EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

Course exercises KEE/EZE

Overview of topics:

1. Reliability of simple systems with application to power unit conditions.
2. Investigation of the self-consumption ratio of power plant units with specific ratios for a thermal power plant and a unit using a turbocharger.
3. Creation of a substitute diagram of the power plant unit and its own consumption, calculation of basic parameters of the substitute circuit.
4. Calculation of the basic design of self-consumption transformers for the HV and LV level from the working and backup source.
5. Control of the power design of the self-consumption power supply transformer for steady state and overload conditions during peak drive start-up and self-start-up.
6. Calculation of short-circuit ratios in the self-consumption of the power plant and the influence of nearby unsymmetrical short-circuits.
7. Moment characteristics of drives in self-consumption power plants, driven equipment, calculation of input power of driven equipment.
8. Starting the engines, operation during the drop - self-starting and re-starting.
9. Voltage ratios and drive warming during start-up or loss of voltage and restart after power failure for motor groups.
10. Phasor diagram of synchronous machine, stability of synchronous machine.
11. Calculation of the size of the impedance elements of the alternator replacement scheme.

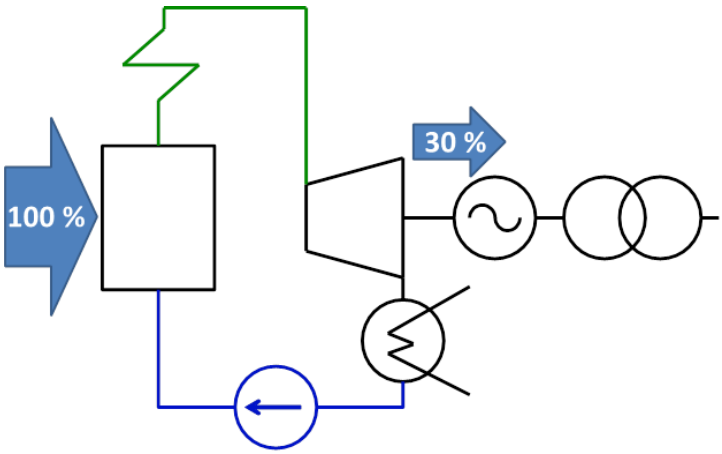
1 Exercise number 1 - 22-03-10

1.1 Calculation tool

For all the examples below, it is possible and convenient to use MATLAB-compatible tools for checking and variant calculations for a deeper understanding of the dependence of results on partial parameters.

For example, the GNU Octave tool (https://octave.org/) can be recommended, which is available free of charge for all major platforms and is even accessible as an online free cloud service (https://octave-online.net/)

1.2 Comparison of the self-consumption of a power plant and a heating plant



1. Own consumption of the power plant

$$V.S.[\%] = \frac{V.S.[MWh]}{A_P[MWh]}100$$

$$V.S.[MWh] = \frac{V.S.[\%]}{100}A_P[MWh]$$

$$A_P[MWh] = Q_{TEP}[MWh]\frac{\eta_E[\%]}{100}$$

$$V.S.[MWh] = \frac{V.S.[\%]}{100}Q_{TEP}[MWh]\frac{\eta_E[\%]}{100}$$

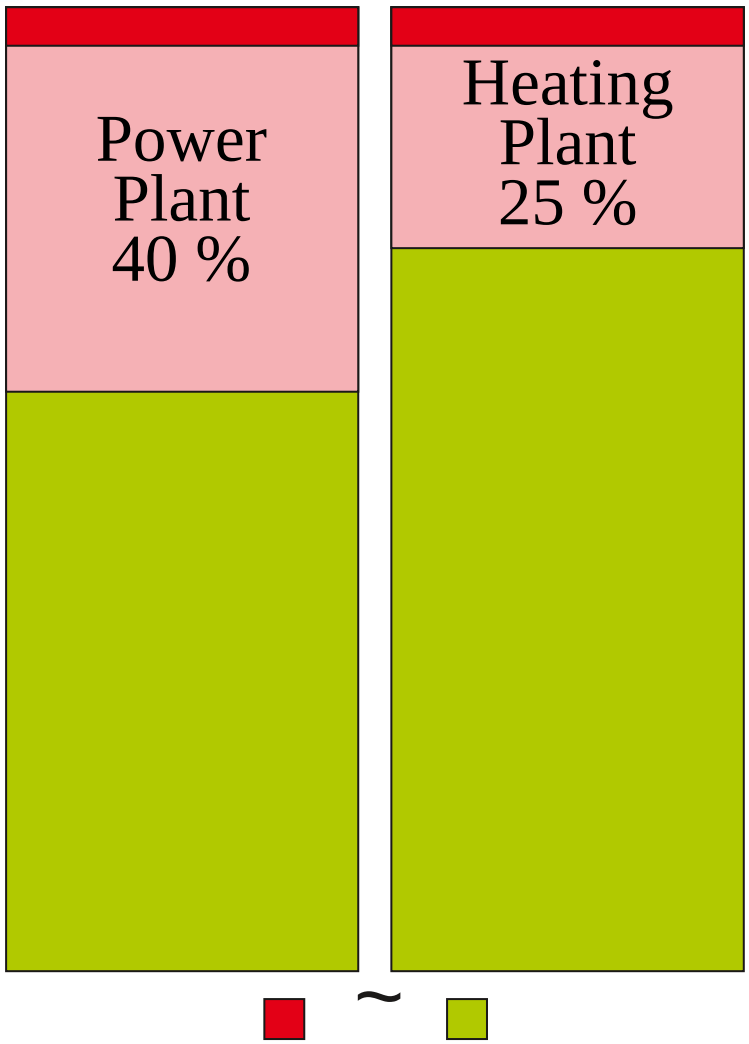
Qtep=100
Qtep_day=24*Qtep
ETAel_el=0.3
VSproc_el=10
VSMWh_el=Qtep_den*ETAel_el*(VSproc_el/100)
Ap_el=Qtep_den*ETAel_el
VSMWh_el=Ap_el*(VSproc_el/100)

Qtep = 100
MW
Qtep_day = 2400
MWh
ETAel_el = 0.3000
-
VSproc_el = 10
%
VSMWh_el = 72
MWh
Ap_el = 720
MWh
VSMWh_el = 72
MWh

