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# Starting current control of high-power asynchronous motors using generator's voltage regulator

*SUMMARY*

*The new starting method of asynchronous motor driving the ship bow thruster when the motor rated power and the generator output are comparable is described. The AVR (Automatic Voltage Regulator) of the generator is fitted with an additional current regulator which keeps adjusted value of motor starting current. The principles of operation and site test results are given.*

## INTRODUCTION

Contemporary advanced ships, mostly container carriers, are fitted with bow thrusters which improve ship manoeuvrability and thus shorten port entering and leaving time. Improvement of ship's manoeuvrability simultaneously decreases berthing costs as using tugs is not necessary.

Bow thrusters are usually driven by asynchronous cage motors of 800 to 1200 kW rated power which is comparable with power of ship electric generating plant. Starting a motor as large as that requires application of special means to maintain plant bus bar voltage not lower than 85% of rated voltage as it is required in the rules of classification societies.

In the article a new method of bow thruster starting is presented. It consists in switching the bow thruster motor on a separated and de-energized generator and maintaining starting current at a prescribed level with the use of an addditional generator's current regulator which controls voltage regulator. The current regulator is switched on during starting time by the automatic control system of the electric generating plant.

This starting method was implemented for container carriers built in series by Gdynia Shipyard, with the use of the RNGY voltage regulator.

## ASYNCHRONOUS MOTOR STARTING METHODS USED ON SHIPS

Two basic conditions should be satisfied to assure correct starting of a high power motor:

- motor stalling avoidance, viz. to assure that the starting torque dependent on supply voltage is greater in the full speed range than the braking torque developed by a driven device.

- avoidance of voltage drop at the electric plant bus bars below a permissible level.

The classical starting method of a large power motor consists in switching it directly on electric plant bus bars. An instantaneous bus bar voltage drop then occurs which can be described as follows:

$$\Delta U_{max} = \frac{X'_{dz}}{X'_{dz} + n\frac{I_{gn}}{I_r}} \qquad (1)$$

where:

- $\Delta U_{max}$ - instantaneous voltage drop in relative units
- $X'_{dz}$ - equivalent transient reactance of a synchronous generator [6]
- n - number of generators working in parallel
- $I_{gn}$ - generator rated current
- $I_r$ - motor starting current at rated supply voltage

The ratio of the generator rated current to the motor starting current assuring maintenance of the bus bar voltage within the required range is described by the following expression:

$$\frac{I_{gn}}{I_r} \geq \frac{X'_{dz}}{n}\left(\frac{1}{\Delta U_{max}} - 1\right) \qquad (2)$$

The ratio of the rated current of one generator to the motor starting current must be greater than 0,567 taking into account that for brushless synchronous generators $X'_{dz}$ = 0,2 (20%), motor starts during simultaneous parallel work of two generators and the permissible instantaneous voltage drop cannot be greater than 0,15 (15%).

Assuming that motor starting current equals six rated current values it can be determined that the minimum ratio of the motor power to the generator power, assuring correct motor start during simultaneous parallel work of two generators, should be, depending on motor efficiency, less than:

$$\frac{P_{ns}}{S_{ng}} \leq 0{,}23 \div 0{,}25 \qquad (3)$$

where:

$P_{ns}$ - rated power of the started asynchronous motor

$S_{ng}$ - rated power of one generator

During the motor start in which voltage drops no more than by the rule value prescribed by the classification societies, starting torque is so large that the motor stalling does not occur. Taking into account that bow thruster power may reach 1200 kW the power of each parallelly working generator should be 5000 to 5200 kVA. This simple estimation demonstrates that the classical start method cannot be used in the case of bow thruster drives.

In Polish shipyards the following methods for starting bow thruster drives have been applied till now:

* star-delta switch application,
* dragged start-up, i.e., switching bow thruster driving motor on still standing generator and starting the diesel-electric generating set supplying the bow thruster motor [4],
* switching motor on rotating de-energized generator and after that generator excitation switching on.

The first of the above mentioned methods is relatively expensive as it requires an additional switchgear and a special motor to be used.

The second and the third method does not control generator current and due to that also the torque applied to diesel engine. It can block start of diesel engine via its safety devices in the case of the higher power motors used for driving bow thrusters. Motor start thyristor systems ( so called soft-start systems ) are not applicable for ships due to their high cost and generation of higher harmonic frequencies.

