REACTIVE POWER ON A POWER LINE CONNECTED FROM ONE END

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Keywords: line testing; reactive power;

Abstract: *Reactive power generated by power lines is one of the factors determining the level of voltage substations bars. Lines are often used for raising or lowering the voltage level. It is very important to monitor the level of voltage and reactive power supply lines. When the power consumption decreases, increases the voltage on transformer stations bars. As a preventive measure off lines that do not impair the operation of the national energy system(SEN). Disconnecting lines produce a decrease in the level of voltage.*

1. INTRODUCTION.

The development of electric power facilities during time had several stages, from energy supplying of each electric power consumer till organizing the grid elements in an electric power system, following the technical development of the equipments and with a high level of reliability and economic efficiency [1].

The electric power system comprises the producing and distribution facilities for the electrical energy on a certain territory [1].

The electric lines from the power grid are air-isolated. The major benefit of this is that they are cheaper comparing with the electrical cables but they will certainly have a reduced exploit being subject to direct weathering [1].

During the analyses of the operation mode of an electric grid we shall build the equivalent circuit of that grid, which results from interconnecting the equivalent wiring diagrams of each system element. Thus we shall calculate the electrical parameters for the grid elements in two cases: for steady state and for electric fault [2].

The computing of the electrical parameters of the power grid it means knowing some factory data or experimental data obtained for each grid element [2].

The electric grid is modeled using equivalent circuits which are connected accordingly with the real situation from the ground. The equivalent circuits of the transmission and distribution grid usually consists of nonlinear passive elements, series or shunt connected. The electrical parameters are (fig.1) R– resistance, X– reactance, B– susceptance, G– conductance[1]

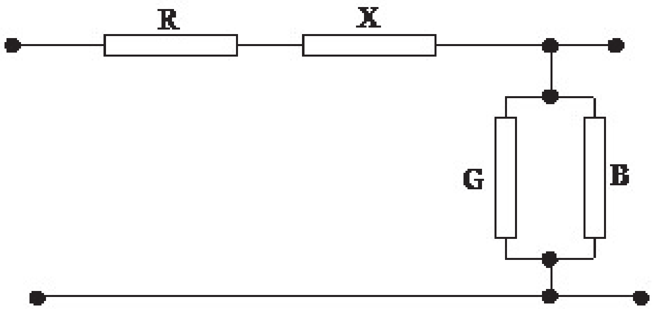


Fig. 1 – Equivalent schematic of the installations for transport and distribution

1.1 The electrical parameters of the overhead power lines

The overhead power lines are three-phase elements of the transmission and distribution grid which sometimes are protected against thunder stroke with a special conductor[1].

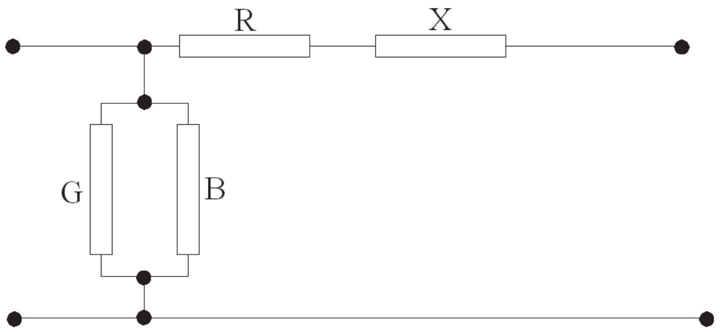


Fig. 2 – Equivalent of a Schematic overhead power lines

The equivalent circuit for an overhead power line consists of the series parameters resistance R and $X = \omega L$ wich together makes the series impedance $Z = R + jX$, the shunt parameters conductance G and susceptance G și $B = \omega C$, wich together makes the shunt admittance $Y = G + jB$, [1].

If the three-phase currents wich flows in the power line are symmetrical and balanced than the addition of these current makes zero so they have no impact on the power line electrical parameters[3].

For the zero phase-sequence currents wich are flowing through the ground, the single-phase loops connecting the line and the ground provides the path for the return of their .In the zero phase-sequence state the grounding system turn path influences the power line electrical parameters[3].

1.1.1 The Power Line Resistance

The resistance of the power line is the active series electrical parameter which represents the series active power losses into the real power line.[1]

For the direct current:

$$R = \rho * \frac{l}{S} [\Omega] \tag{1}$$

In which: ρ – is the resistivity of the electrical conductor , in $\Omega mm^2 / m$

l – is the electrical conductor's length, in m

S – is the conductor's cross-section in mm^2

For the alternating current:

$$R = \frac{\Delta P}{I^2} [\Omega] \tag{2}$$

In which: ΔP are the series active power losses

1.1.2 The Power Line Reactance

The inductive reactance for a single phase circuit is:[1]

$$X = \omega L = 2\pi f L [\Omega] \tag{3}$$

In which: L is the phase inductance in H, and f is the a.c. current frequency in Hz.

