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Computerized Study of the Naval Electric Power Flow

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Abstract. Modelling and design of the naval electric power system (NEPS) represents a complete and great importance task, giving information for the generation, transmission and distribution system. NEPS is very complex as configuration, but also as technical electrical analysis. This engineering scientific approach needs professional software tools dedicated. - Energy Distribution System Analysis (EDSA) software is one of the valuable professional tools capable to give the complete analysis for all power systems technical aspects, like safety, power flow continuity, stability, efficiency, maintenance, quality. The paper focuses on a real study case of an oil tanker NEPS. The results of the analysis, show that most consumers are active and reactive power consumers and some consumers introduce reactive power into the system and are therefore reactive power sources. Active and reactive detailed power flow results show equipment power loading, power losses values, total electric power balance. It reflects the designing state and NEPS functional conditions accuracy.
Keywords: Marine Industry, Computer Design, Naval Power System, Power Flow Efficiency.

1. Introduction

The electrical power system is constantly evolving. The need to study the behaviour of networks has led to the development of a series of special professional programs for system analysis (Woud& Stapersma, 2019), (ICCT, 2011), (Ivanova, 2021). Energy Distribution System Analysis (EDSA) is a collection of over 50 software programs dedicated to the design, analysis and operation of electrical networks and systems. The integrated EDSA program system represents a set of powerful calculation and modelling tools that allow solving electrical problems from the design phase to the operation and maintenance phase of electrical systems and networks. The design advantages are:

- analysis according to IEC and IEEE standards;
- unlimited number of buses and branches can be modelled;
- unlimited scenarios can exist;
- no frequency/impedance limits;
- database with many symbols and electrical equipment;
- allows to create new symbol catalogues and introduces new equipment data;
- 100% AUTOCAD® compatible;
- import/export dwg, dxf, html, doc, xls;
- organize the project on multiple pages or drawings

The technologies used are: ActiveShapes technology, Plugs&Sockets technology, Back Annotation technology, Coloring technology, Hyperlink technology. The types of the system modelling refer to: three-phase electric power systems, non- symmetrical three-phase electric power systems, three-phase single-phase combined electric power systems, single-phase electric power systems, alternating current, direct current combined electric power systems, direct current electric power systems. The areas of application are:

- electricity transmission and distribution networks;
- power plants hydroelectric, thermoelectric, nuclear;

- petrochemical plants, refineries and oil platforms;
- industrial electrical power systems;
- naval electrical power systems.

2. EDSA power flow module description

Steady-state analysis module include: three-phase and single-phase alternating current networks, alternating and/or direct current networks, engine starting mode analysis, steady-state analysis over time periods, voltage stability analysis and contingency analysis (Abel-Günther&Geisler, 1999), (Boon&Poorte,2003), ().

Advanced Power Flow program is a robust algorithm that includes the following modelling capabilities:

- Local Generators with node voltage control;
- Solution techniques: Newton-Raphson Fast De-coupled, Advanced Gauss Seidel;
- Generator models can have different operating modes: fixed power, fixed active power & voltage control;
- Voltage control using two- or three-winding transformers;
- Transformers can be equipped with on-load tap changers for voltage control in the local node or in the remote node;
- Reactive compensation, shunt capacitor and reactor can be modeled;
- Power transfer between regions. Each region has a dedicated generator to control the bridging in the connecting power line;
- Modeling of DC lines and converters;
- Motor starting characteristics based on IEEE standards;
- No limitation on the number of nodes.

Program outputs include node angles and voltages, reactive power, voltages and nodes controlled remotely (if any), power factor for generators, reactive, active power circulation and branch power circulation factor; line and total system losses, total power generation, consumption, power losses and system mismatch detection, voltage drop ratios vs. user-defined values.

