"HENRI COANDA"
AIR FORCE ACADEMY
ROMANIA

"GENERAL M.R. STEFANIK"
ARMED FORCES ACADEMY
SLOVAK REPUBLIC

INTERNATIONAL CONFERENCE of SCIENTIFIC PAPER
AFASES 2012
Brasov, 24-26 May 2012

REACTIVE POWER DISTRIBUTION BETWEEN SYNCHRONOUS GENERATORS OF A SHIP

Gheorghe SAMOILESCU *, Serghei RADU **

*"Mircea cel Batran" Naval Academy, Constanta, Romania, ** "Barklav"Mar.Ag., Constanta, Romania

Abstract: *This paper explores the realization of uniform distribution of reactive power when synchronous generators run in parallel. It presents the role of voltage automatic regulators within the electro energetic naval system. It analyzes various situations in case of generator parallel running: when both equipment have the same or different voltages; when the excitation value of the generator is increased; when generator power is similar or different.*

This work aims to establish constructive solutions for technical equipment which is designed to provide a more complete automation of the engine compartment on board a vessel.

Keywords: *synchronous generators, reactive power, parallel running, excitation current, statism degree, auto voltage regulator, electro energetic naval plant*

1. INTRODUCTION

The following factors characterize the operation of a naval electrical equipment [1,2,8,9,10]:

- ship roll and pitch shall be determined depending on the weather;
- hull vibrations, whose values are determined by the number of blades and the frequency of rotation of the propeller;
- dynamic vibrations created by waves and ice;
- trim constants (longitudinal and athwart-ship) whose value is determined by the loading degree of the ship and compartment flooding;
- relative humidity on the vessel;
- petroleum vapors;
- water spashes, ice formation and solar radiation affecting the deck plants.

According to the international requirements in force all installations and systems that make up the electrical equipment of a ship are calculated with: a normal air humidity of 75%; temperature between - 25°C and + 35°C; athwart-ship inclination of up to 22.5° and longitudinal inclination of up to 5° or rolling up to 22.5°; pitching up to 10° from the vertical axis; vibrations with a frequency ranging from 5 to 30 Hz (with a magnitude of 5mm at 5 ~ 8Hz frequencies and 5m/s^2 acceleration at frequencies from 8~30Hz); dynamic blows with 30m/s^2 and frequency of 40 ~ 80 strokes per minute.

Naval electric power plants are designed for producing electric power and for conversion and distribution of electric energy.

Generators ensure electric energy aboard the ship. Transformers, rectifiers, inverters etc. are used as electric power converters.

The first phase of designing a naval power plant involves calculating the power required by the consumers in different running regimes. The power consumed by a naval power plant depends on: the nominal power of the consumers; the number of consumers in operation; the running mode (cruise, maneuver, stopped with or without loading-discharging operations, damage condition, fire or flooding).

Depending on the total power factor (cos φ) of the chosen generators and electric motors, the ship's energy balance is calculated. Electric generators allow an overloading of 10% for up to two hours, 25% for 30 min and 50% for 5 min.

2. THE OPERATION OF THE TWO GENERATORS IN PARALLEL

For synchronous generators coupled in parallel, the active and reactive loads must be proportionally distributed according to their nominal power [35]. Because the winding reactance is much greater than its resistance, in case of a difference between the electro-motor voltages of the two generators, an equalization current with 90° angle of deviation from ΔE – the difference between the two electro-motor voltages - will appear between their secondary windings.

Consider two generators coupled in parallel with the electro-motor voltages E_1 and E_2, the currents I_1 and I_2, equal voltages $U_1 = U_2=U$, δ_1 and δ_2 the phase angle deviation between the voltages, Xd_1 and Xd_2 the synchronous reactance and ρ_1 and ρ_2 the phase angle deviation between currents. When coupling a load of a certain reactive power, if the external characteristic of the two generators does not have the same degree of droop as the system does, then there are no differences between E_1 and E_2 and $\Delta E=0$. considering two generating sets with E_1 and E_2 as total output voltages, $E_1>E_2$ and $\Delta E=E_1-E_2$, then this difference causes an equalization current between generators having a direction for a generator, I_{e1}, and a contrary direction for the second generator, I_{e2}. The active load distribution between the two generators is modified by changing the electro-motor voltage and the current equalization.

If, in the case of two generators running in parallel, the excitation current for one of the generators is increased, then it will charge with a reactive load. The connector voltage will stay constant and the other generator will discharge the same reactive load [1,3].

The change of the reactive load can be achieved manually or automatically by arousing the equalization circuit between the excitation windings of the two generators; or by the existence of the active power circuit or transducer of the two regulators. Theoretically, the reactive load distribution between coupled generators in parallel and whose external characteristics have degrees of droop of the system s_1 and s_2 can not be achieved.

At a U_N voltage, if an additional reactive load I_{gr} is coupled, the first generator will load with ΔI_{gr1} and second one with I_{gr2} so that:

$$\Delta I_g = \Delta I_{gr1} + \Delta I_{gr2} \tag{1}$$

By coupling a consumer, the voltage drops to U_1, where:

$$U_1 = U_N - \Delta U \tag{2}$$

Than:

$$tg\alpha_1 = \frac{\Delta U}{\Delta I_{gr1}} = s_1 \qquad tg\alpha_2 = \frac{\Delta U}{\Delta I_{gr2}} = s_2 \tag{3}$$

from where:

$$\Delta I_{gr1} = \frac{\Delta U}{s_1} \qquad \Delta I_{gr2} = \frac{\Delta U}{s_2} \tag{4}$$

generaly resulting:

$$\Delta U = \frac{\sum_{i=1}^{m} \Delta I_{gr1}}{\sum_{i=1}^{m} \frac{1}{s_i}} \tag{5}$$

Reactive load is distributed inversely proportional to the degree of droop of the characteristic.