The inductance is given by the total magnetic flux through a surface surrounded by a loop divided by the electrical current flowing through that loop.

$$L = \frac{\Phi_t}{i} [H] \tag{4}$$

1.1.3 The Power Line susceptance capacitive

Conductors of power lines form a capacitor, with the metal conductors and earth reinforcement. Thus, if a three-phase line without protective conductor are six capacitors, three between line and earth conductors with capacity C_{10}, C_{20}, C_{30}, and three between pairs of capacitors, with partial capacity C_{12}, C_{23}, C_{31} (fig.3)[1]

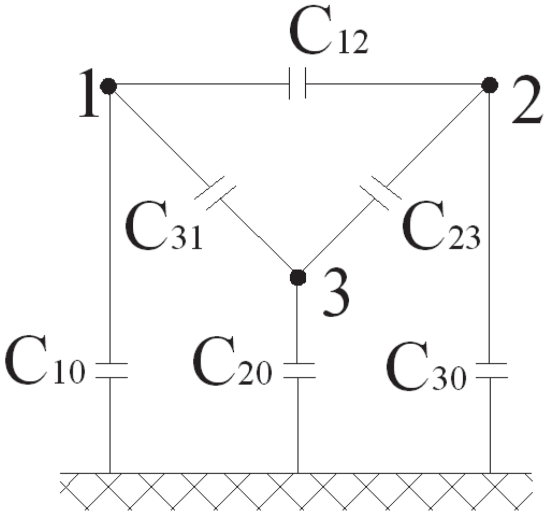


Fig.3 – The Power Line partial capacity

The capacity of a parallel earth conductor is defined by the relation (5):

$$C = \frac{q}{V}[\mu F] \tag{5}$$

1.1.4 The Power Line conductance

Transverse conductance parameter of the scheme is equivalent to a corresponding power lines cross the active power losses [1].

Overhead electrical lines these losses are due to imperfection of insulation and corona phenomenon. [1] The conductance of an airline per unit length of the line (1km) is determined by the relation (6):

$$G_0 = \frac{\Delta P_{iz} + \Delta P_c}{U_n^2} * 10^{-3}[S/km] \tag{6}$$

In witch: ΔP_{iz} și ΔP_c three phase power losses are due to imperfection of insulation that corona phenomenon, in kW/km, and Un is the nominal voltage of the grid [1].

Due to the imperfection of cable insulation at points of attachment to a current leakage occurs posts by insulation to earth. They are more intense as the weather conditions are adverse (fog, rain, etc.) [4, 7]

1.2 Presentation power transmission line model SEL-1/EV

In order to study the reactive power flow we use power transmission line mod. SEL 1-/EV manufacturing Elettronica Veneta Italy (fig. 4).[5]

Two high-voltage power transmission lines with the possibility of varying their parameters are reproduced in this equipment. This simulator enables to learn and test the characteristics and the management of high-voltage mains systems on components of reduced scale. The various electric devices installed, partially connected with each other and with safety terminals, start working with very simple and fast operations offering the possibility of modifying parameters and circuits at operators' will.[5,6,8]

The frontal panel is made of aluminum alloy, the power transmission lines are represented with international electric symbols; using unified educational terminals and safety jumpers with a high degree of protection against accidental contacts, will enable to carry out series / parallel connections. Acting some lever switches will change the electrical parameters (resistance, inductance and capacitance) according to different sections and lengths of the line. Voltage is signaled by warning lights, whereas the protection against overloads and/or short circuits is carried out by fast-blow fuses. [5,6,8]

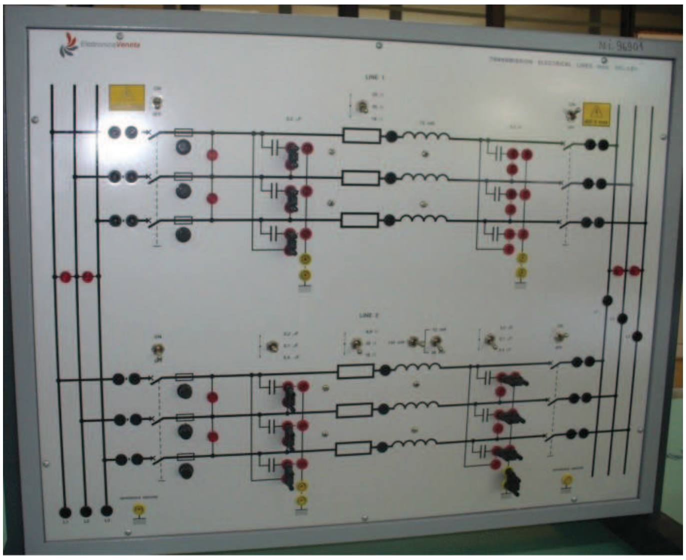


Fig.4 Power Transmission line mod SEL-1/EV- Front view

1.2.1 Technical characteristics

Line 1[5]