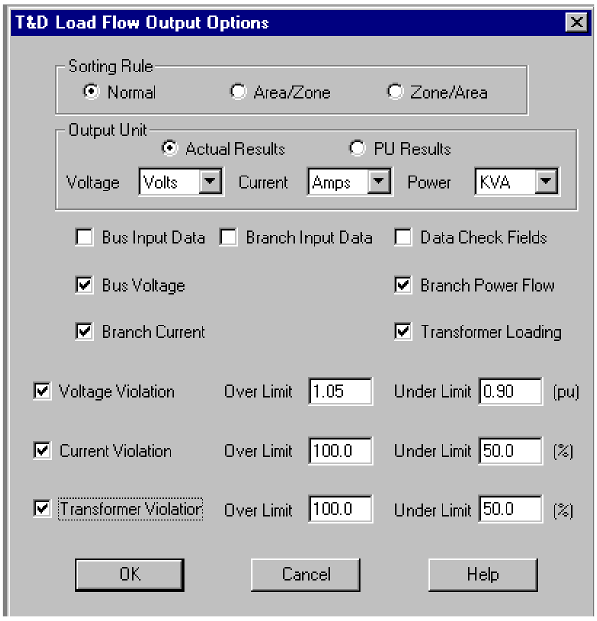

Figure 1. Load flow module - output setting options

In Figure 1 can be seen that is possible to check Bus Voltage, Branch Power Flow, Branch Current and Transformer Loading. Also is possible to change the tolerances for voltage, current and transformer loading, enabling voltage level violation, current level violation, transformer loading violation. Figure 2 shows for example bus voltage EDSA results: voltage level, voltage drop, active power P, reactive power Q, power factor PF. You will notice that we have some unacceptable voltage drops at a few nodes.

T&D Load Flow Output

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Copyright (c) 1983-2003, EDSA MICRO CORP.
EDSA AC Load Flow Program v3.20.00

Page 4

Job File: C:\EDSAT2K\Projects\Cosmin\LAB2-EDITARE ECHIPAMENTE 03/30/2004 00:39:34 pm

Checked by: Date:

Bus Voltage Results

#	BUS	Label		V (VOLTS)	DROP (%)	ANG (DEG)	P (KW)	Q (KVAR)	PF (%)
1	UTILITY		S	13800	0.00	0.0	1414	1073	79.66
2	GEN1		GPQ	467	2.66	-1.4	1000	500	89.44
3	480MTR1		L	465	3.03	-1.4	-333	-152	91.00
4	480MTR2		L	465	3.03	-1.4	-333	-152	91.00
5	BUS1		N	3871	6.96	-4.4	0.000	0.000	
6	BUS2		N	467	2.72	-1.4	0.000	0.000	
7	J#1018		N	466	2.99	-1.4	0.000	0.000	
8	J#1020		N	466	2.99	-1.4	0.000	0.000	
9	J#1022		N	466	3.01	-1.4	0.000	0.000	
10	J#1024		N	466	3.01	-1.4	0.000	0.000	
11	MOTOR1		L	3871	6.96	-4.4	-857	-531	85.00
12	MOTOR2		L	3871	6.96	-4.4	-857	-531	85.00

Figure 2. Load flow module – bus voltage overview.

Auto Bus Voltage Control Output

Exit Print Print Setup Printer Font Clipboard Save As DONE

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EDSA AC Load Flow Program v3.20.00

Page 1

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*** Voltage Corrective Strategy ***

iterations = 1

Bus Voltage Results

BusID	No	V(old)	V(new)	Vmax	Vmin
480MTR1	1	0.9697	0.9989	1.0500	0.9500
480MTR2	2	0.9697	0.9989	1.0500	0.9500
BUS1	3	0.9304 *	0.9606	1.0500	0.9500
BUS2	4	0.9728	1.0018	1.0500	0.9500
GEN1	5	0.9734	1.0024	1.0500	0.9500
J#1018	6	0.9701	0.9993	1.1000	0.9500
J#1020	7	0.9701	0.9993	1.1000	0.9500
J#1022	8	0.9699	0.9991	1.1000	0.9500
J#1024	9	0.9699	0.9991	1.1000	0.9500
MOTOR1	10	0.9304 *	0.9606	1.0500	0.9500
MOTOR2	11	0.9304 *	0.9606	1.0500	0.9500

Control Variables Are Transformer Taps

Transformer Tap Control Results

FromID	ToID	No	Tap(old) (pu)	(tap)	T(new) (pu)	(tap)	Steps	T(max) (pu)	T(min) (pu)
BUS1	BUS2	1	1.000	0	1.000	0	30	1.101	0.899
UTILITY	BUS1	11	1.000	0	0.973	-4	30	1.101	0.899

Figure 3. Load flow module results– automatic voltage control implementation

Automatic Voltage Control is a very powerful tool (Vasilikis et al, 2023), (Kaanders, 2005) . It is implemented in all EDSA packages. As can be seen from the load flow analysis results, there were some unacceptable voltage drops at some busbars. EDSA can implement Tap Settings (Setting transformer taps), Capacitor Sizes (sizing and placing capacitors), Generator Kvar settings (Setting the reactive power of generators), or any combination of these three methods.

