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Ship power plant operating problems connected with reactive power distribution between electric generators working in parallel

Summary

Operating problems connected with improper reactive power distribution between parallelly working marine electric generators are presented in this article. Reactive power distribution mechanism in electric power system is discussed. Methods of identifying proper reactive power distribution in the ship power plant depending on main switchboard measuring equipment are shown.

Reactive power distribution corrective algorithm for selected excitation systems and voltage regulators is formulated.

INTRODUCTION

One of the impotant problems appearing in operation of electric power plant on contemporary ships is improper distribution of active and reactive power between generators working in parallel. The problem is especially vital during e.g. ship manoeuvres when parallel operation of generators determines the electric plant reliability and the ship's operation safety being therefore necessary and required by the classification societies. Electric power demand during manoeuvres is higher than average and time-variable which is connected with frequent starts of different electric motors.

In such situation a limiting factor for electric energy supply is improper power distribution between parallelly working generators. Magnitude of unproportional power distribution substantially influences the load capacity of electric plant. At an increased power demand so called apparent overload of electric plant may happen. In its effect protective system, viz. Mayer's system, may enter into operation or generators switch-off (blackout) be executed in an extreme case. The situation is even more complicated if improper reactive power and active power distributions coincide. These are however two different problems which should be solved seperately.

In this paper attention is mainly paid to reactive power distribution and active power distribution is marginally considered.

CORRECTNESS CONTROL OF REACTIVE POWER DISTRIBUTION BETWEEN GENERATORS WORKING IN PARALLEL

Most classification societies (including PRS) permit the irregularity in reactive power distribution ΔQ at parallel operation of generators not greater than 10% of reactive rated power Q_n of the highest power installed generator (if installed generators are of different rated power) [1]. It can be expressed as follows:

$$\frac{\Delta Q}{Q_n} < \pm 0{,}1 \qquad (1)$$

These are requirements for excitation systems fitted with voltage regulators as proper reactive power distribution, i.e. proportionally to rated power of each generator, depends on the fitted regulators. In this paper therefore such systems are only considered.

Correctness control of reactive power distribution between parallelly working generators can be carried out based on indications of measuring instruments fitted in the Main Electric Switchboard (MES). A set consisting of kilowatt-meter and kVar-meter for each generator is the most suitable for this purpose. Generator's active and reactive loading can be simultaneously monitored in such situation. Another solution is application of a single meter with possible switching it from active power measurement to reactive power measurement and back. If however MES is not equipped with kVar-meter then it is very hard to recognize improper reactive power distribution between generators working in parallel. In such situation the condition for determination of reactive power distribution is to introduce parallelly working generators into a state of proportional active power loading which means, in the case of two generators of equal rated power, that identical indications of kilowattmeters would be obtained. Different indications of ammeters, which measure the apparent current but not the active one, would disclose an improper reactive power distribution at such parameters' adjustment of the electric power plant. Different currents which load generators at the same active power result from different excitation currents of the generators (assuming the same type and rated power of them). The latter ones are signals emmitted by excitation and voltage regulation systems. Reactive power distribution would be correct when at variable reactive power load in ship's electric network excitation currents of the generators change in the same way. External characteristics U = f(I), and more precisely U = f(Q), of equal rated power generators have therefore to coincide and to effect this way correct reactive power distribution. In the case when the generators' characteristics do not coincide reactive power distribution proceeds, for instance, in the way shown in Fig. 1.