- Modifiable parameter: Section
- Model of line used: P I
- Simulated voltage:120 kV(working U 3x400Vmax.)
- Simulated power: P 10 - 15 - 20 MVA
- Working current: 1 A
- Equivalent resistance: 18 - 25 - 35 Ω
- Equivalent inductance: 72 mH
- Equivalent distributed capacitance: 2 x 0.2 μF
- Breakers at the beginning and at the end of the line
- Protection fuses 1A

Line 2 [5]

- Modifiable parameter: Section
- Model of line used: P I
- Simulated voltage:120 kV(working U 3x400Vmax.)
- Simulated power: P 20 MVA
- Working current: 1 A
- Equivalent resistance: 8.9 - 25 - 35 Ω
- Equivalent inductance: 144-72-36 mH
- Equivalent distributed capacitance:2 x 0.1-0.2-0.4 µF
- Breakers at the beginning and at the end of the line
- Protection fuses 1A

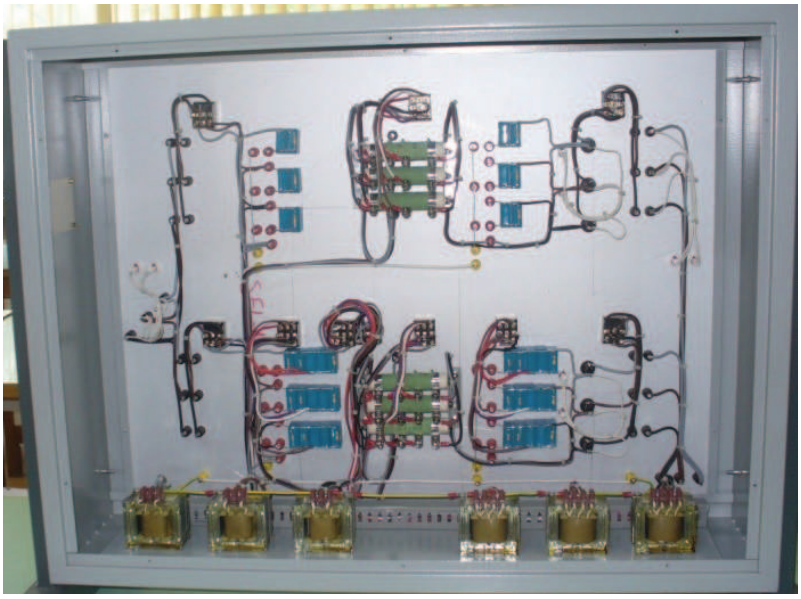


Fig.5 Power Transmission line mod SEL-1/EV- Connect components

1.2.2 Using the simulator

— Generally the power transmission lines reproduced in the simulator are powered on the left side of the schematic diagram so that the protection fuses are located at the origin of the line [5].

— The busway (vertical lines of the left side) is powered through the terminals indicated by L1 - L2- L3; the warning lights indicate the availability of mains voltage[5].

— The LINE 1 and/or the LINE 2 will be shunted from the left busway, through jumpers or leads with plugs. The lever switches available at the origin of each line enable to cut them out of the starting busway . Each line is also protected from overcurrents (overload and short circuit) with fast-blow fuses, and provided with warning lights for indicating the availability of mains voltage, at its origin[5].

— The right busway is connected at the end of the lines (right side) still through jumpers or leads with plugs; the transferred energy can be drawn from this busway. The lever switches available at the end of each line enable to cut them out of the destination busway[5].

1.2.3 Configuration and typical use of a line

— Remove all the jumpers of the LINE 2 not considered.

— Connect the jumpers at the origin and at the end of the LINE 1.

— Turn the breakers at the origin and at the end of the LINE 1, to OFF.

— Connect the jumpers with the left capacitors, only in the LINE 1, to reproduce the capacitance between active conductors.

— Connect the jumpers with the right capacitors, only in the LINE 1, to reproduce the capacitance between the active conductors and the ground.

— Adjust the position of the selector Resistance LINE 1 at the desired value.

— Connect with the three-phase power supply, and power (the allowed voltage value ranges from 0 to 400 V, and only if this value is around at half range, the warning lights available on the left busway will be on).