EDSA shows the old voltage values, the new values improved according to the recommendation, and the deviations you requested. EDSA also shows the tap on which the transformer was initially operating and the one on which it should operate now, Figure 3.

3. Naval electric power system study case modelling

We will build in EDSA program the single diagram of an oil tanker. The electrical system of the oil tanker is divided into two identical regions that can be connected in case of failure by an automatic switch. Each region is powered by two diesel electric generators with a power of 4000kW. Voltage levels found in the system are:

- 11kW for the power busbars: “BUS1”, “BUS2”;
- 6kV for the power busbars: “BUS3”, “BUS5”, “BUS7”, “BUS9”;
- 380V for the power busbars: “BUS4”, “BUS6”, “BUS8”, “BUS10”.

The program allows editing the scheme by colour, depending on the voltage level. The study case electrical power system is presented in Figure 4.

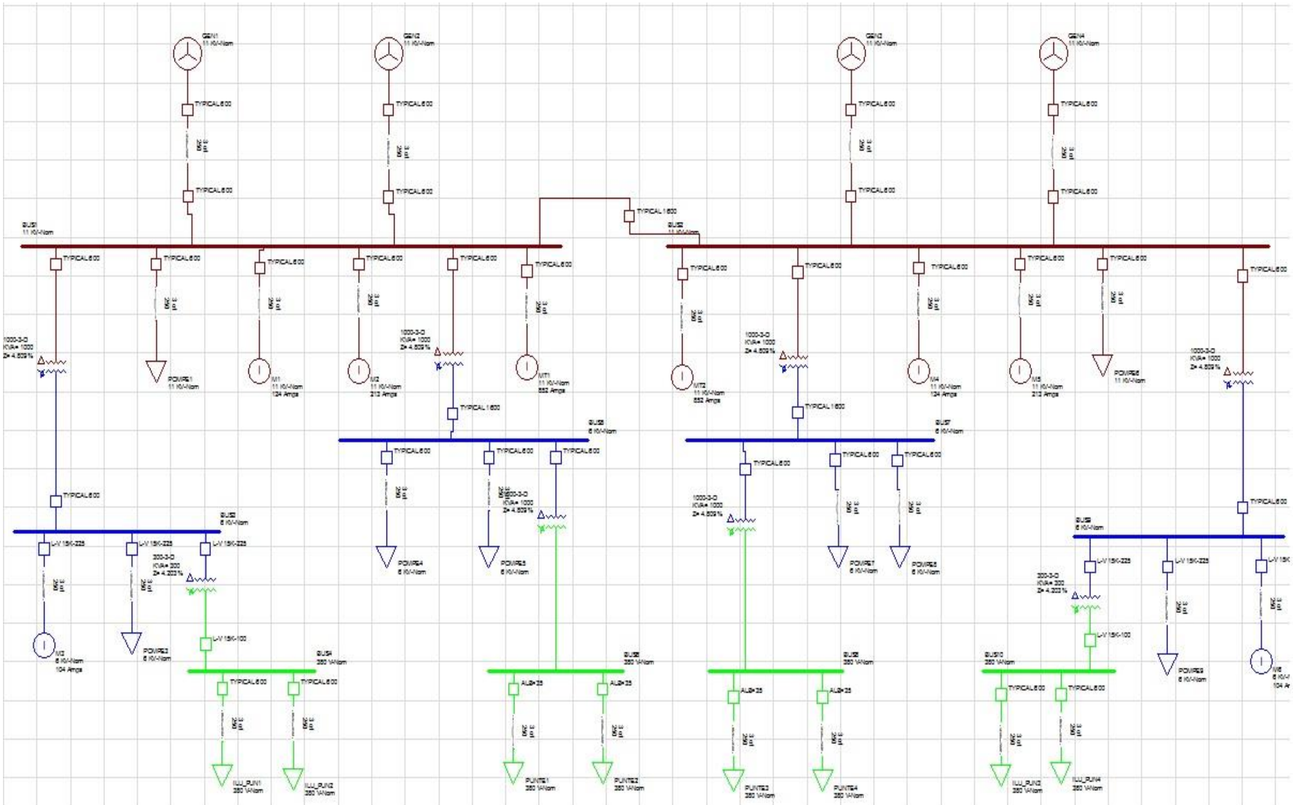

Figure 4. Single diagram for naval power system – presented on different voltage levels.

