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Optimization of ship electrical power system modes according to reactive power

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Abstract: The use of high quality electricity is essential to ensure optimal modes of the ship's electrical installations. One of the indicators of the quality of electricity is the power factor, which can be increased by reducing the reactive power. One of the ways to solve this problem is the optimal distribution of reactive / inactive power. This paper discusses the determination of reactive source capacities based on the relative increment method with minimal losses.
Keywords: Active power losses; Reactive power losses; Reactive power compensation.

1. Introduction

On the scale of raising automatization quality of modern ship's power plants and propulsion machinery, simultaneously raises the demand on the quality of produced electricity.

The improvement of technical economical indicator of ship's power plants can be carried out by creating ship's electro-energetical system, which can provides with electrical power not only ship's common electro-consumers, but in case of necessity, the ship's propulsive system.

Ship's electro-energetic system is aotonomous system, which includes limited number of generators and large amount of loading, the majority of them consists of asynchronous motors. From the point of view of electro-energetic balance, choosing the generators must be done while designing a ship, in order to meet all energetic requirements, namely, according to active power (W) and reactive power (VAR).

Very often carried out analysis on electric loading includes requirements only about active power (Prousalidis JM 2015 [8]). Accordingly, the problems about the meeting of requirements of reactive power arise. The correct distribution of reactive power defines the load value of the electrical power system and efficiency improvement.

2. Main text

It is possible to provide optimal modes of ship power plants by using power plants control systems. Accordingly, the demand for high quality electricity is increasing. Many factors affect negatively on the electricity quality. Power losses are mainly caused by: active power (I^2R) losses, energy (I^2Rt) losses, cable overheating and voltage drop (IR) losses. All these losses mainly depend on the power circulating in the network. Also, modern power network is unthinkable without semiconductor converters and regulators. This, in turn, leads to distortion of the sinusoidal current (the content of higher harmonics increases), decrease in power factor so increase of inactive powers.

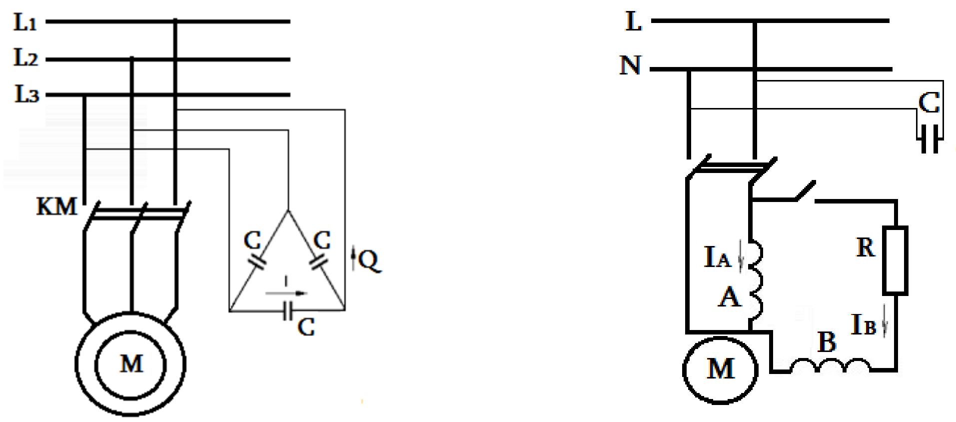
Reducing / eliminating of these negative factors is the most important task of the ship's power system. Nowadays, there are two ways of solving inactive power compensation (Dudko S. 2018 [2], Luong Thu Phong 2009, [4]): reactive power compensation; distortion power compensation. Reactive power compensator (RPC) and active filter (AF) are the basic elements of a compensating device.

Traditional approaches to inactive power compensation don't meet modern requirements, due to huge mass-size indicators, low efficieny, small frequency regulation range, and other factors. Usually changing any units in the electrical power system in order to improve the quality of electricity causes a number of difficulties. It's better to use compensating devices, which can be located at any point of electrical power system.

It should also be taken into account, that asymmetric loads are frequent in electrical systems in general and on board ships too. In these cases, the use of a three-phase compensating device based on static capacitor batteries is unacceptable. Due to the asymmetry of the reactive load, it is advisable to determine individually the compensation capacity for different phases (Chunashvili B. 2016 [1]).

In ship's electrical power systems, where shaft-generators are in operation, synchronous compensators are used to compensate reactive capacities. A synchronous compensator is a synchronous motor, that is not loaded and is connected in parallel with the electrical power supply system. Like synchronous generators, their reactive power is regulated by excitation connected to an autonomous voltage regulator, which regulates the excitation current of the rotor coil. In this case the compensator acts as a reactive energy source or as an inductor that absorbs the reactive power (Prousalidis JM, 2009 [6]).

Compared to all methods of reactive power compensation, it is considered that the best method is the correct distribution of reactive power in the electrical network (Prousalidis JM, 2011 [7]). The expected changes in the distribution of reactive power in the large loads mode of the electric network is minimal. In case of small loads no significant effect will be obtained. This is caused due to the following factors: in the case of large loads, the reactive power reserve is relatively small; transmission of reactive power in the network is associated with an increase in voltage loss. In addition to the above mentioned, reactive power transmission is connected with the increase of active and reactive power losses. Therefore, the task of transmitting reactive power will be substantially reduced to the use of the nearest compensating device to the consumers, as a result, transmission lines will be protected from overload (Makharadze G, 2000 [5]).



a b

Figure 1. a - 3-phase motor with reactive power compensation capacitor battery;

b - single-phase motor with reactive power compensation capacitor.