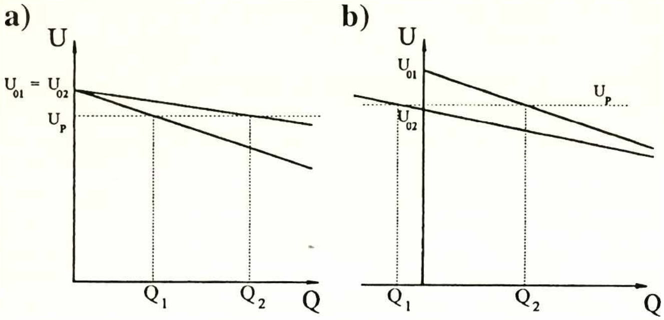

Fig. 1. Improper reactive power distribution between generators working in parallel, of the same rated power $S_{n1}=S_{n2}$, but at different external characteristics of them.
a) Equal generator idle run voltages $U_{01}=U_{02}$, but different droop of the characteristics. A difference in reactive power loading the generators is seen, $0<Q_1<Q_2$, at a given reactive power loading electric power plant and working voltage U_p identical for both generators, resulting of that
b) Different generator idle run voltages and different droop of characteristics. One of the generators gives the capacitive reactive power $Q_1<0$ back to the electric network, the other - the inductive reactive power $Q_2>0$

Measuring instruments' indications would be in the effect of such reactive power distribution as shown in Fig. 2.

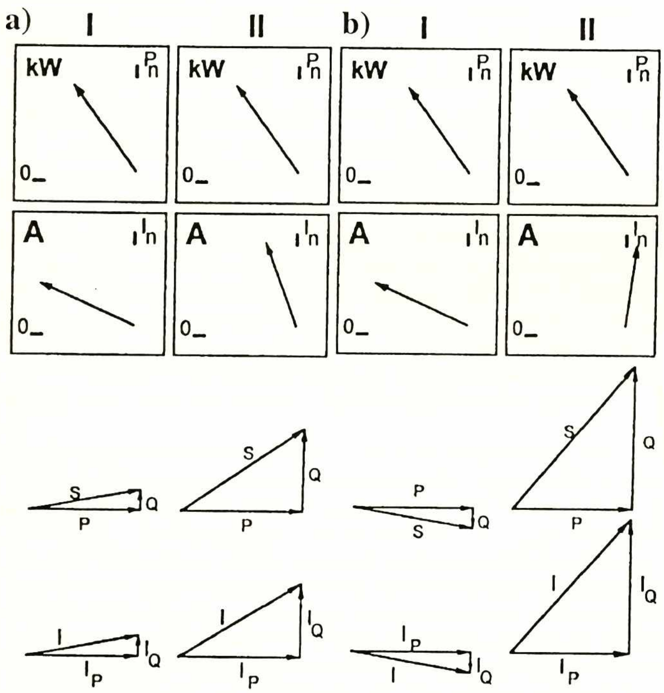

Fig. 2. Measuring instruments' indications and phasor diagrams for two generators working in parallel in the case of:
a) uniform active power distribution and unequal distributed reactive power
b) uniform active power distribution and extremally incorrect reactive power distribution (generator I gives up capacitive reactive power)

Fig. 2b illustrates extremally incorrect reactive power distribution. Ammeter of generator II indicates its overload at substantial margin of active power which could yet be applied to that generator. Moreover, the generator, being current-overloaded, will be switched off by master switch or Mayer's protective system will operate, and that will happen without any real overload of electric power plant (i. e., at apparent overload of it).

MECHANISM OF REACTIVE POWER DISTRIBUTION BETWEEN GENERATORS WORKING IN PARALLEL

Incorrect reactive power distribution is caused by an improper ratio of currents exciting generators working in parallel. For the same type and rated power of the generators their excitation currents should be equal at a given power plant load. It is field regulator (i.e. generator's excitation system fitted with voltage regulator) which governs excitation current. Fig. 3. shows block diagram of a synchronic generator fitted with field regulator.