— Turn the breakers at the origin and at the end of the LINE 1, to ON, in sequence; now the destination busway is energized and the voltage will be indicated by respective warning lights.

2. MEASUREMENTS AND DISCUSSIONS

2.1. Studying the operation of a power transmission line in no-load conditions (no-load current of the transmission line).

To perform the measurements we will need:

— Simulator of electric lines mod. SEL-1/EV

— Variable three-phase power supply mod. AMT-3/EV, in option threephase line generated by the generator control board mod. GCB-1/EV, or a fixed three-phase line 3 x 380 V

— Three-phase transformer mod. P 14A/EV

— Set of leads/jumpers for electrical connections

— 2 electromagnetic voltmeters with range of 250 - 500 Vac

— 1 electromagnetic ammeter with range of 100 mAac

— 1 electromagnetic wattmeter with low power factor 1-2 A / 240-480 V

— The instruments of the generator control boards mod. GCB-1/EV or two digital instruments for measuring the parameters of electric energy in three- phase systems mod. AZ-VIP, can be used as alternative.

Preparing the exercise:

- Considering the transmission LINE 1 with the following constants: Resistance = 25 Ω; Capacitance = 0.2 μF; Inductance = 0.072 H; Length = 50 km; Section = 35 mm2 – conductor of copper.
- Remove all the jumpers of the LINE 2 not considered.
- Turn the breakers at the origin and at the end of the LINE 1, to OFF.
- Connect the measuring instruments between the left busway and the terminals at the beginning of the LINE 1.
- Connect the measuring instruments between the end terminals of the LINE 1 and the right busway.
- Connect the jumpers with the set of left capacitors, only in the LINE 1, to reproduce the capacitance between active conductors (called CL). These capacitors can be connected either in star or delta configuration. The delta connection will ensure stronger capacitive currents.
- Connect the jumpers with the set of right capacitors, only in the LINE 1, to reproduce the capacitance between the active conductors and the ground (called CE); connect also the jumper that grounds the star centre of the capacitors. In this case the only star connection can be carried out because each line conductor generates a capacitance to the ground.
- Adjust the position of the selector Resistance LINE 1 at the value of 25 Ω.
- Connect with the variable three-phase power supply by inserting the three-phase insulation transformer.

The reference electric diagram, the connections and configuratation of the line are respectively shown în the figure 6.

- Enable and adjust the voltage of the power supply at 380 V. The warning lights of the left busway will be on .Turn the breaker at the origin of the LINE 1, to ON.
- All the parameters of the starting energy can be measured with the digital instrument available at the origin of the line.
- Turn the breaker at the end of the LINE 1, to ON.
- Read the electric quantities on the measuring instruments and write them down in the following table compare the reactive power measured on the line to that calculated with the following formulae:

$$Q_L = \Omega * C_L * U_1^2 = 2 * \pi * 50 * 0{,}2 * 10^{-6} * 380^2 = 9VAR \tag{7}$$

$$Q_E = \Omega * C_E * U_0^2 = 2 * \pi * 50 * 0{,}2 * 10^{-6} * 220^2 = 3VAR \tag{8}$$

Q_L - reactive power due to the capacitance between two active conductors;

Q_E - reactive power due to the capacitance between an active conductor and the ground.

Q_L and Q_E resulting from the formulae indicated above are calculated for only one phase. The total reactive power of the three-phase system will result from the sum of the powers of both the three line capacitors and the three capacitors to the ground.

Total reactive power of the transmission line:

$$Q_{TOT} = 3*Q_L + 3*Q_E = 36VAR \tag{9}$$

The sign – (minus) indicates that the reactive power is of capacitive type

2.1.1 Reactive power calculation as a function of variations in voltage.

$$Q_L = \Omega * C_L * U_1^2 = 2*\pi*50*0,2*10^{-6}*400^2 = 10VAR \tag{10}$$

$$Q_E = \Omega * C_E * U_0^2 = 2*\pi*50*0,2*10^{-6}*220^2 = 3VAR \tag{11}$$

$$Q_{TOT} = 3*Q_L + 3*Q_E = 39VAR \tag{12}$$

$$Q_L = \Omega * C_L * U_1^2 = 2*\pi*50*0,2*10^{-6}*390^2 = 9,55VAR \tag{13}$$

$$Q_E = \Omega * C_E * U_0^2 = 2*\pi*50*0,2*10^{-6}*220^2 = 3VAR \tag{14}$$

$$Q_{TOT} = 3*Q_L + 3*Q_E = 37,66VAR \tag{15}$$

$$Q_L = \Omega * C_L * U_1^2 = 2*\pi*50*0,2*10^{-6}*380^2 = 9VAR \tag{16}$$

$$Q_E = \Omega * C_E * U_0^2 = 2*\pi*50*0,2*10^{-6}*220^2 = 3VAR \tag{17}$$

$$Q_{TOT} = 3*Q_L + 3*Q_E = 36VAR \tag{18}$$

$$Q_L = \Omega * C_L * U_1^2 = 2*\pi*50*0,2*10^{-6}*370^2 = 8,56VAR \tag{19}$$

$$Q_E = \Omega * C_E * U_0^2 = 2*\pi*50*0,2*10^{-6}*220^2 = 3VAR \tag{20}$$

$$Q_{TOT} = 3*Q_L + 3*Q_E = 34,7VAR \tag{21}$$

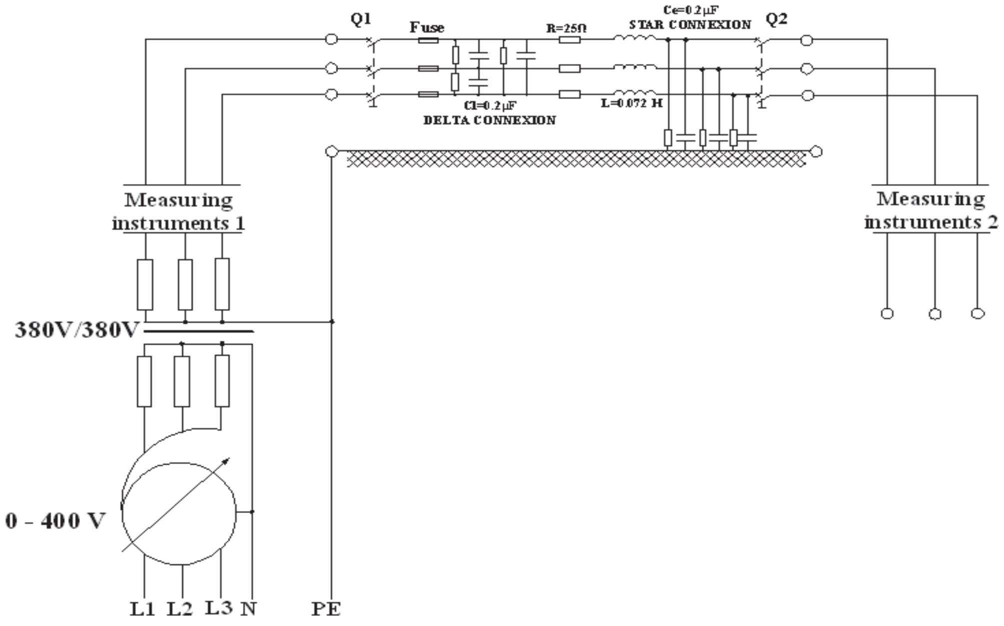


Fig.6 Power transmission line in no-load condition. Reference electric diagram

$$Q_L = \Omega * C_L * U_1^2 = 2*\pi*50*0,2*10^{-6}*360^2 = 8,14VAR \qquad (22)$$

$$Q_E = \Omega * C_E * U_0^2 = 2*\pi*50*0,2*10^{-6}*220^2 = 3VAR \qquad (23)$$

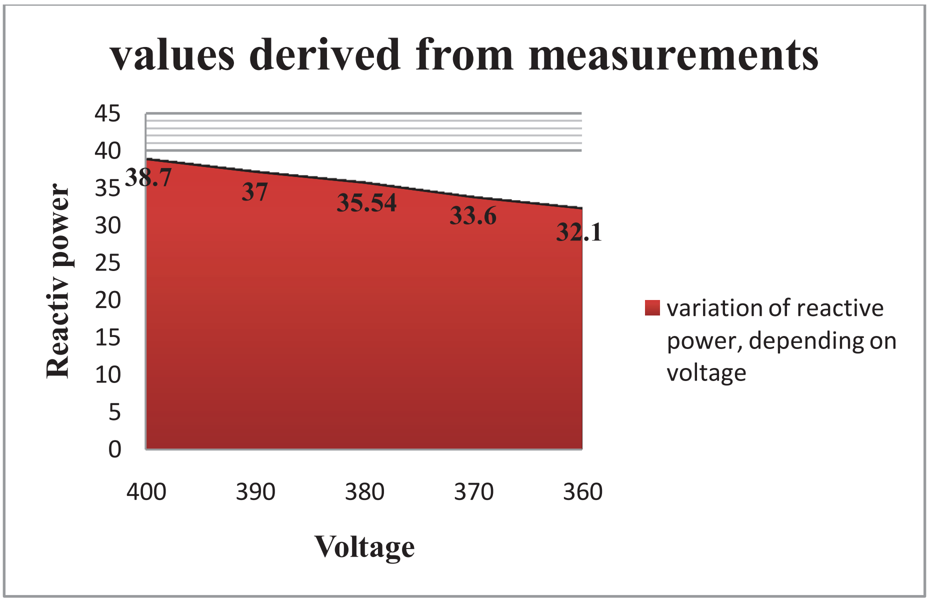
$$Q_{TOT} = 3*Q_L + 3*Q_E = 33,42VAR \qquad (24)$$