The experiments carried out showed the importance of the correct selection of the capacitor battery. It must be selected individually for each induction load. Table 1 shows the experiment results, which clearly shows the effect of a properly selected capacitor battery. The parameters without index correspond to the parameters of the inductive user connected to the network without a compensating device, and the index 1 – parameters of capacitor battery in case of switched on mode. Specifically, if triangly connected capacitors with 10 microfarads capacitance are connected in parallel to a 3-phase motor (Figure 1. a), the reactive power will increase and the power coefficient will decrease - at nominal load (M = 1.57Nm) from 0.77 to 0.37.

When connected capacitors with 2 microfarads capacitance to the same motor, the reactive power significantly reduced and the power factor incread maximally - at nominal load (M = 1,57Nm) from 0,77 to 0,86, the importance of the circulating current value was also reduced from 0,87 A to 0.66 A. It is also effective to connect capacitor battery to a single-phase motor (Figure 1.b), the power factor has been increased from 0.68 to 0.86, the current has been reduced from 0.12 A to 0.1A.

Table 1

Motor type	**1phase motor**	**3 phase motor**			**3 phase motor**		
P (W)	18	470	287	448	470	287	448
Q (VAR)	18	131	402	371	131	402	371
S (VA)	27	491	494	581	491	494	581
cosϕ	0,68	0,27	0,58	0,77	0,27	0,58	0,77
I (A)	0,12	0,74	0,74	0,87	0,74	0,74	0,873
U (V)	220	387	387	387	387	387	387
M (Nm)	0,123	0	1	1,57	0	1	1,57
n (1/min)	1400	1484	1424	1350	1484	1424	1350
C (μF)	0,74	3x10	3x10	3x10	3x2	3x2	3x2
I_1 (A)	0,1	1,44	1,63	1,74	0,35	0,47	0,66
P_1 (W)	18	144	303	427	130	293	436
Q_1 (VAR)	8	-958	-1036	-1053	188	112	86
S_1 (VA)	21	987	1099	1158	232	315	445
$\cos\phi_1$	0,86	0,15	0,26	0,37	0,56	0,93	0,96

The optimal distribution of reactive power Q, without taking into account the technical limitations, can be calculated by the relative increment method that is the Lagrange method. Assume reactive power generation is not associated with any costs. In this case, the only aim of the optimal distribution of reactive power should be the reduction of active power losses. Suppose, active powers are given and they are unchanged. Such assumption is approximate, because the changes of losses in network and are caused by changes of active powers in the electrical power plants. The losses due to this assumption will depend on the Q reactive power. It is possible to determine the minimum of a function by using the Lagrange method (Idelchik V.I 1988 [3]):

$$\boldsymbol{F = \Delta P + \lambda W_Q} \tag{1}$$

Where,

$W_Q = Q_{r1} + Q_{r2} + \cdots . + Q_{rk} - Q_{\wp} - \Delta Q = 0$ – reactive power balance equation;

ΔQ - reactive power loss;

k – the number of reactive power sources;

Q_L - total load value, which in the given case is constant $Q_L = const$

$\boldsymbol{\lambda}$ **–** horozontal vector of the matrix created by appropriate parameters,

$$\boldsymbol{\lambda = \frac{\partial F}{\partial S} = (\frac{\partial F}{\partial P}, \frac{\partial F}{\partial Q})} \tag{2}$$

If reactive power generation don’s require costs, the optimal conditition will be recorded as follows:

$$\begin{cases} \dfrac{\partial F}{\partial Q_{r1}} = \dfrac{\partial \Delta P}{\partial Q_{r1}} + \lambda\left(1 - \dfrac{\partial \Delta Q}{\partial Q_{r1}}\right) = 0; \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . \\ \dfrac{\partial F}{\partial Q_{rk}} = \dfrac{\partial \Delta P}{\partial Q_{rk}} + \lambda\left(1 - \dfrac{\partial \Delta Q}{\partial Q_{rk}}\right) = 0, \end{cases} \tag{3}$$

From this,

$$-\boldsymbol{\lambda}=\frac{\frac{\partial \Delta P}{\partial Q_{r1}}}{1-\frac{\partial \Delta Q}{\partial Q_{r1}}}=\cdots=\frac{\frac{\partial \Delta P}{\partial Q_{rk}}}{1-\frac{\partial \Delta Q}{\partial Q_{rk}}}=\mathbf{const}$$

(4)

This equation allows us to determine the reactive power of all sources, corresponding to the ΔP minimum losses of the active power of the network. As a result, energy losses in the network will be reduced. It should be noted that for generating 1 kilowatt of electricity on average, 0.084 litres (0.07 kg) of diesel fuel is used. As a result of its burning, 3 times the mass of CO_2 (approximately 0.21 kg) is produced (Prousalidis JM 2015 [8]). Therefore, the reduction of losses is directly reflected on reduction of emissions.

3. Conclusion

All the measures tend to solve ecological problem are very important today. In this regard, it is important to reduce emissions. The world fleet is very large and consequently the volume of emissions received from the production of electricity on each ship are large. Reducing losses in the electrical system is one of the ways to reduce emissions. This is achieved by optimizing the power system modes according to the reactive power. We can choose two ways:

- Only a small number of vessels are equipped with reactive power compensators. That's why, it is necessary to modernize the ship's electric power systems, which means to install static capacitors in parallel with inductive loads. The selection of the capacitance of the capacitors should be done according to the inductive loads.
- The correct distribution of reactive power at the stage of ship planning is very important. It is possible to determine the reactive power sources with minimal losses using the relative increment method (Lagrange method), followed by the minimum active power loss in the net and the increase of system efficiency.

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