2. Own consumption of the heating plant

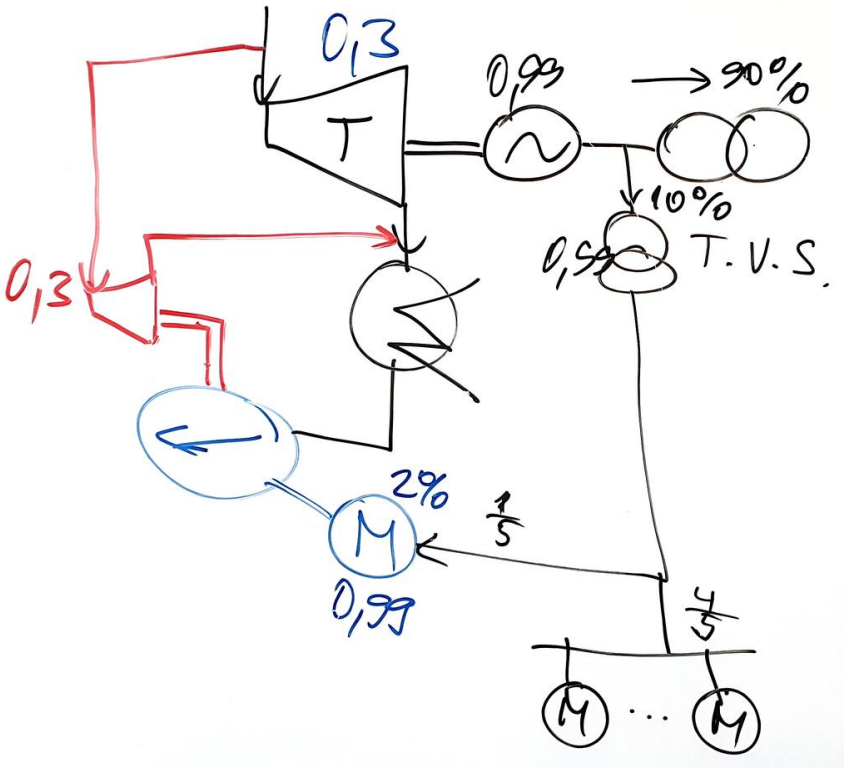
ETAel_tep=0.2
VSproc_tep=14
VSMWh_tep=Qtep_den*ETAel_tep*(VSproc_tep/100)
Ap_tep=Qtep_day*ETAel_tep
VSMWh_tep=Ap_tep*(VSproc_tep/100)

ETAel_tep = 0.2000
-
VSproc_tep = 14
%
VSMWh_tep = 67.200
MWh
Ap_tep = 480
MWh
VSMWh_tep = 67.200
MWh



The difference between the self-consumption of the power plant (10 MW) and the heating plant (12 MW) is small in named units (megawatts) and corresponds to the same heat output Q_{TEP}despite the apparent visual difference in the percentage of self-consumption between the two types of power generation.

1.3 Economic evaluation of the replacement of the electrocautery with a turbocautery



1. Drive the feed pump with an electric motor

Required power input to the main turbine to meet the needs of the power plant:

$$P_{TURB} = \frac{P_{NAP}}{\eta_{GENER} \cdot \eta_{TRANSF} \cdot \eta_{POHON}} = \frac{\frac{2\%}{100} P_N}{0.99^3} = 0.020612 \cdot P_N$$

Qtep=100
ETAel_el=0.3
VSnap=2
Pelnap=Qtep*ETAel_el*VSnap/100
ETAtransf=0.99
Pturb=Pelnap/ETAtransf^3

Qtep = 100
MW
ETAel_el = 0.30000
-
VSnap = 2

%
Pelnap = 0.60000
MW
ETAtransf = 0.99000
-
Pturb = 0.61837
MW

2. Drive of the feed pump by steam turbine

Pturnap=Pelnap
Pturnap = 0.60000
MW

The required power increase of the feed pump electric engine compared to the feed pump drive by steam turbine and the annual electricity saved by installing the steam turbine:

$$\Delta P = (0.020612 - 0.02) \cdot P_N$$

$$\Delta A_P|_{ROK} = 0.000612 \cdot P_N \cdot \tau_{ROK}$$

deltaP=(Pturb-Pturnap)
TauP=24*365
deltaAp=deltaP*TauP

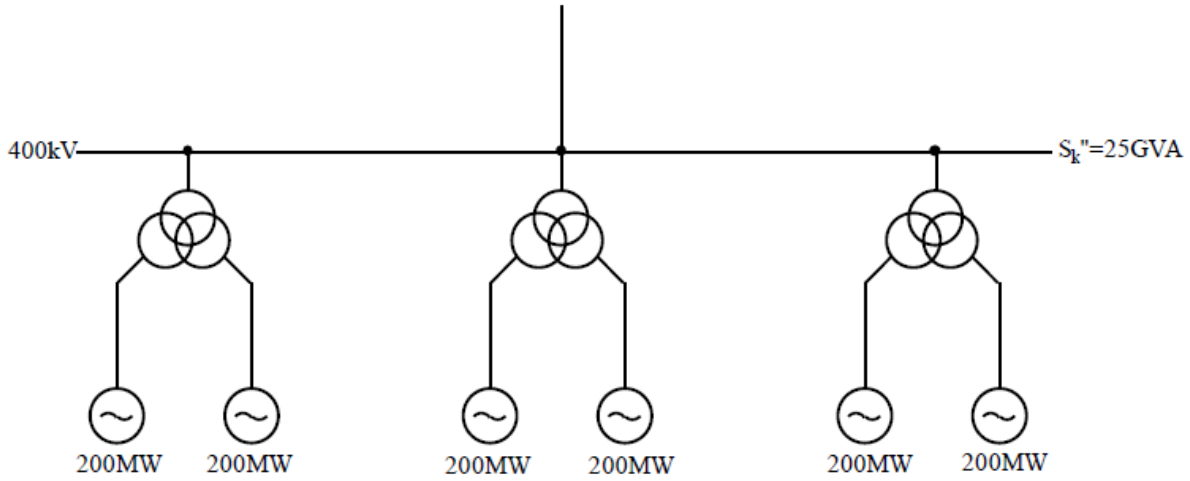
deltaP = 0.018366
MW
TauP = 8760
h
deltaAp = 160.89
MWh

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2 Exercise number 2 - 22-03-17

2.1 Design of the size of the power plant's self-consumption sources

Example script Beran, Hajek, Mertlová - Examples from transmission and distribution
Connection of a power plant 2 x 200 MW