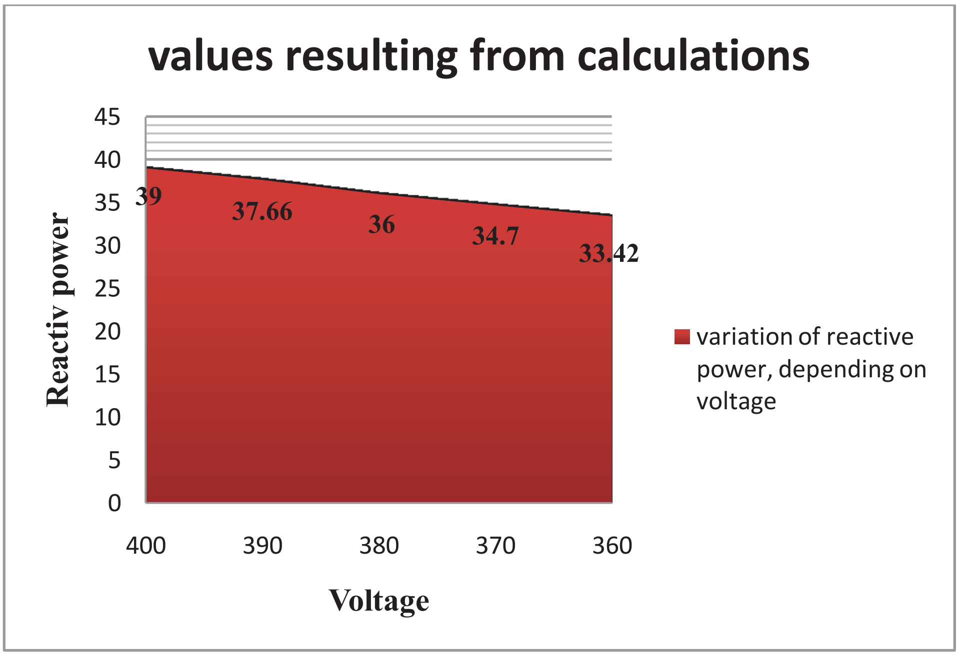
Table 1. The value measurements carried out on the basis of voltage variation

Interlinked voltage measured at the rigin of the line U1 (V)	Line current measured at the origin of the line I1 (A)	Active power measured at the origin of the line P1 (W)	Interlinked voltage measured at the end of the line U2 (V)	Reactive power measured at the origin of the line Q1 (Var)
400V	0,056A	0W	400V	-38,7Var
390V	0,055A	0W	390V	-37Var
380V	0,054A	0W	380V	-35,54Var
370V	0,052A	0W	370V	-33,6Var
360V	0,051	0W	360V	-32,1Var

Table 2. reactive power and current results of calculations

Voltage U1[V]	Current I [A]	Reactive power Q1 (Var)
400V	0,057A	39Var
390V	0,056A	37,66Var
380V	0,055A	36Var
370V	0,054A	34,7Var
360V	0,053A	33,42Var





2.2. Studying the operation of a transmission line in no-load conditions with increased capacitance (no-load current of the transmission line)