Single diagram of NEPS study case has busbars and branches equipment explained bellow.

- BUS1/BUS2:
  - Trafo 1/3 –11kV/6kV, 5000MVA;
  - Pomp 1/6 –101A, 1600kW;

- M1/4 – motor propulsion 1750kW, 124A;
- M2/5 – motor propulsion 3000kW, 212A;
- Trafo 2/4 – 11kV/6kV, 1000MVA;
- MT1/MT2 – principal motor propulsion 12000kW, 851A.

- BUS 3/BUS9:
  - Trafo 5/8 –6kV/0.4kV, 300kVA;
  - Pomp 3/9 –20A, 176kW;
  - M3/6 – motor 800kW, 104A;
- BUS 4/BUS10:
  - Ilum punte 1/3 –50A;
  - Ilum punte 2/4 –50A.
- BUS 5/BUS7:
  - Pomp 4/7 –100A, 883kW;
  - Pomp 5/8 –100A, 883kW;
  - Trafo 6/7 –11kV/6kV, 1000kVA;
- BUS 6/BUS8:
  - Punte 1/3 –20A;
  - Punte 2/4 –20A.

To highlight how the diagram was obtained in the EDSA technical program, the configuration modes of some of the electrical equipment used in the oil tanker's electrical power system are presented in Figures 5, 6.

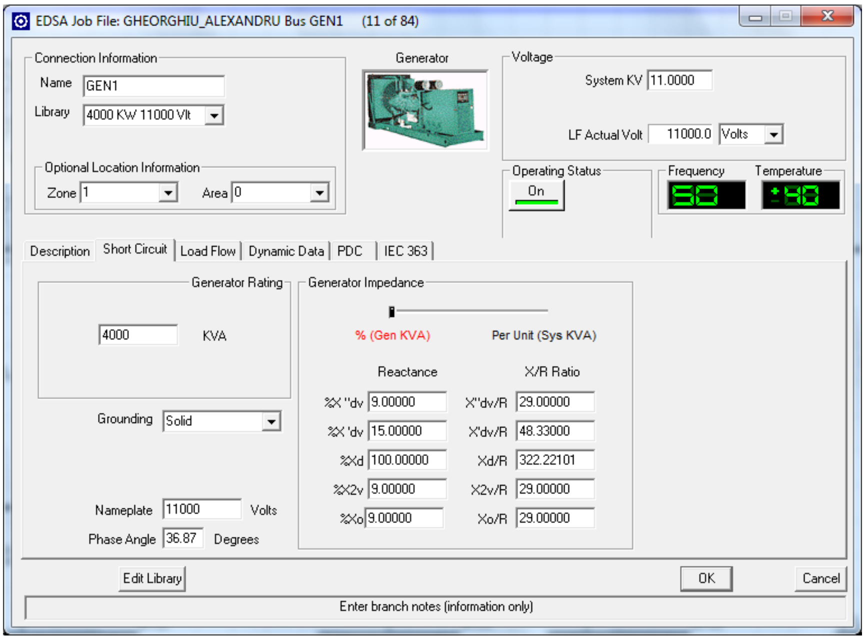

Figure 5. Parameters window for the electric generator

The windows present the short-circuit data of the diesel-electric generator and the active power supplied to the system. The program allows the selection from its own library of motors with the parameters required by the project. In the electric motor window are presented essential motor parameters such as power factor, efficiency, number of poles, shaft power and supply voltage, which are required. Short-circuit parameters are also presented in this window.