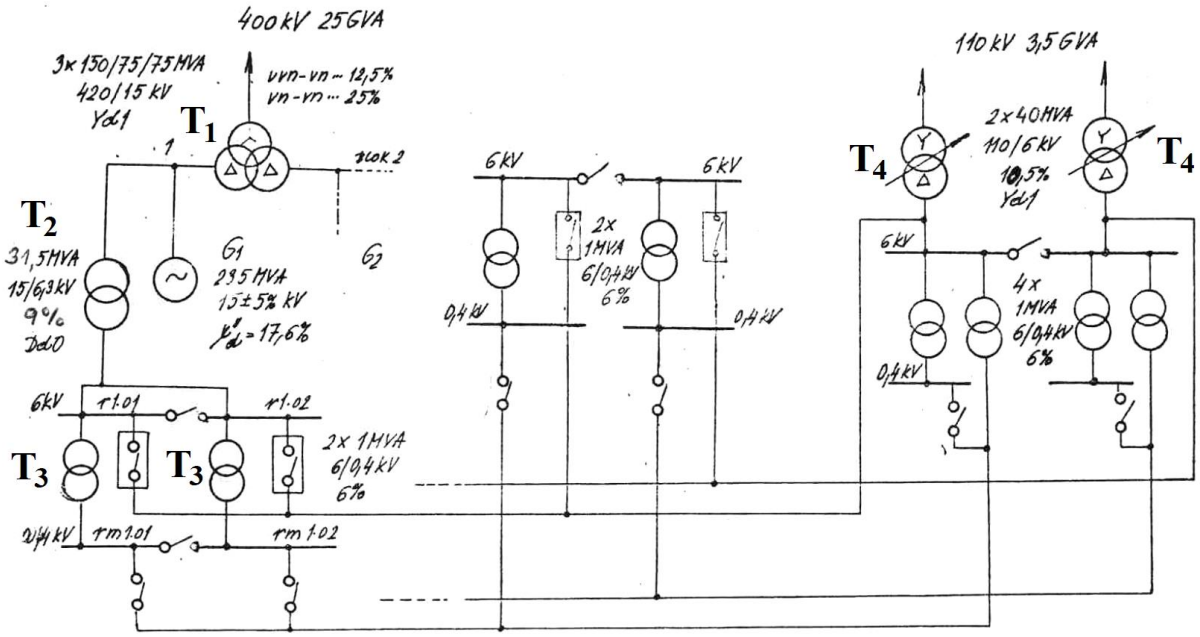


Inventory of appliances in the power plant's own consumption:

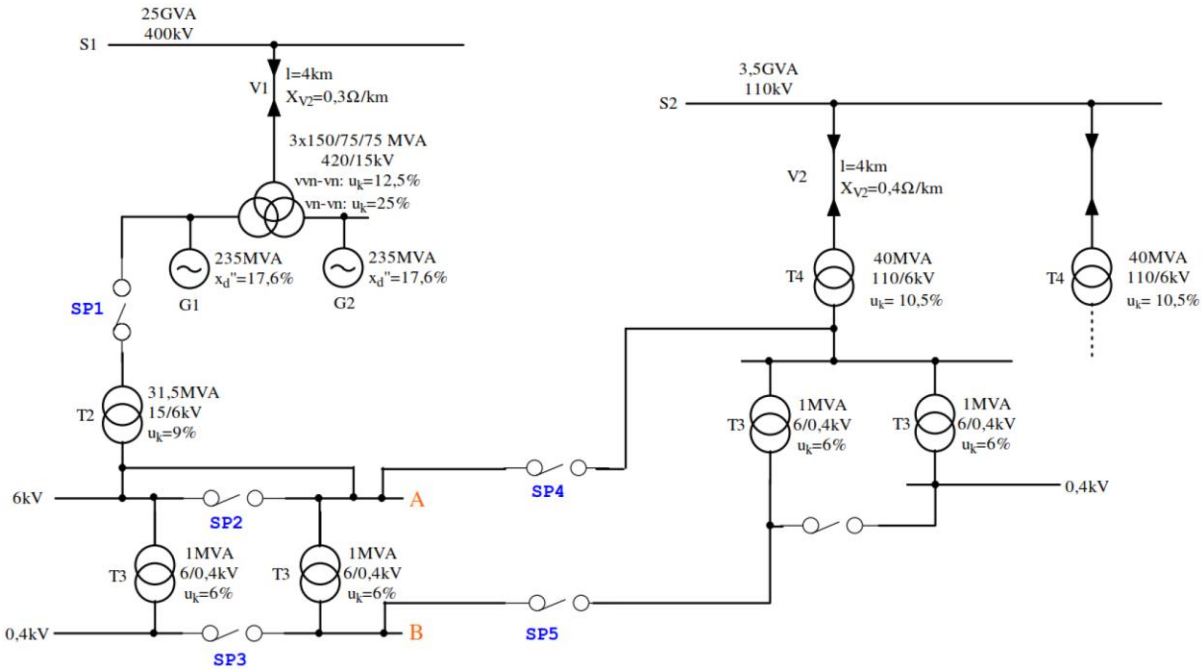
Location	Appliance	U_n [kV]	P_i [kW]	P_{ic} [kW]
Engine Room	Electric power supply	6	2x4250	8500
	Condens. pump	6	3x400	1200
	Cooling pump	6	2x1000	2000
	Pump for water pump	6	2x250	500
	Dredging pump	6	2x320	640
	Condensate pumping	0,4	1x140	140
	Impure condensate pump	0,4	1x100	100
	Feed pump electric power supply	0,4	1x140	140
	Pump warmer. cold. water	0,4	1x120	120
	Small drives	0,4	100	100
Engine room total				**13440 kW**

Location	Appliance	U_n [kV]	P_i [kW]	P_{iC} [kW]
Boiler Room	Smoke fan	6	2x1700	3400
	Fan mills	6	8x500	4000
	Air fan	6	2x800	1600
	Small drives	0,4	800	800
Total boiler room				**9800 kW**

Total engine room and boiler room	**23240 kW**



Total self-consumption (charging, oil station, water treatment plant) 6700 kW.



2.1.1 Design of power transformers

$$\beta = \frac{k_S . k_V}{\eta_S . \eta_m} \qquad P_P = \beta . \sum P_i \qquad S_P = \frac{P_P}{\cos \varphi_{STŘ}}$$

CosFi = 0.6
Kv = 0.95
Ks = 0.9
Etas = 0.99
Etam = 0.99
Beta = Kv * Ks / (Etas * Etam)

CosFi = 0.60000
Kv = 0.95000
Ks = 0.90000
Etas = 0.99000
Etam = 0.99000
Beta = 0.87236

CSN 34 1610 for own consumption of thermal power plants:
demand coefficient φ = 0.78
mean power factor cos $\varphi_{stř}$ = 0.75.

CosFi = 0.75
Beta = 0.78

CosFi = 0.75000
Beta = 0.78000

Design procedure: From lower voltage to higher voltage.