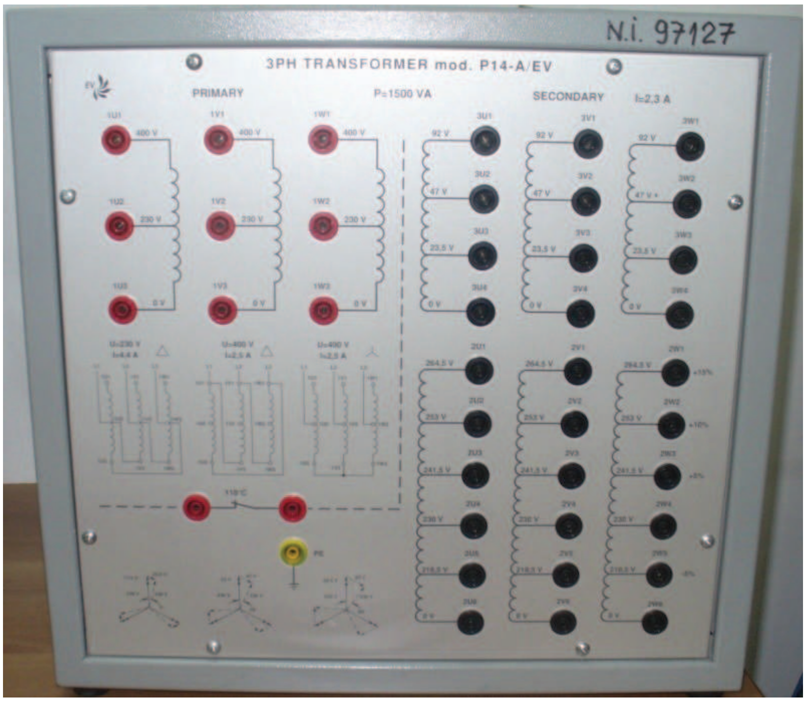


Fig 7. Three-phase transformer mod. P 14A/EV

Preparing the exercise:

It uses the same type of equipment as the previous year following completion:

- Battery of capacitors, for instance that of 3 x 2 μF of the module AZ 191b, with the respective discharge resistances.

Prearrange the simulator as in the previous exercise(fig 6) and connect the capacitors of the module AZ 191a in parallel with CL(becoming CLaux).-fig 8

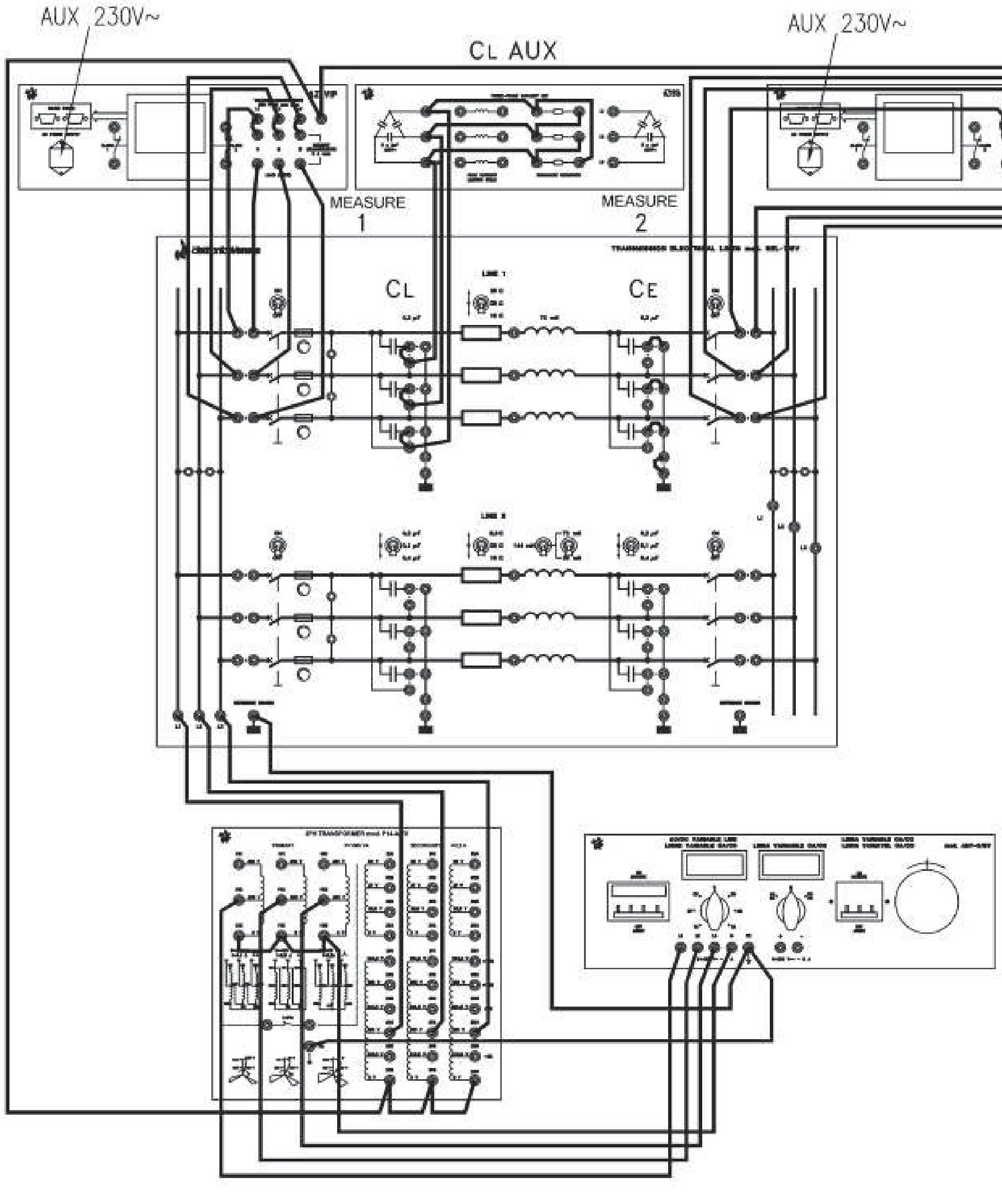


Fig 8. No-load performance of a power transmission line with increased capacitance