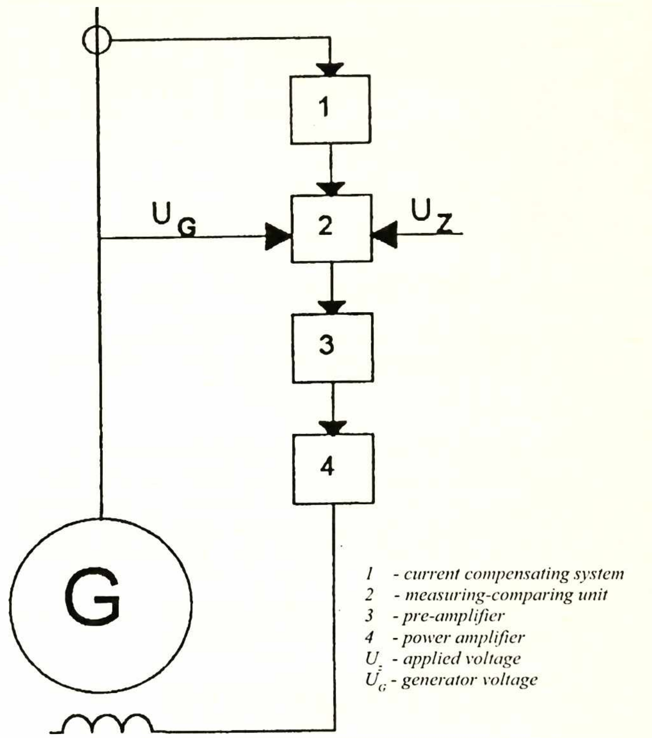

Fig. 3. Block diagram of voltage regulator

The measuring-comparing unit is very important as it makes generator's external characteristics dependent on loading characteristics. The most frequently used current compensating system is that with impedance [3], as it is shown in Fig. 4.

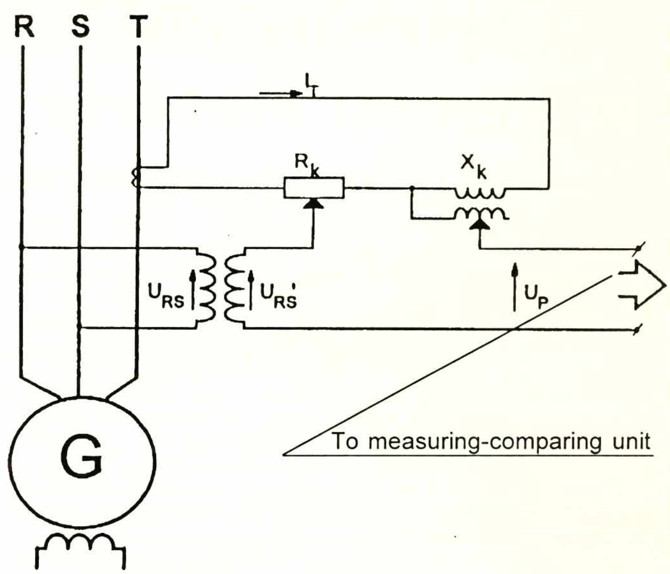

Fig. 4. Scheme of current compensating system with impedance
I_T - phase current, U_{RS} - phase-to-phase voltage, U_{RS}' - lowered phase-to-phase voltage, U_p - measurement voltage, R_k - resistance, X_k - choke

Signal measurement with the use of measuring unit is done in the same way as reactive power measurement with watt-meter in three-phase network. Voltage U_p is then dependent on loading character (cos φ) and is vector sum of U_{RS}, lowered by transformer to a value U_{RS}', and voltage drops due to resistance R_k and choke X_k.

The voltage drops at these elements are forced by secondary current of generator's phase-T current transformer. Voltage phasor diagrams for current neutralization system are illustrated in Fig. 5., and generator external characteristics for extremally different power factors - in Fig. 6.