NN: $\sum P_{inst}$

T3 - boiler room and engine room separately, the boiler room is the heavier load $P_{inst} = 800\ kW$

Pinstnn=800/1000
Ppnn=0.8*Beta
Spnn=Ppnn/CosFi

Pinstnn = 0.80000
Ppnn = 0.62400
Spnn = 0.83200

We choose the transformer power from the power series $S_{NT3} = 1\ MVA$

HV: $\sum P_{inst}$

T2 - boiler room and engine room together $P_{inst} = 23\ 240\ kW$

Pinstvn=23240/1000
Ppvn = Pinstvn * Beta
Spvn = Ppvn/CosFi

Pinstvn = 23.240
Ppvn = 18.127
Spvn = 24.170

We choose the transformer power from the power series $S_{NT2} = 31.5\ MVA$

T4 - total consumption of unit 1 plus consumption of unit 2 for runtime (40%) plus 50% of total self-consumption

Pinstspol=6700/1000
Ppz = (Pinstvn + Pinstvn*0.4 + Pinstspol*0.5)*Beta
Spz = Ppz/CosFi

Pinstspol = 6.7000
Ppz = 27.991
Spz = 37.321

We choose the transformer power from the power series $S_{NT4} = 40\ MVA$

Exercise recap:
CosFi = 0.75
Beta = 0.78
Pinstnn=800/1000
Ppnn=Pinstnn*Beta
Spnn=Ppnn/CosFi
Pinstvn=23240/1000
Ppvn = Pinstvn * Beta
Spvn = Ppvn/CosFi
Pinstspol=6700/1000
Ppz = (Pinstvn + Pinstvn*0.4 + 6.7*0.5)*Beta
Spz = Ppz/CosFi

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3 Exercise number 3 - 22-03-24

3.1 Short circuit calculations

3.1.1 Short circuit calculations without motor contributions

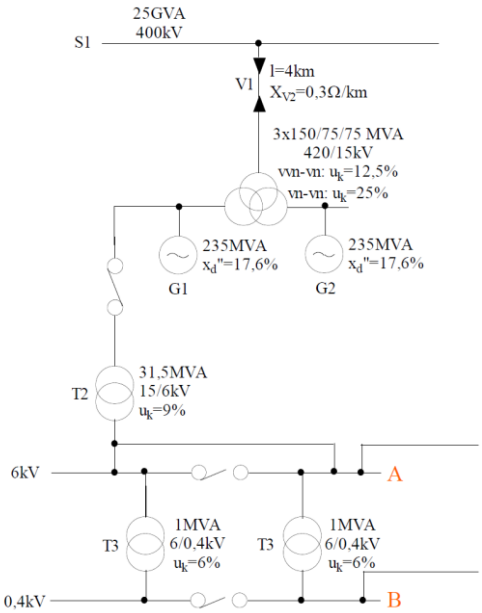
Alternate relative impedances of the elements and conversion of the scheme to a uniform voltage level

U, S
U2 = U1/Un1*Un2
S = 3*Uf*I = sqrt(3)*U*I
Z = U*U/S
Z2 = Z1/(Un1*Un1)*(Un2*Un2)
I2 = I1*Un1/Un2
S2 = sqrt(3)*U2*I2 = S1= sqrt(3)*U1*I1
U2 = U1/Un1*Un2
Y2 = Y1/(Un2*Un2)*(Un1*Un1)

Calculation settings:

- using proportional values,
- we consider only the reactances of the elements,
- fictitious transformer conversion,
- uniform reference power Sv = 235 MVA

We identify the locations of the most serious short-circuit faults:



Calculation of proportional values:

alpha = ALPHA / ALPHAn
= Z/Zn Zn = Un/(sqrt(3)*In) = Un*Un/Sn z = Z*Sn/(Un*Un)

$$z_{recalulated} = z_{p.u.}\frac{Z_N}{Z_V}p^2 = z_{p.u.}\frac{\frac{U_N^2}{S_N}}{\frac{U_V^2}{S_V}}\cdot\frac{U_V^2}{U_N^2} = z_{p.u.}\frac{S_V}{S_N}$$

Calculation of recalculated ratio values for different input parameters:

1. Entering the proportional $z_1(-)$ or percentage value $z_1(\%)$:
   $z_2 = z_1(-)\frac{S_V}{S_N}$ $z_2 = \frac{z_1(\%)}{100}\cdot\frac{S_V}{S_N}$
2. Entering a named value $Z_1(\Omega)$:
   $$z_2 = \frac{Z_1(\Omega)}{Z_V}p^2 = Z_1(\Omega)\frac{S_V}{{U_V}^2}\cdot\frac{{U_V}^2}{{U_{N1}}^2} = Z_1(\Omega)\frac{S_V}{{U_{N1}}^2}$$
3. Input of the corresponding short-circuit power $S_{K1}(MVA)$:
   $$z_2 = \frac{X_1(\Omega)}{Z_V}p^2 = c\frac{{U_{N1}}^2}{S_{K1}(MVA)}\cdot\frac{S_V}{{U_V}^2}\cdot\frac{{U_V}^2}{{U_{N1}}^2} = c\frac{S_V}{S_{K1}(MVA)}$$

   Details of the derivation of the proportional values and their recalculation are available in the document:
   https://home.zcu.cz/~nohac/EE1/Prepocet_velicin/Prepocty_velicin_v_elektroenergetice-ENG.pdf

For the example just solved:

G:

$$x_g = x_d''\frac{S_V}{S_{ng}} = 0{,}176\frac{235}{235} = 0{,}176$$

T_2:

$$x_{T2} = u_{kT2}\frac{S_V}{S_{nT2}} = 0{,}09\frac{235}{31{,}5} = 0{,}671$$

T_3:

$$x_{T3} = u_{kT3}\frac{S_V}{S_{nT3}} = 0{,}06\frac{235}{1} = 14{,}100$$

T_4:

$$x_{T4} = u_{kT4}\frac{S_V}{S_{nT4}} = 0{,}105\frac{235}{40} = 0{,}617$$

V_1 :

$$X_{V1} = X.l = 0,3.4 = 1,2\Omega$$

$$x_{V1} = X_{V1}.\frac{S_V}{U_{NV1}^2}1,2\frac{235}{400^2} = 0,002$$

V_2 :

$$X_{V2} = X.l = 0,4.4 = 1,6\Omega$$

$$x_{V2} = X_{V2}.\frac{S_V}{U_{NV2}^2} = 1,6.\frac{235}{110^2} = 0,031$$

S_2 :

$$x_{S2} = c\frac{S_V}{S_K''} = 1,1.\frac{235}{3,5.10^3} = 0,074$$

Sv = 235
Sg = 235
Xdcc=17.6
Xg=Xdcc/100*Sv/Sg

Sv = 235
Sg = 235
Xdcc = 17.600
Xg = 0.17600

Snt2 = 31.5
Ukt2 = 9
Xt2=Ukt2/100*Sv/Snt2

Snt3 = 1
Ukt3 = 6
Xt3=Ukt3/100*Sv/Snt3

Snt4 = 40
Ukt4 = 10.5
Xt4=Ukt4/100*Sv/Snt4

Snt2 = 31.500
Ukt2 = 9
Xt2 = 0.67143
Snt3 = 1
Ukt3 = 6
Xt3 = 14.100

Snt4 = 40
Ukt4 = 10.500
Xt4 = 0.61688

St1=450
Uk12=12.5
Uk13=12.5
Uk23=25

X1=(Uk12+Uk13-Uk23)/200*Sv/St1
X2=(Uk12+Uk23-Uk13)/200*Sv/St1
X3=(Uk13+Uk23-Uk12)/200*Sv/St1

