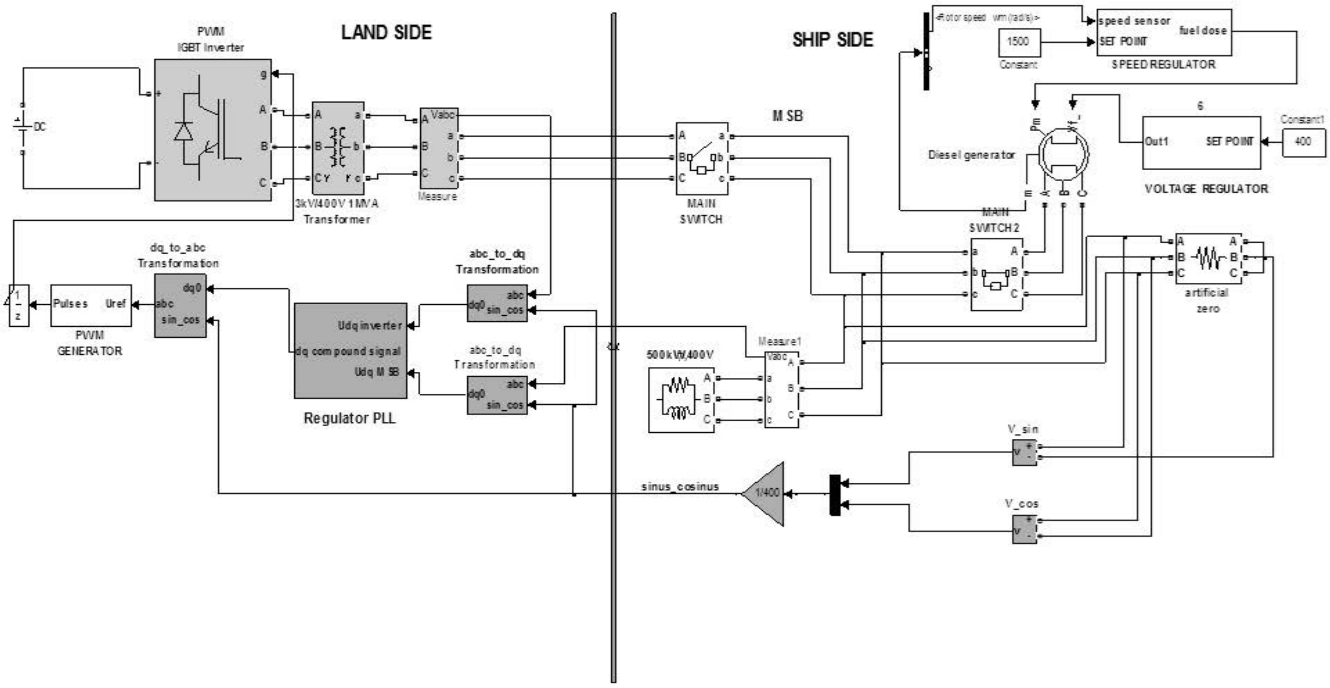

Fig. 6 The simulation model of synchronization in the STS system employing PLL
Simulation data: Synchronous generator: 400V, 50 Hz, 600 kVA, IGBT inverter controlled by PWM
Power load: 500kW, 288 kVAR, Transformer 1 MVA, 50 Hz, Sampling frequency 1Mhz