Actual measurements carried out on the LINE 1 with: Resistance = 25 Ω; Capacitance = variable 0.2 – 2.2 – 4.2 μF; Inductance = 0.072 H

Table 3 - transmission lines with auxiliary capacitors CLaux from the origin of the line

Capacitance (µF)	Interlinked voltage at the origin of line U1 (V)	Current at the origin of the line I1 (A)	Active power at the origin of line P1 (W)	Interlinked voltage at the end of the line U2 (V)	Reactive power at the origin of line Q1 (Var)
0.2 µF	380 V	0.052 A	0	380 V	- 34.5 VAr
2.2 µF	380 V	0.520 A	0	380 V	- 340 VAr
4.2 µF	380 V	0.860 A	0	380 V	- 568 VAr

Studying the transmission lines represented with concentrated parameters will lead to consider that shifting the set of auxiliary capacitors CLaux from the origin of the line to the half length of the line and to the end of the line determines what is explained herebelow:

- when the auxiliary capacitors CLaux are connected at the origin of the transmission line, the capacitive current crossing it will concern only the generator and it does not provoke any effect on the line resistance inductance;
- when the auxiliary capacitors CLaux are connected at half length of the transmission line, the capacitive current crossing it will also affect the resistance where it provokes a power loss by Joule effect R x I^2;
- when the auxiliary capacitors CLaux are connected at the end of the transmission line, the capacitive current will cross not only the resistor (as in the previous point), but also the coil where it provokes a further power loss R x I^2due to the resistive component of the coil (the coils of the simulator are wound on a ferromagnetic core and consequently they also have a resistive component).

Actual measurements carried out on the LINE 1 with: Resistance = 25 Ω; Capacitance = variable 0.2 – 2.2 – 4.2 µF; Inductance = 0.072 H

Table 4 - transmission lines with auxiliary capacitors CLaux from the origin of the line to the half length of the line and to the end of the line

Capacitance (µF)	Interlinked voltage at the origin of line U1 (V)	Current at the origin of the line I1 (A)	Active power at the origin of line P1 (W)	Interlinked voltage at the end of the line U2 (V)	Reactive power at the origin of line Q1 (Var)
0.2 µF origin of line	380 V	0.052 A	0	380 V	-34.5 Var
0.2 µF half line	380 V	0.044 A	4 W	380 V	-29Var
0.2 µF end of line	380 V	0.055 A	6 W	380 V	-36 Var
2.2 µF origin of line	380 V	0.52 A	0	380 V	-340 Var
2.2 µF half line	380 V	0.51 A	18 W	380 V	-335Var
2.2 µF end of line	380 V	0.53 A	23 W	380 V	-350 Var

4.2 µF origin of line	380 V	0.86 A	0	380 V	-568 Var
4.2 µF half line	380 V	0.82 A	26 W	380 V	-540Var
4.2 µF end of line	380 V	0.90 A	32 W	380 V	-590 Var

The sign – (minus) indicates that the reactive power is of capacitive type. The measured power can have a deviation of +/- 10 % for the tolerance of capacitors

3. CONCLUSIONS

Following measurements it was found that the values resulting from calculations are very close to the results of measurements. The difference is due to errors of measurement devices. It is found in the presented reactive power measured is directly proportional to the mains voltage.

The parameter of capacitance is directly proportional to the length of the transmission line .It is concentrated into an equivalent total capacitance only for an easier study. Actually the “parameters” of a transmission line (capacitance and resistance in this particular case) are distributed; crossing the line resistors the capacitive currents will provoke power

The values obtained from the calculations can help both the operating personnel, working with the line having voltage levels 6,10,20,35,110,220,400,750 kV, the understanding of how power flows reactive Upon awakening in the line is in operation only one end the other is the backup, and the measures to be taken to control reactive power influencing the nodes tensions.

ACNOWLEDGMENT

This paper is supported by the Sectoral Operational Programme Human Resources Development POSDRU/159/1.5/S/137516 financed from the European Social Fund and by the Romanian Government

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