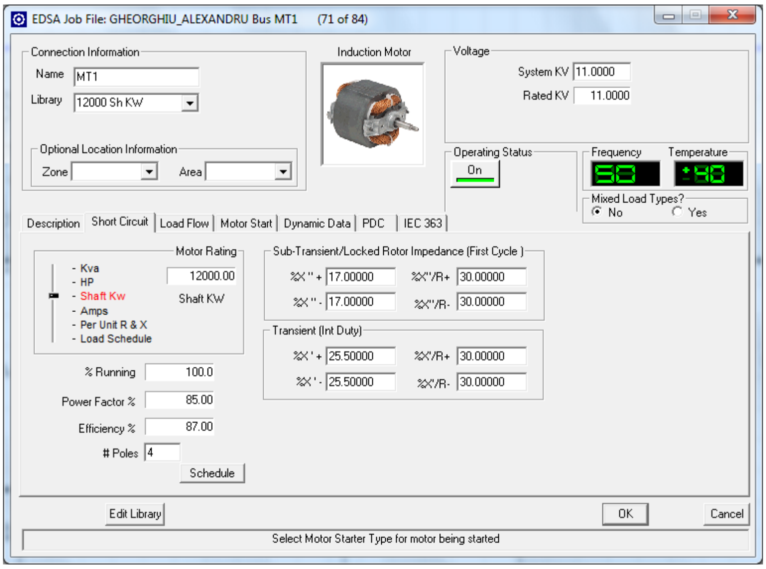

Figure 6. Parameters window for the electric motor

In the “Dynamic Data” section, the motor starting mode can be chosen depending on the operating requirements. The starting mode, chosen for all motors in the power system, is by regulating of the frequency for the supply voltage.

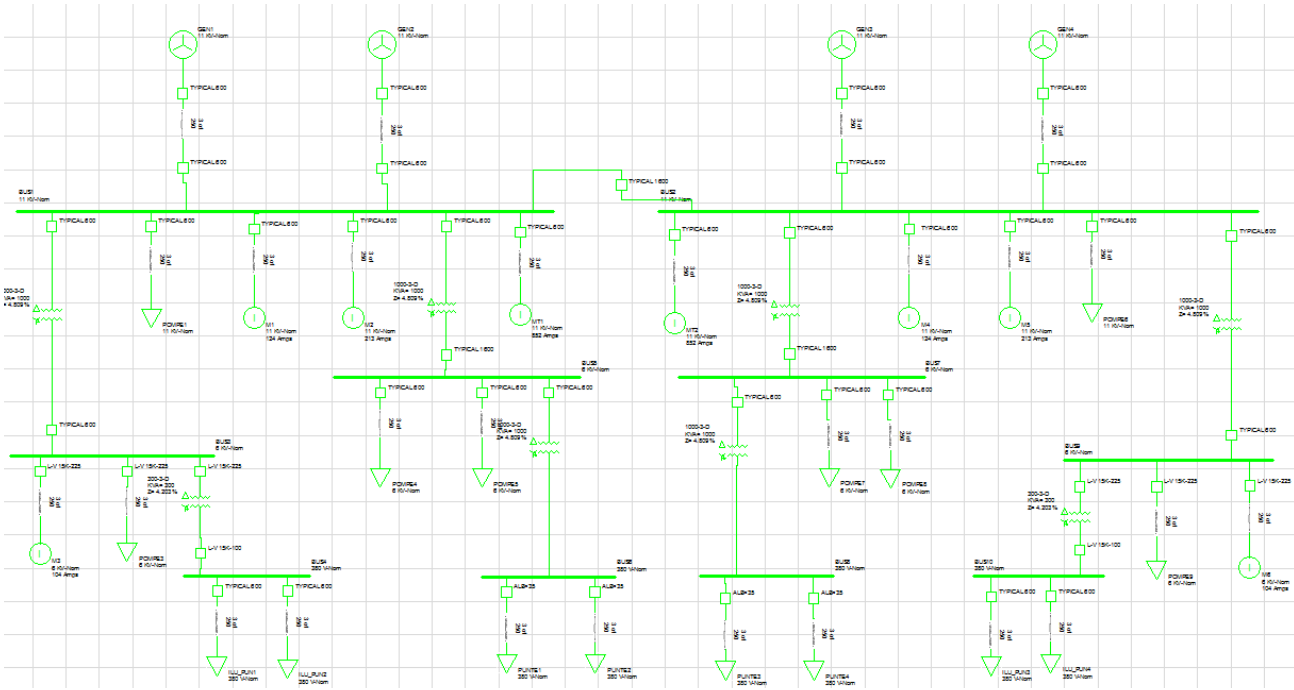

Figure 7. Power flow analysis performed by highlighting problem areas

The program allows the power flow analysis to be performed by highlighting problem areas in red and problem-free areas in green. This analysis also highlights areas, that may have problems in operation and indicates the electrical equipment that has been used and is not overloaded because it was chosen correctly by the designer. Figure 7 shows these results.