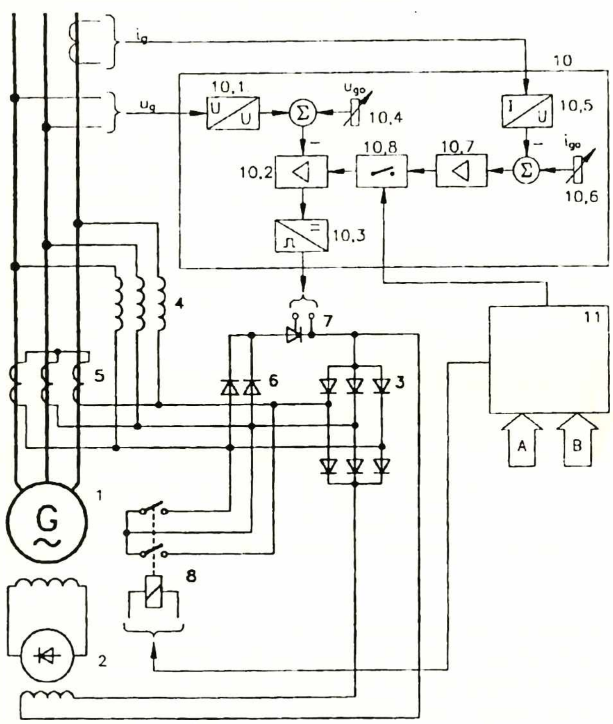



*Fig. 1. Simplified block diagram of the RNGY voltage regulator used for ship asynchronic generators :*
*1 - generator,*
*2 - excitations with rotational diodes,*
*3 - exciter's excitation rectifier,*
*4 - linear choke,*
*5 - current transformers,*
*6 - diod unit,*
*7 - control thyristor,*
*8 - generator's de-energizing switch,*
*9 - current transformer,*
*10 - voltage regulator's electric part,*
*10.1 - generator's voltage measuring unit,*
*10.2 - preliminary amplifier,*
*10.3 - thyristor's release unit,*
*10.4 - generator's voltage controller,*
*10.5 - generator's current measuring unit,*
*10.6 - starting current controller,*
*10.7 - current regulator's preliminary amplifier,*
*10.8 - electronic gate switching on current limiter,*
*11 - electric plant control system,*
*A - analogue signals entering control system (voltages, currents),*
*B - binary signals (switches' states).*

## STARTING CURRENT CONTROL IN THE RNGY REGULATOR

Starting current system principle of operation is shown in Fig. 1. The RNGY regulator absorbes power for excitation of the exciter (2) from the generator's terminals (1) via the choke (4) and the current transformers (5) connected into phase compoundation system. The energy supplies excitation winding of the exciter after rectifying it in the rectifier (3).

Parameters of the choke (4) and current transformers (5) have been so selected as to produce excitation current in the system greater than the required for given generator load conditions. Exciter's excitation current adjustment to the required value for maintaining the assumed voltage at generator's terminals is obtained by bridging-over exciter's excitation rectifier (3) with the use of two diodes (6) and the thyristor (7).

The thyristor is released by the releasing system (10.3) which generates thyristor controlling pulse train with a phase dependent on output voltage of the preliminary amplifier (10.2). Generator's de-energizing is realized by the switch (8) which short-circuits the exciter excitation rectifier's terminals on the alternating current side.

To make possible the control of generator's current supplying the high power motor, the starting current regulator was provided in the electronic part of the voltage regulator (10) consisting of:

the current regulator amplifier (10.5),
the starting current controller (10.6),
the current regulator amplifier (10.7)
and the electronic gate (10.8) which blocks signal supply from the current regulator to the pre-amplifier.

Control of the current regulator switch-on and the de-energizing switch-off is carried out by signals sent from the engine room automation system (11).

The current regulator is switched on for the motor starting time only. It is necessary to block current regulator influence on the voltage regulator as the bow thruster motor start is executed at the generator's current, set on the 150 to 200% range of the rated current, but the energizing system must provide during short-circuiting a steady short-circuit current three times greater than the rated one.

The rotational speed of the started bow thruster is described by the following expression:

$$\omega = \frac{1}{T_m}\int_0^{\infty}\left[M_e(\omega)U_g^2 - M_m(\omega)\right]dt \qquad (4)$$

where:

$\omega$ - bow thruster rotational speed

$T_m$ - electromechanical constant of the motor - bow thruster system

$M_e(\omega)$ - electric motor torque developed at the rated supply voltage in function of rotational speed

$M_m(\omega)$ - bow thruster braking torque

$U_g$ - relative generator voltage

Changing the assumed value of the starting current $I_{go}$ it is possible to change the generator voltage $U_g$ supplying the starting motor and thus its electric torque. It is possible this way to influence the speed course of the starting thruster and the generator developed braking torque loading the diesel engine.