St1 = 450
Uk12 = 12,500
Uk13 = 12,500
Uk23 = 25
X1 = 0
X2 = 0.065278
X3 = 0.065278

% Xv by Sv
Xv1=4*0.3*Sv/400^2
Xv2=4*0.4*Sv/110^2

Xv1 = 0.0017625
Xv2 = 0.031074

% alternatively by Uv and Zv
Uv = 6

Zv=Uv^2/Sv
Xv1=4*0.3/Zv*Uv^2/400^2
Xv2=4*0.4/Zv*Uv^2/110^2

Uv = 6
Zv = 0.15319
Xv1 = 0.0017625
Xv2 = 0.031074

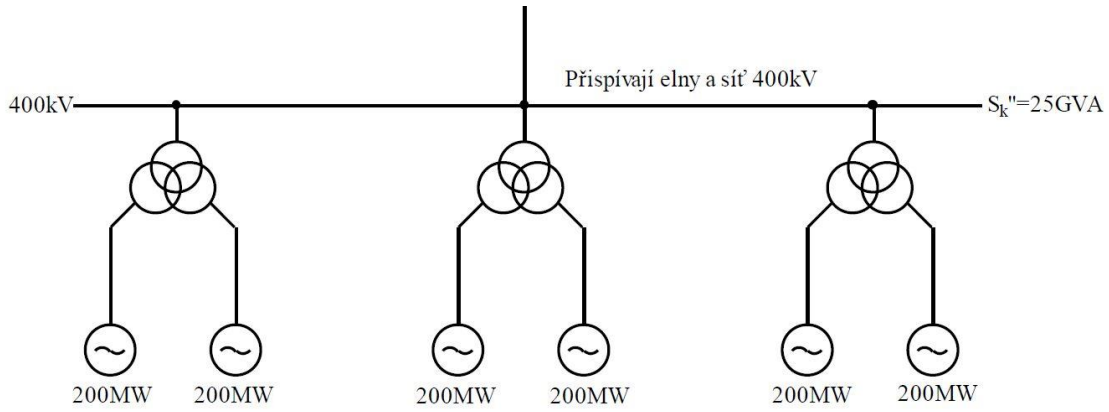
c=1.1
% Xs2 by Sv
Xs2 = c*Sv/3500

c = 1.1000
Xs2 = 0.073857

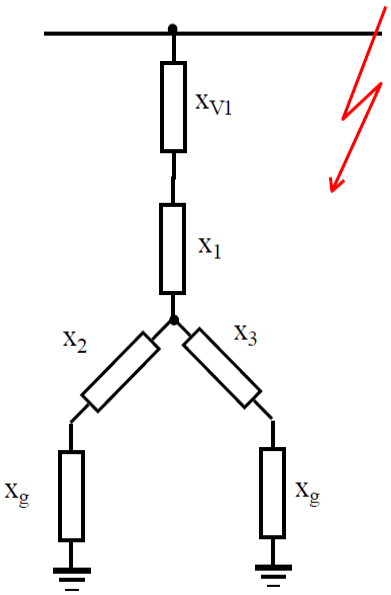
% alternatively by Uv and Zv
Xs2 = c*(110*110)/3500/Zv*(Uv*Uv)/(110*110)
Xs2 = c*1/3500/Zv*(Uv*Uv)

3.2 Short circuit calculations (continued)

Consideration of the effect of a pair of blocks on the total short circuit power of 25 GVA



Calculation of the short-circuit power of one pair of power plant units:



$$x_k = (x_{v1} + x_1) + \left[(x_2 + x_g) \| (x_2 + x_g)\right] = x_{V1} + x_1 + \frac{(x_2 + x_g)(x_3 + x_g)}{(x_2 + x_g) + (x_3 + x_g)}$$

Xk400=(Xv1+X1)+((X2+Xg)*(X3+Xg))/((X2+Xg)+(X3+Xg))
% alternativně
Xk400=Xv1+X1+1/(1/(X2+Xg)+1/(X3+Xg))
Xk400=Xv1+X1+1/(2/(X2+Xg))

Sk400=c*Sv/Xk400
% alternatively
Xk400Ohm=Xk400*Uv^2/Sv
Sk400=c*400^2/Xk400Ohm/400^2*Uv^2
Sk400=c*400^2/Xk400/Uv^2*Sv/400^2*Uv^2

Skcelk = 25000
Sksit1=Skcelk-Sk400
Xs1=c*Sv/Sksit1

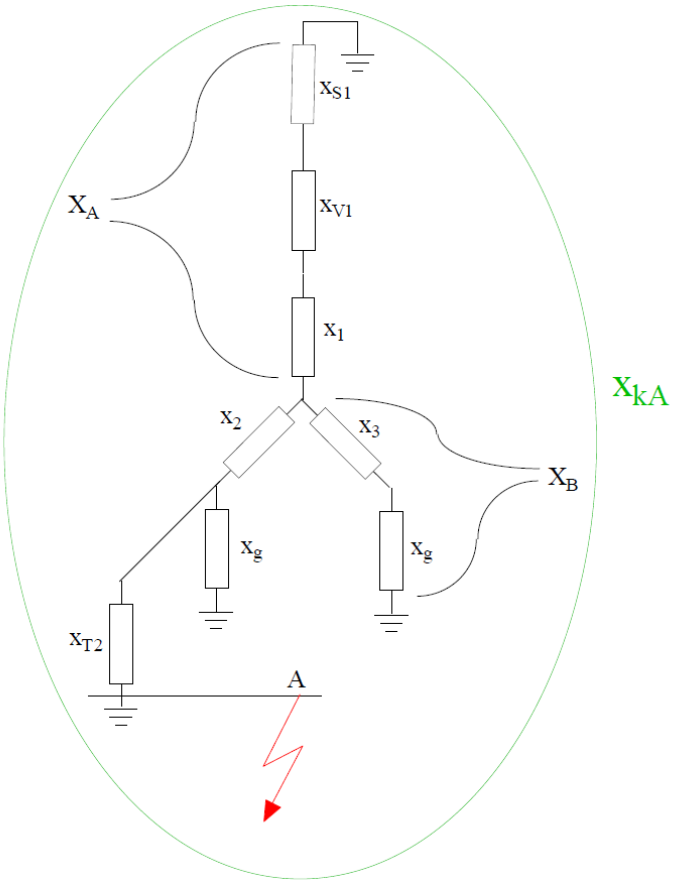
Xk400 = 0.12240
Sk400 = 2111.9
Xk400Ohm = 0.018751
Sk400 = 2111.9
Skcelk = 25000
Sksit1 = 22888.09586
Xs1 = 0.011294