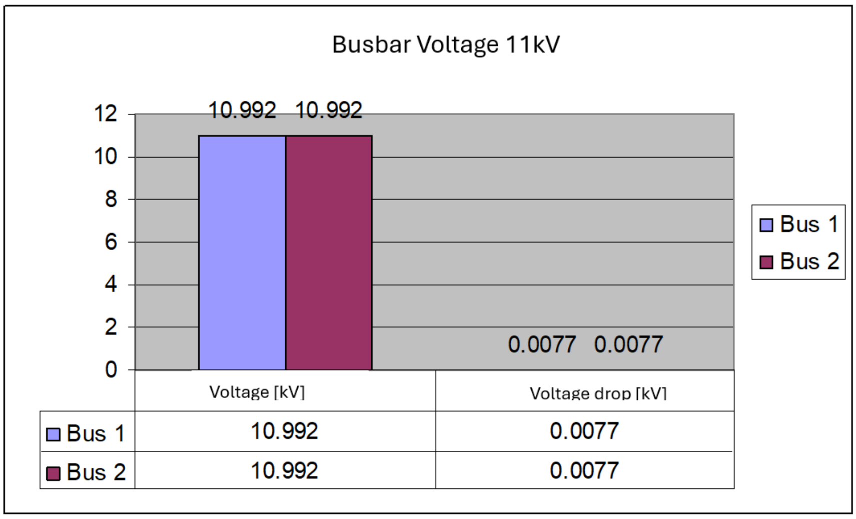

Figure 8. Power flow analysis 11kV busbars

Figure 8 shows voltage levels and voltage drops for 11kV busbars which are "BUS1" and "BUS2". This analysis gives us a view of the behaviour of the power electric system in the real operating environment. Figure 9 shows voltage levels and voltage drops for 6kV busbars, having the same purpose as 11kV busbars, only that in this case the voltage does not come directly from the generator, it comes from the power transformer station. In Figure 10, the same analysis is made for 400V supply busbars namely "BUS 4", "BUS 6", "BUS 8" and "BUS 10". These busbars show a very low voltage drop considering that the voltage level is also low. These power lines were fed by means of two transformer power stations, 11kV, 6kV respectively.

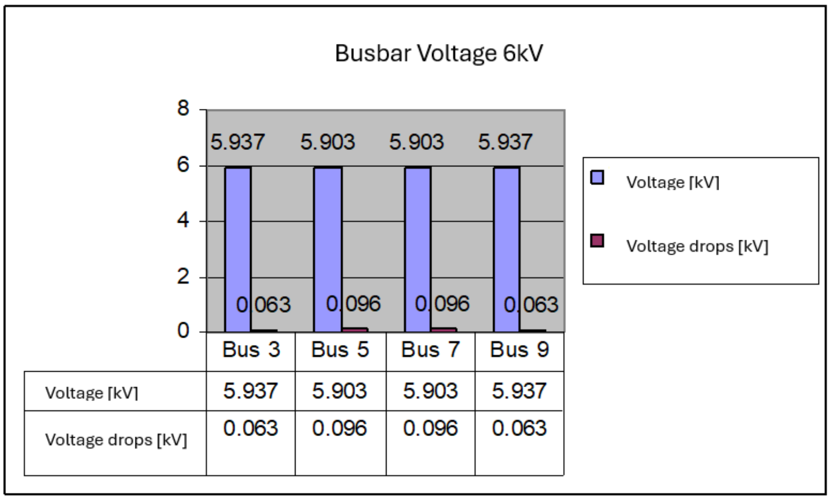

Figure 9. Power flow analysis 6kV busbars

A detailed analysis is needed for the efficiency evaluation of the electric power systems (YIĞIT, 2022), (Nijland& Van Beek, 2008), (Ivanova, 2020, 2021). EDSA software can give detailed about systems performance and is giving information about the efficiency and safety of the power system. Figure 11 and Table 1 show the analysis computerized results for the electric generators such as nominal voltage, active and reactive power, consummers power demand, power losses.