## TESTING OF THE BOW THRUSTER STARTING SYSTEM WITH THE RNGA VOLTAGE REGULATOR FITTED WITH THE STARTING CURRENT REGULATOR

The developed starting system with the current regulator was implemented on container carriers built in series by Gdynia Shipyard S.A. The electric generating plants of the ships were fitted out with three GDB-148s generators of 1375 kVA rating. Two out of the three installed generators were adjusted for starting the bow thruster motor ( see Fig. 2).

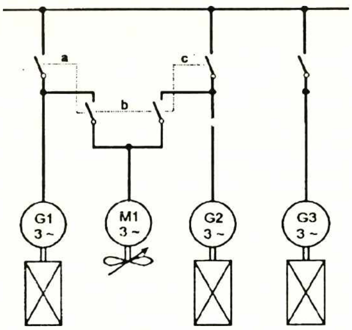
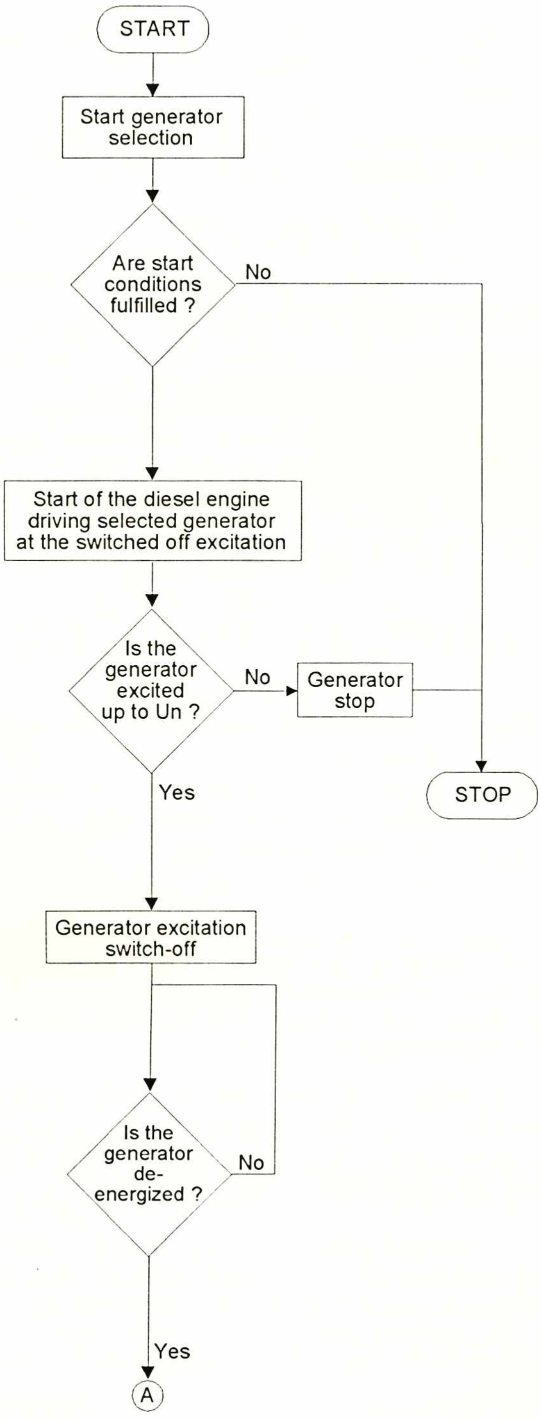



*Fig. 2. Electric plant block diagram of the 8111/1 container carrier a,b,c, - switch mutual blockings.*

The motor starts in a sequence executed by the engine room automation system. The start sequence is shown in Fig. 3.



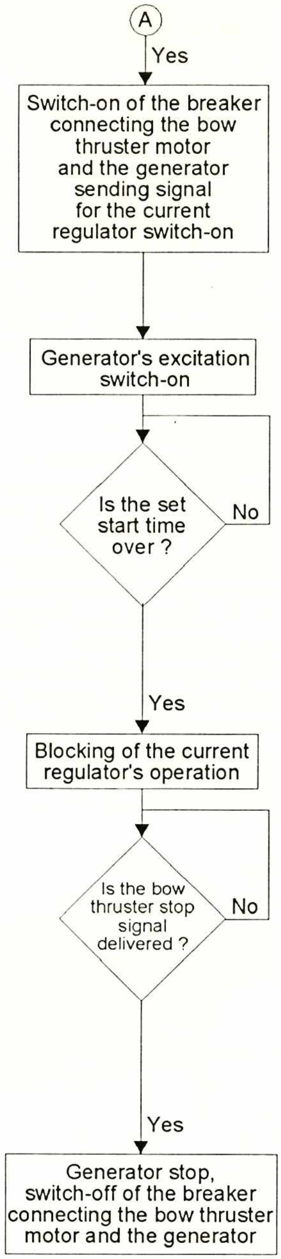




*Fig. 3. Bow thruster start sequence.*

It begins with selection of a generator for bow thruster starting. Having checked conditions necessary for starting, the automation system sends the generator start signal and after obtaining the rated speed and voltage - the next signal for generator de-energizing.