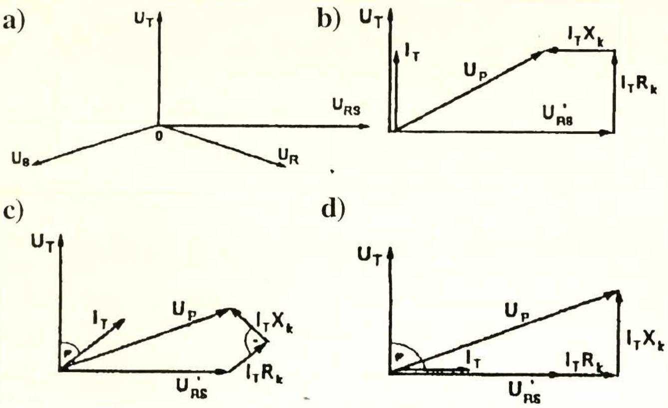

Fig. 5. Voltage phasor diagrams for current neutralization system and different power factors:
a) voltage star for three-phase generator shown in Fig. 4
b) voltage phasor diagram for cos $\varphi = 1$
(current I_T is in phase with voltage U_T): $U_P < U_{RS}'$
c) voltage phasor diagram for cos $\varphi = 0.8_{ind}$; $U_P = U_{RS}'$
d) voltage phasor diagram for cos $\varphi = 0_{ind}$;
(current I_T is lagged against voltage U_T by $\pi/2$): $U_P > U_{RS}'$.

The following relationship between voltage vectors, given in Fig. 5., may be written :

$$\vec{U}_P = \vec{U}_{RS}{}' + \vec{I}_T \vec{Z}_k = \vec{U}_{RS}{}' + \vec{I}_T (R_k + jX_k) \qquad (2)$$

Taking into account phase lag between phase-to-phase voltage vector $\vec{U}_{RS}{}'$ and phase current vector $\vec{I}_T$ equation (2) can be rewritten in relation to absolute value U_P as follows:

$$U_P = U_{RS}' + R_k I_T \sin\varphi + X_k I_T \cos\varphi \qquad (3)$$

where:

$$U_P = |\vec{U}_P| \quad , \quad U_{RS}' = |\vec{U}_{RS}{}'| \quad , \quad I_T = |\vec{I}_T|$$

and:

$$\vec{I}_T = I_T \sin\varphi + I_T \cos\varphi$$

Generalizing notation for current components of phase T, equation (3) may be written as:

$$U_P = U_{RS}' + R_k I_Q + X_k I_P \qquad (4)$$

where:

$$I_Q = I_T \sin\varphi \quad , \quad I_P = I_T \cos\varphi$$

External characteristics of a generator, whose voltage regulator is fitted with current compensating unit, may be expressed as follows [4]:

$$U(I) = U_0 - k_Q I_Q + k_P I_P \qquad (5)$$

where: U_0 - initial voltage

Generator's voltage U(I) from (5) is proportional to the lowered generator's voltage U_{RS}' from (4) therefore having compared these expressions it can be stated that: $R_k = k_Q$ and $X_k = k_P$. These coefficients can take positive or negative values, but the negative compensation of reactive power ($-k_Q I_Q$) is normally used and the positive one of active power ($+k_P I_P$) to obtain proper work of generators in parallel.

This is in accordance with the basic and necessary condition for stable reactive power distribution between generators working in parallel and fitted with excitation regulator. The condition is a descending external characteristics U=f(Q) of each generator, which can be expressed as:

$$\frac{\partial U}{\partial Q} < 0 \quad \text{for} \quad P = const \qquad (6)$$

where: P - active power

The condition (6) can be fulfilled and constant voltage on bus bars assured for a given power factor value if parameters k_Q and k_P are properly selected.

Constant voltage is obtained when the condition $k_Q = k_P$ is satisfied. For power coefficient value cos φ = 0,8 ,usually used as nominal, the parameters k_Q and k_P are so selected as to obtain $k_P = 0{,}75 k_Q$.

It is reflected in generator's external characteristics U=f(I) for different power factors cosφ, which correspond to the phasor diagrams from Fig. 5b-d, and is shown in Fig. 6.