For synchronous generators with same power, that run in parallel, in order to load them with the same reactive load, it is necessary that both have overlapping characteristics. If the generators are of different powers, their external characteristics should have such a degree of droop of the system that they will load with a reactive power proportional to the nominal power in the limits allowed by international naval registers which require an allocation of reactive power with a deviation of less than 10% of the nominal power of the largest generator.

Onboard the vessel each synchronous generator is equipped with an independent automatic voltage regulator system. In case of load variation from idle to the nominal load, with nominal power factor, the voltage will change between $U_N \pm$ 2.5% values.

For naval synchronous generators is allowed a variation of voltage not exceeding 3.5% if power factor (cos φ) takes values between 0.6 and 0.9, other than nominal.

3. THE ROLE OF AUTOMATIC VOLTAGE REGULATOR

Automatic voltage regulator accomplishes the following functions [3, 4, 6, 7]:

- limit the maximum value of generator voltage output;
- distribute evenly the reactive power between coupled generators in parallel;
- adjusts the excitation current value depending of active and reactive load;
- increases generators running stability in case of short circuit and so on.

Maintaining the generator's voltage constant at the load change is made by:

a) maintaining phase electro-motor voltage constant and modifying reactance of the connecting elements between the generator and the main distribution board with power factor and revolution constant;
b) modifying the phase electro-motor voltage on the reactance of the connecting elements between the generator and the main distribution board with power factor and revolution constant.

When a consumer is connected with a load of a certain value, the phase angle deviation between voltages, δ, will tend to a limited value in terms of the static stability, $\delta_{\lim} = \frac{\pi}{2}$. When the load changes with a certain value, the values for current and voltage increase, so the reactive power grows also.

The advantages of using the automatic voltage regulator onboard the vessels consist of:

- increasing the reserve stability;
- increasing dynamic growth stability;
- increasing the maximum power that can be produced in static running mod.

Automatic voltage regulator, through its component blocks: starting, supplying, control, ignition, interference suppressor, the equalization corrector and current limiter, allows the equipment on board a vessel to operate in the prescribed parameters.

If the reactive load has the tendency to grow (when generators run in parallel), at the main switchboard bars, along with the increase of the φ angle, the value of the resulting voltage proportionally increases. The automatic voltage regulator, by increasing the amount of signal applied at the entrance; issue a command to decrease excitation current value. With the aim of maintaining constant the coupled electric power, the droop of the system degree increases. Therefore, the regulator ensures the stability of reactive power by increasing the droop of the system degree. A reactive load distribution between the generators that run in parallel, without a change in the level of droop of the system, can achieve if the primary of a transformer windings, of a voltage automatic regulator, are made of two halves connected in opposition and the circuit has an equalization switch.

4. CONCLUSIONS

Uniform distribution of the reactive power of synchronous generators connected in parallel, can be done by performing electrical connections which equalize the exciting currents, or by linking in parallel the output windings of the compensation transformers in case of systems with auto-excitation.

Automatic voltage regulator allows the stabilization of reactive power by increasing the degree of droop of the system. The equalization corrector of reactive power between two generators coupled in parallel introduces corrections to the control voltage of the ignition oscillator block. In case of incorrect adjustment of reactive power equalization on the two generators a equalization current appears. The fall of voltage, due to this current, will be added to the obtained signal. The excitation current will be corrected, so the automatic equalization of reactive power on the two generators will be achieved.

This paper presents the functional particularities of naval electric power systems containing a large diversity of consumers. The veracity of the methods used in the analysis of the processes taking place on board a vessel and the synthesis of parameters allows developing electric power plants that meet the required needs.

REFERENCES

[1.] Samoilescu Gheorghe –„Centrale electrice navale", Ed. Leda & Muntenia, Constanta, 1999.

[2.] Samoilescu Gheorghe – „Perturbatiile electromagnetice ale sistemului electroenergetic naval", Ed. Academiei Navale „Mircea cel Batran", Constanta, 2000.

[3.] Samoilescu Gheorghe – „Exploatarea sistemelor electroenergetice navale", Ed. Academiei Navale „Mircea cel Batran", Constanta, 2004.

[4.] Nanu Dumitru – „Sisteme lectroenergetice navale", Ed. Muntenia, Constanta, 2004.

[5.] Alf Kare Adnanes – „Maritime electrical instalations and Diesel electrical propulsion", Oslo, ABB As, Marine, 2003.

[6.] Gheorghe Silviu, s.a. – „Masini si sisteme de actionari electrice navale", Ed. Academiei Romane, Bucuresti, 2004.

[7.] Stefanescu Lucica – „Masini electrice", Ed. Academiei Navale „Mircea cel Batran", Constanta, 1995.

[8.] xxx Veritas.

[9.] xxx Loyd's ship manager.

[10.] xxx Manualul ofiterului mecanic, Ed. Muntenia, Constanta, 1997.