After voltage drop at generator terminals to a value lower than 10% of $U_{gn}$ the switch connecting the bow thruster motor with the selected generator is on and after a short delay the generator energizing system is blocked off (switching off the switch (8) in Fig. 1). At the same time a signal is sent to the gate (10.8), shown in Fig. 1, switching on the generator current regulator which due to its higher amplification is decisive for the energizing regulation system. The current regulator limits the generator current at a given level, set with the controller. The starting current maximum value is set within the 1,5 to 1,75 $I_n$ range in order not to let the diesel engine get overloaded and the bow thruster motor stalled. When the rated motor speed is achieved the current absorbed from the generator decreases and the voltage at its terminals increases to the rated value and the current regulator is switched off due to the removal of the gate controlling impulse. The starting course of the SBJVm-136s motor of 950 kW rated power is exemplified in Fig. 4.

During motor starting time of 12 s the current does not exceed the permissible value and the generator driving diesel engine is not overloaded.

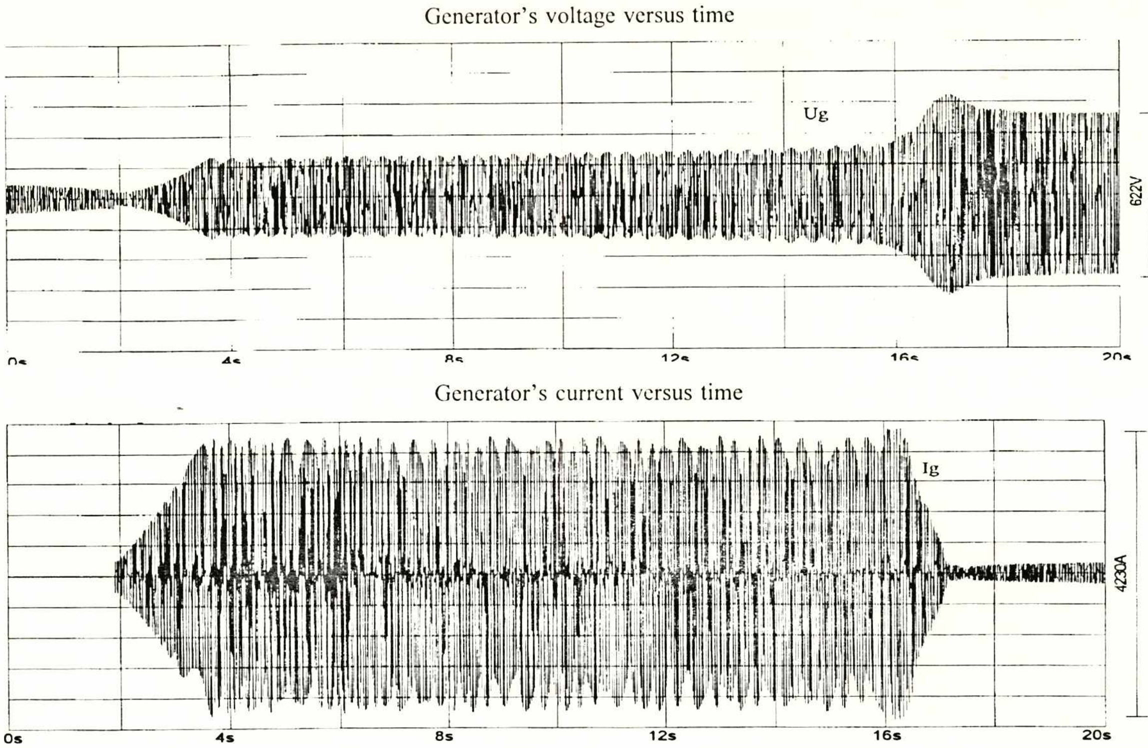



*Fig. 4. Examples of the generator current and voltage diagrams registered during the bow thruster start with the applied generator's current control: $U_g$ - generator voltage, $I_g$ - generator current.*

## CONCLUSIONS

- The described starting system was implemented and put into service on the 8111/1, 8109/1 and 8113/1 shipyard number ships, built in Gdynia Shipyard S.A. for German owners.

- The system tests showed its correct operation and the advantageous feature of possible setting a starting current value in such a way as to avoid the bow thruster motor stall and the generator driving engine overload.

- The developed starting method does not cause an excessive generator overload.

- The starting current regulating elements were fixed on the plate of the RNGY regulator. EFA Glina, the regulators' maker, supplies on shipyard's request the RNGY regulator already fitted with the starting current regulating unit.

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