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4 Exercise number 4 - 22-03-31

Calculation of short-circuit ratios at point "A":



Xa=Xs1+Xv1+X1
Xb=X3+Xg
Xc=Xa*Xb/(Xa+Xb)+X2
Xc=1/(1/Xa+1/Xb)+X2

Xa = 0.013057
Xb = 0.24128
Xc = 0.077664

$$x_{kA} = \left\{ \left[\left(x_A \| x_B \right) + x_2 \right] \| x_g \right\} + x_{T2}$$

$$x_{kA} = \frac{\left[\frac{\left(x_{S1} + x_{V1} + x_1 \right).\left(x_3 + x_g \right)}{\left(x_{S1} + x_{V1} + x_1 \right) + \left(x_3 + x_g \right)} + x_2 \right].x_g}{\left[\frac{\left(x_{S1} + x_{V1} + x_1 \right).\left(x_3 + x_g \right)}{\left(x_{S1} + x_{V1} + x_1 \right) + \left(x_3 + x_g \right)} + x_2 \right] + x_g} + x_{T2}$$

Xka = Xc*Xg/(Xc+Xg)+Xt2
Xka = 1/(1/Xc+1/Xg)+Xt2

Xka = 0.72531

$$S''_{k3} = c\frac{S_V}{x_{kA}} =$$

$$I''_{k3} = \frac{S''_{k3}}{\sqrt{3}U_m}$$

Ska=c*Sv/Xka
Ika=Ska/(sqrt(3)*Uv)

Ska = 356.40
Ika = 34.294

Calculation of short-circuit ratios at point "B":

Xkb=Xka+Xt3
Skb=c*Sv/Xkb
Ikba=Skb/(sqrt(3)*Uv)
Ikbb=Ikba*(Uv/0.4)
Ikbb=Skb/(sqrt(3)*0.4)

Xkb = 14.825
Skb = 17.436
Ikba = 1.6778
Ikbb = 25.167

Calculation of short-circuit ratios at point "A" from the backup source:

Xkaz=Xs2+Xv2+Xt4
Skaz=c*Sv/Xkaz
Skaz=c*Uv^2/(Xkaz*Zv)
Ikaz=Skaz/(sqrt(3)*Uv)
Ikaz=c*Uv/(sqrt(3)*Xkaz*Zv)

Xkaz = 0.72181
Skaz = 358.13
Ikaz = 34.461

Calculation of short-circuit ratios at point "B" from the backup source:

Xkbz = Xkaz + Xt3/3
Skbz=c*Sv/Xkbz
Skbz=c*Uv^2/(Xkbz*Zv)
Ikbza=Skbz/(sqrt(3)*Uv)
Ikbzb=Ikbza*(Uv/0.4)
Ikbzb=Skbz/(sqrt(3)*0.4)

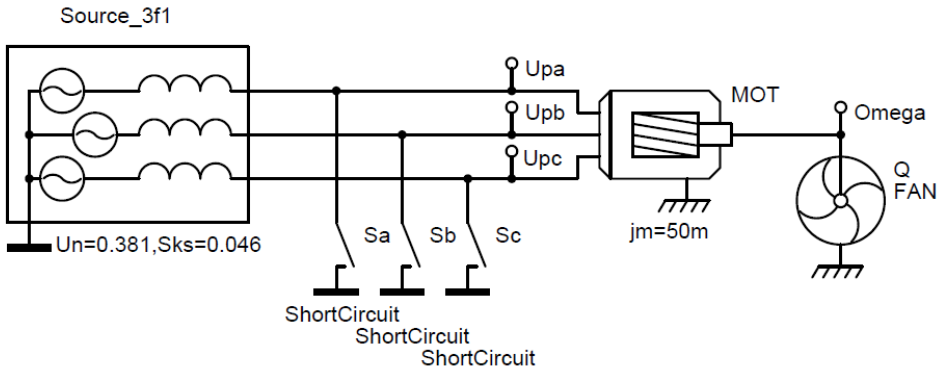
Xkbz = 5.4218
Skbz = 47.678
Skbz = 47.678
Ikbza = 4.5878
Ikbzb = 68.817