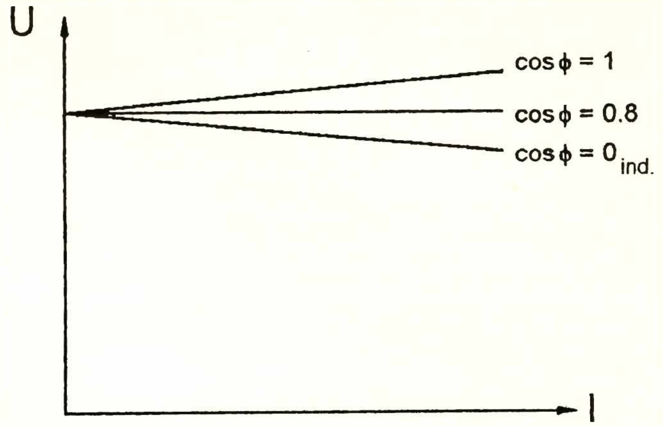

Fig. 6. External characteristics U=f(I) of a generator fitted with field regulator, at different power factors cosφ

CORRECTION OF REACTIVE POWER DISTRIBUTION BETWEEN GENERATORS WORKING IN PARALLEL

A problem arises how to correct reactive power improper distribution and where it is to be done. It seems to be an easy task looking at characterisics U=f(Q) as correct distribution can be assured only if the characteristics for both generators coincide. Correction of characteristics droop and its parallel shift is usually performed applying a regulator with two controllers (resistors), e.g. Polish voltage regulators of TUR, WGSY or RNGY types. One of the controllers is a resistor used for voltage level selecting (parallel shifting of characteristics) whereas the other is a reactive power potentiometer used for changing the characteristics droop.

In modern voltage regulators controlling resistors are avoided which in heavy shipboard working conditions (vibration, humidity, changeable temperature, salenity) change their technical parameters causing errors in voltage regulating system. Therefore constant-value resistors are soldered in voltage regulators, with resistance empirically selected in advance for a given electric power plant.

Identification of needed resistors is an additional difficulty in this situation. Characteristics droop and voltage level regulation is usually executed, regardless of the type of voltage regulator, in the same voltage regulator's unit (Fig. 3.), i.e. in its measuring-comparing unit. A signal from this unit, in a form of voltage error, is amplified in a pre-amplifier and then in a power amplifier, and as an output signal, it controls excitation current in generator's excitation system.

The correction procedure is the same for different types of field regulators. The crucial step is to draw external characteristics of both generators to a common point, i.e. levelling idle run voltage to the same value $U_{01} = U_{02}$. The task is simple but requiring a sensitive and good voltmeter to be used. At idle run it is necessary to regulate generator's phase-to-phase voltage to,say, 390 V, using potentiometer for voltage level control; then to switch on the generator for parallel work and load it as much as it is possible, not exceeding, of course, its rated power. The greater is the load the more distinct is the difference ΔQ between reactive power loadings of two generators, which is illustrated in Fig. 7.

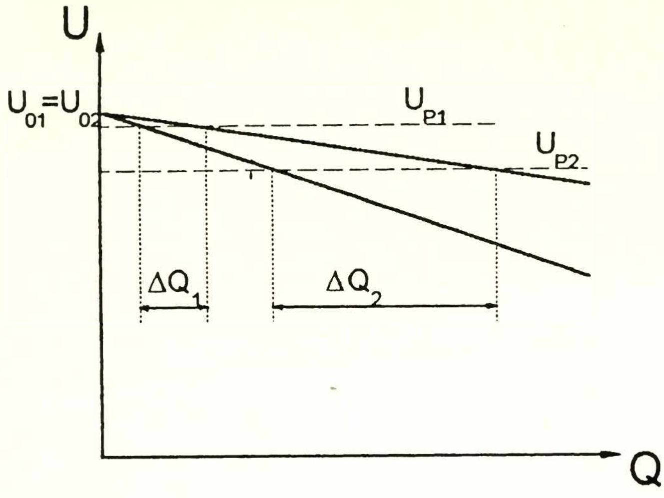

Fig. 7. Reactive power load difference ΔQ in relation to reactive power summary load of generators at different characteristics droop and equal idle run voltage $U_{01}=U_{02}$. U_{P1}, U_{P2} - load run voltages at different network loads.