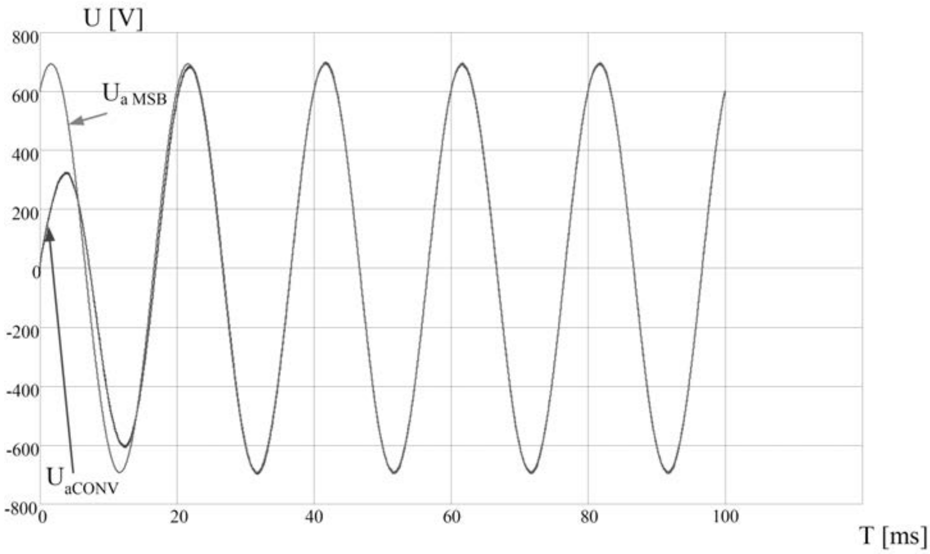

Fig. 7 Voltage Waveform of Phase "a" $U_{a\ MSB}$ of ship network and Voltage Waveform of Phase "a" of converter STS system $U_{a\ CONV}$ during synchronization with using PLL

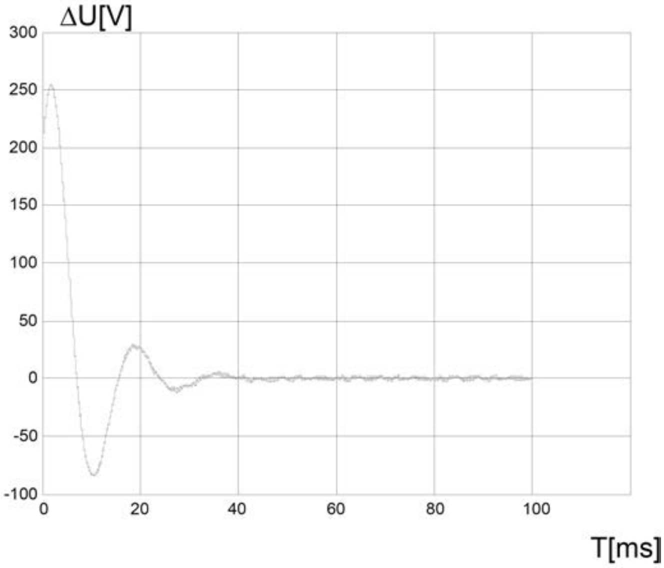

Fig. 8 Synchronization error time course employing PLL

CONCLUSIONS

Providing uninterruptible work of vessel electrical devices is directly connected to safety of the ship. When a ship lies in port, its connection to the power supply from national grid has to be performed with the use of synchronization between national grid and ship's network. The idea of synchronization system employing PLL presented in the article shows the following merits:

- high dynamics of the synchronisation system – the connection between the systems can be realized after only two periods (40ms),
- 'adjustability' of national grid (that is not loaded before the connection) to 'soft' vessel network.

REFERENCES

[1] Tarnapowicz D., Borkowski T., Nicewicz G.: Ships moored in the port with threat to the natural environment. Management Systems in Production Engineering. No 2 (6), 2012.
[2] Tarnapowicz D.: An alternative power supply: the use of ships in port as an environmentally friendly solution. Management Systems in Production Engineering. No 3 (3), 2011.
[3] EU (2006/339/EC) COMMISSION RECOMMENDATION of 8 May 2006 On the promotion of shore-side electricity for use by ships at berth in Community ports (Text with EEA relevance).
[4] Białek R, Gnat K.: Elektrotechnika dla studentów Wydziału Nawigacyjnego. WSM. Szczecin 2000.
[5] Grono A, Redlarski G, Zawalich J.: Komputerowe wspomaganie badania układów automatycznej synchronizacji prądnic. Wydawnictwo Politechniki Gdańskiej. Gdańsk 2005.
[6] SELCO: Protection relays and controls catalog may. 2012.
[7] Piróg S i in.: Metody synchronizacji przekształtników energoelektronicznych z siecią zasilającą. Przeglad Elektrotechniczny. Nr 2,2010.
[8] Fernández F.D.F.: Contributions to Grid-Synchronization Techniques for Power Electronic Converters. Vigo University Department of Electronic Technology. 2009.
[9] Park R.: Two reaction theory of synchronous machines. AIEE Transactions. Vol. 48, 1929, pp. 716-730.

dr inż. Dariusz Tarnapowicz
Maritime University of Szczecin, Faculty of Mechanical Engineering
Department of Marine Electrical Engineering and Electronics
ul. Wały Chrobrego 1-2, 70-500 Szczecin, POLAND
e-mail: d.tarnapowicz@am.szczecin.pl

Artykuł w polskiej wersji językowej dostępny na stronie internetowej czasopisma.

The article in Polish language version available on the website of the journal