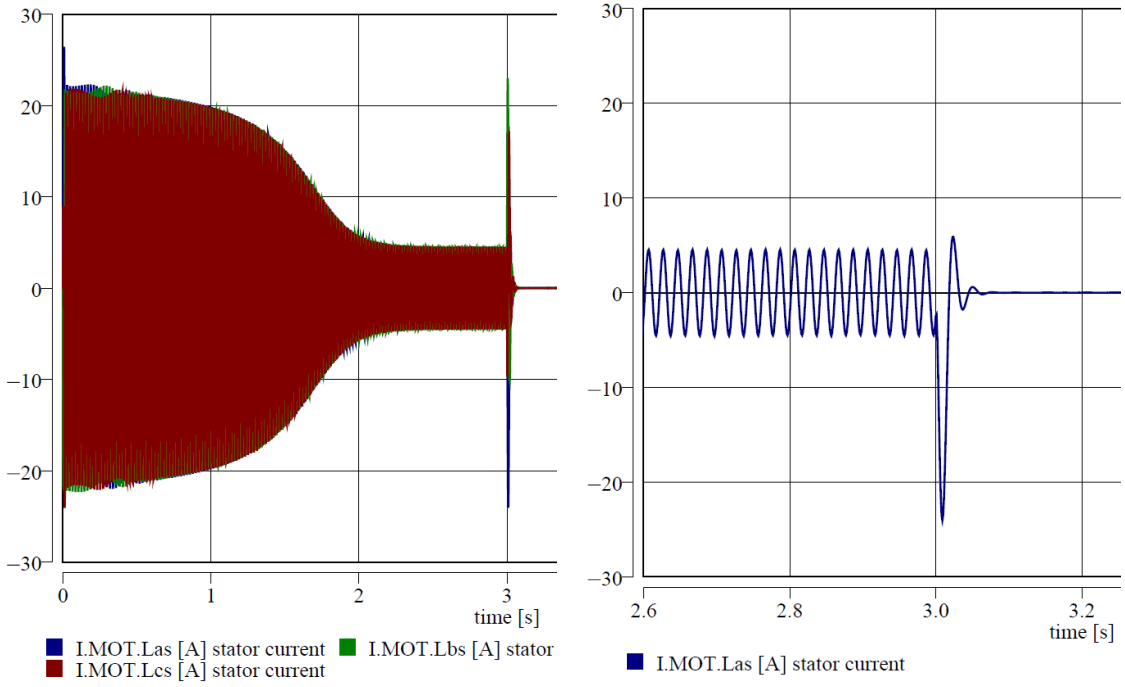
5 Exercise number 5 - 22-04-07

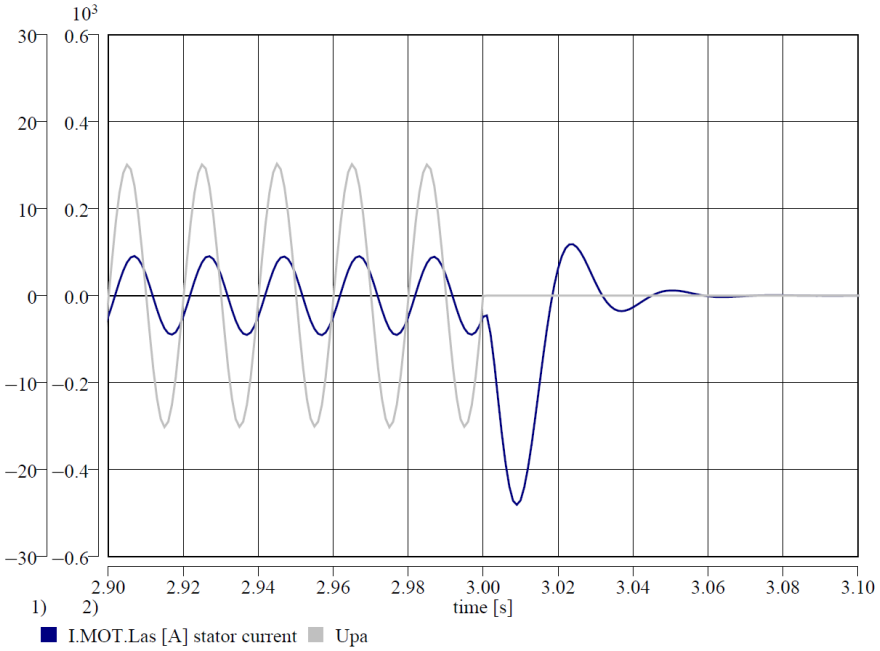
5.1 Short circuit calculations (continued)

5.1.1 Calculation of short-circuit ratios with consideration of motor contributions

The motors at the time of a short circuit close to their terminals supply current in the first instant:







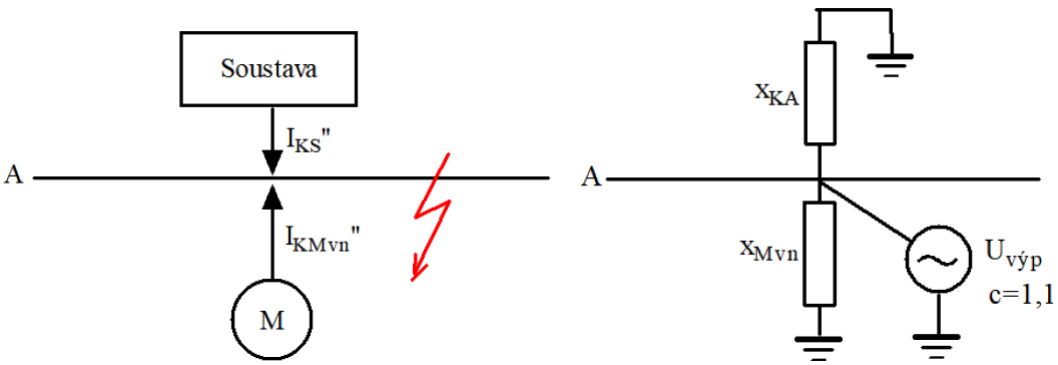
The principle of calculation is according to ČSN 60909-0 Short-circuit ratios in 3f AC systems, part 0: "Calculation of currents"

The contribution of LV motors must be included in the calculation in VS power plants and in industrial plants, motors (group of motors) can only be neglected if

- Total I_N of engines shall not exceed 1% $I_K{}^{//}$ calculated without the contribution of these engines
- motors contribute to the short circuit point via 2 transformers

Only simultaneously running motors are considered, there is no point in considering backup motors.

For our example, we will consider that the power of the simultaneously running motors ($k_S \cdot P_i$) is equal to the calculated load of the motor group P_P.



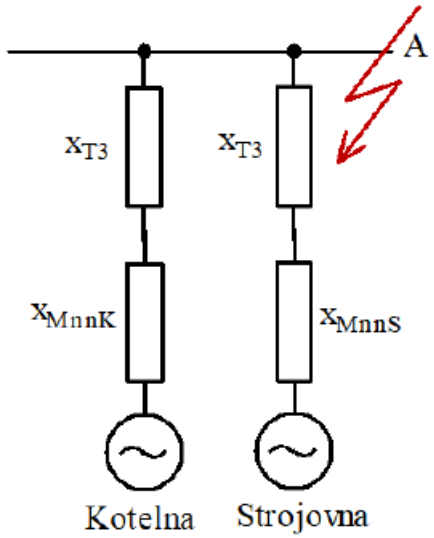
$$S_P = \frac{P_P}{\cos\varphi_{STŘ}} \qquad P_P = \beta.\sum P_i \qquad \beta = \frac{k_S.k_V}{\eta_S.\eta_m}$$

Contribution of HV motors to the short-circuit point "A"

Pp6s= Beta*(8500+1200+2000+500+640+3400+4000+1600)/1000Sp6s=Pp6s/CosFi
ik=5Xp6s=1/ik*Sv/Sp6s

Pp6s = 17.035
Sp6s = 22.714
ik = 5
Xp6s = 2.0692

Contribution of LV motors to the short-circuit point "A"



Pp04str= 0.6*Beta
Sp04str=Pp04str/CosFi
Xp04str=1/ik*Sv/Sp04str

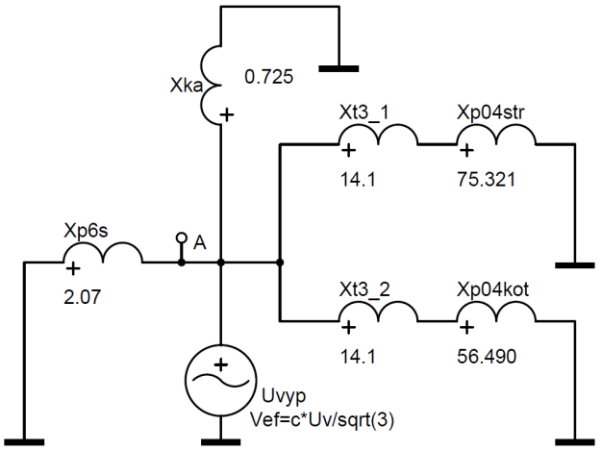
Pp04str = 0.46800
Sp04str = 0.62400
Xp04str = 75.321