Induction motors which must work in some ship's operation conditions may be used, for instance, as main energy consumers at addition reactive power loading of generators. It may be stand-by motors of the main engine auxiliary mechanisms, ventilators, hydraulic pump motors of deck cranes etc. These motors may be idle running as induction motors have a low power factor cosφ in that condition, consuming mainly inductive reactive power.

Proper active power distribution (set e.g. by hand) is a conditional for correction of reactive power distribution especially when kVar-meter are not installed and ammeters indications of parallelly working generators are the only sources of data on improper reactive power distribution. The last step in reactive power correction is setting external characteristics droops to be identical with the use of the a.m. potentiometer for reactive power distribution control. The potentiometer is not always installed outside voltage regulator and in such situation the regulator's structure should be examined for identification of parameters of reactive power distribution resistor and setting their new values.

The regulation is made in such a way as to cause indications of kVar-meters (or ammeters) to be identical at correct active power distribution. In the effect, identical indications of kVar-meters (or ammeters) should be observed at a variable-in-time load of the electric power plant.

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Appraised by Ryszard Białek, Assist. Prof., D. Sc., E.E.

Miscellanea

Polish Academy of Sciences contributes to maritime research

The importance of the sea for the economy, scientific research on the sea and its environment and the influence of the sea on climate and living conditions are appreciated in Poland. Dealing with these problems in Poland can be traced even to 200 years ago.

Polish famous voyager and geographer, H. Arctowski, professor of the University of Lwów was famous of his Arctic explorations. Another geographer, A.B. Dobrowolski headed a Belgian Antarctic expedition in 1897-1899 and later, in 1910 carried out research on Spitsbergen. Other Polish scientists contributed to sea exploration even before 1918, when Poland did not exist as an independent state.

In the period 1918-1939 Polish zoologist M. Siedlecki, professor of Kraków and Wilno Universities was very active in a research on Baltic Sea. There were also many others.

When Poland acquired an access to the sea, with all relevant economic advantages, the efforts in research increased and concerned not only Baltic Sea, but much further. The Arctic expeditions, continuation of those by Arctowski and Dobrowolski, were regularly organised.

After the World War II the research programs were resumed again. In the period 1960-1980 two research vessels were built: PROFESOR SIEDLECKI and PROFESOR BOGUCKI. Both ships played a very important role in the research for Polish fishery and living resources of the sea, like krill. The ships took part in a wide range of international research programs and did a good job there.

Poland wants to share all the benefits of sea resources, but does not avoid sharing the duties resulting from the international research programs, of both economic and purely scientific nature.

The Institute of Geophysics, Polish Academy of Sciences (IG PAN) is engaged in various long-term research programs. The research station of IG PAN on Spitsbergen operates permanently as a part of Arctic exploration project. The results of the research carried out by the scientists of Spitsbergen Station and the other one on King George Island have been an important contribution to those projects.

The Institute of Oceanology, Polish Academy of Sciences, in Sopot concentrates mainly on a research in Baltic Sea, acting in co-operation with other institutes of the European Union countries. The main subject of the research program carried out by the staff of the Institute have been sea resources and climate deviations related to the sea. But the same institute has also been a part of the research program of the Secretariat for Ocean and Polar Research, European Union. The Institute's research ship OCEANIA will undertake 10 voyages on Baltic Sea and several others to Arctic Zone to collect experimental data and observations.

Polish financial participation in the international research of the sea problems has been always significant, although recently limited due to restrictions of the fishing over the World Ocean. These limitations do not concern either the Institute of Geophysics, Polish Academy of Sciences, Spitsbergen Station, Institute of Ecology (King George Island Station) or the Institute of Oceanology. Therefore the Polish contribution to the science and exploration of the sea still remains significant and so are the results of the research achieved by Polish scientists.