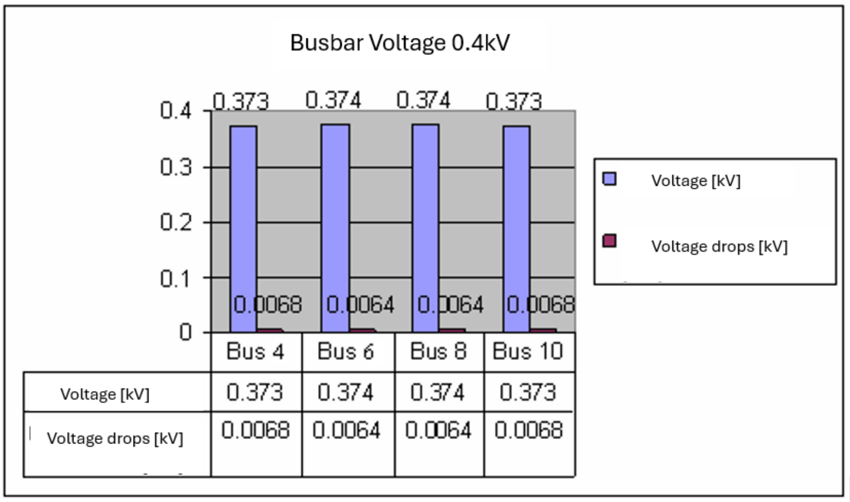

Figure 10. Power flow analysis 0.4kV busbars

It is necessary to visualize these parameters because they help us in selecting the number of active consumers and the number of consumers in reserve because the generators are chosen for a certain load.

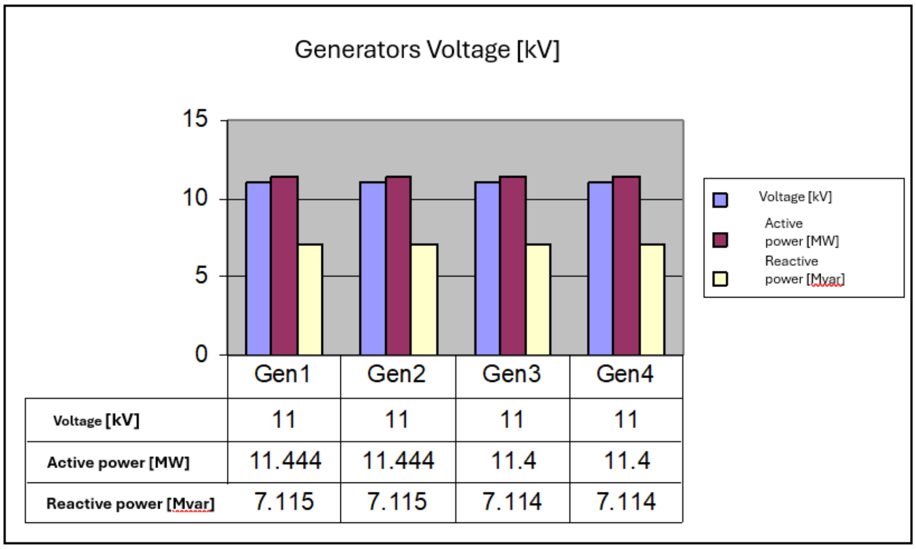

Figure 11. Power flow for electric generators supplying the consumers

Table 1 Summary of Total Generation and Demand

	P [MW]	Q [MVAR]	S [MVA]	PF [%]
Generators	45.688	28.459	53.827	84.88
Static Load	7.282	4.513	8.567	85.00
Motor Load	38.333	23.757	45.098	85.00
Total Loss	0.073	0.189		

4. Conclusions

Computerized Study of the Naval Electric Power Flow needs an advanced software packages dedicated to the design, analysis and operation of electrical networks and systems using personal computers (PCs). EDSA (Energy Distribution System Analysis) is one of the most powerful integrated software systems. It represents a set of powerful calculation and modeling tools that allow solving electrical problems from the design phase to the operation and maintenance phase of electrical systems and networks. EDSA represents the design, analysis and modeling tool necessary in the engineering and management of electrical energy distribution. It reduces the time required for design, increases the quality of projects and makes it possible to operate the electrical system at optimal performance.

Some of the conclusions, related to the abstract results of the analysis, show that most consumers are active and reactive power consumers and some consumers introduce reactive power into the system and are therefore reactive power sources. This type of active power consumers are capacitive loads. The total active and reactive power consumed reflects the fact that the generators are loaded around 90% of their capacity, which is an important positive result, considering that in this analysis the motors and pumps that are in reserves for other motors were also considered. It can be said that the power circulation in the naval electric power system is detailed represented, according with EDSA analysis.

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