Pp04kot=0.8*Beta
Sp04kot=Pp04kot/CosFi
Xp04kot=1/ik*Sv/Sp04kot

Pp04kot = 0.62400
Sp04kot = 0.83200

Xp04kot = 56.490

Current contributions to the total short-circuit current at location "A"



Total short-circuit current including contribution of drives from both voltage levels

Xksoucta= (1/(Xp04kot+Xt3)+1/(Xp04str+Xt3) + 1/Xp6s + 1/Xka)^(-1)
Sksoucta=c*Sv/Xksoucta
Iksoucta= Sksoucta/(sqrt(3)*Uv)
Xksoucta = 0.52985
Sksoucta = 487.87
Ixoucta = 46.946

Different variants of Ip6s calculation including two versions of current divider

Sp6s=c*Sv/Xp6s
Ip6s=Sp6s/(sqrt(3)*Uv)
Ip6s = c*Uv/(sqrt(3)*Xp6s*Zv)
Ip6s = c*Uv/sqrt(3)/Xp6s*(Sv/Uv^2)
Ip6s=Ixoucta*Xxoucta/Xp6s
Xppc=1/(1/(Xt3+Xp04str)+1/(Xt3+Xp04kot))
Ip6s=(Ixoucta-Ika)*Xppc/(Xp6s+Xppc)
Sp6s = 124.92
Ip6s = 12.021
Xppc = 39.449
Ip6s = 12.021

Engine room and boiler room contributions
Ip6str=(Iksoucta-Ika-Ip6s)*(Xp04kot+Xt3)/(Xp04kot+Xt3+Xt3+Xp04str)
Ip6kot=(Iksoucta-Ika-Ip6s)*(Xp04str+Xt3)/(Xp04kot+Xt3+Xt3+Xp04str)
Ip6str=c*Uv/(sqrt(3)*(Xp04str+Xt3)*Zv)
Ip6kot=c*Uv/(sqrt(3)*(Xp04kot+Xt3)*Zv)

Ip6str = 0.27817
Ip6kot = 0.35237

Total contribution of drives from both voltage levels:

Ipa=Ip6s+Ip6str+Ip6kot

Ipa = 12.651

The checksum of the individual components:

Ixoucta=Ipa+Ika

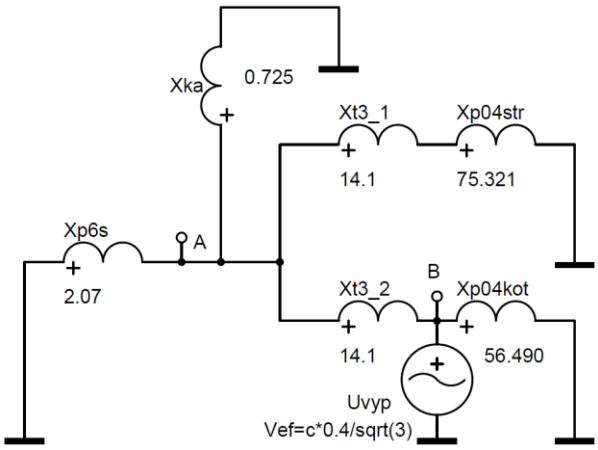
Ixoucta = 46.946

Percentage contribution of drives from both voltage levels to the total short-circuit current

Ipap=Ipa/Ixoucta*100

Ipap = 26.949

Current contributions to the total short-circuit current at location "B"



Xkbc1=1/(1/Xp6s + 1/Xka + 1/(Xt3 + Xp04str)) + Xt3
Xkbc=1/(1/Xkbc1+1/Xp04kot)
% alternatively
Xkbc=1/(1/(1/Xp6s + 1/Xka + 1/(Xt3+Xp04str)) + Xt3) + 1/Xp04kot)
Sksouctb=c*Sv/Xkbc
Iksouctb=Sksouctb/(sqrt(3)*0.4)
% alternatively with current conversion to 0.4
Iksouctb=c*Uv/(sqrt(3)*Xkbc*Zv)*(Uv/0.4)
% alternatively with conversion of voltage and Zv to 0.4
Iksouctb=c*0.4/(sqrt(3)*Xkbc*(0.4^2/Sv))

Xkbc1 = 14.634
Xkbc = 11.623
Sksouctb = 22.241
Iksouctb = 32.101

6 Exercise number 6 - 22-04-21

Determining the current contribution of drives from the engine room in two steps:

Ikbc1=Iksouctb*Xkbc/Xkbc1
Ikbstr=Ikbc1*(Xkbc1-Xt3)/(Xt3+Xp04str)
% alternatively
Xp6ska=1/(1/Xp6s + 1/Xka)
Ikbstr=Ikbc1*Xp6ska/(Xp6ska+Xt3+Xp04str)

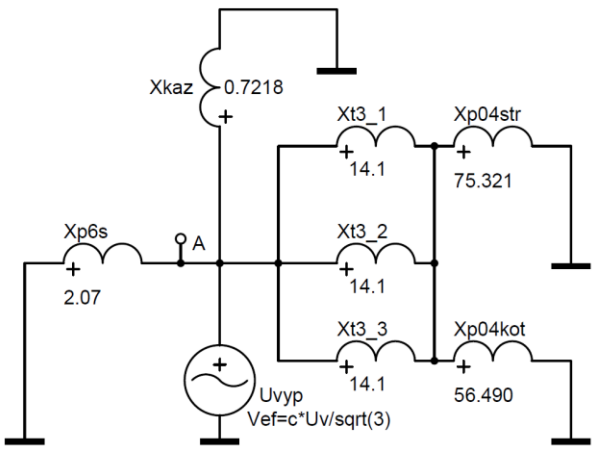
Ikbc1 = 25.497
Ikbstr = 0.15222
Xp6ska = 0.53706
Ikbstr = 0.15222

Ikbstrp=Ikbstr/Iksouctb*100

Ikbstrp = 0.47418

This reverses the standard option of neglecting the contributions of drives contributing through two transformers, because the contribution of drives from the machine room is at the same time less than one percent of the total short-circuit current.

Calculation of short-circuit ratios at location "A" from the backup source with motor contributions:



Contribution from the boiler and engine room branch:

Xkazks=Xt3/3+1/(1/Xp04str+1/Xp04kot)

Xkazks = 36.980

Total short-circuit power at location "A" from the backup source with motor contributions:

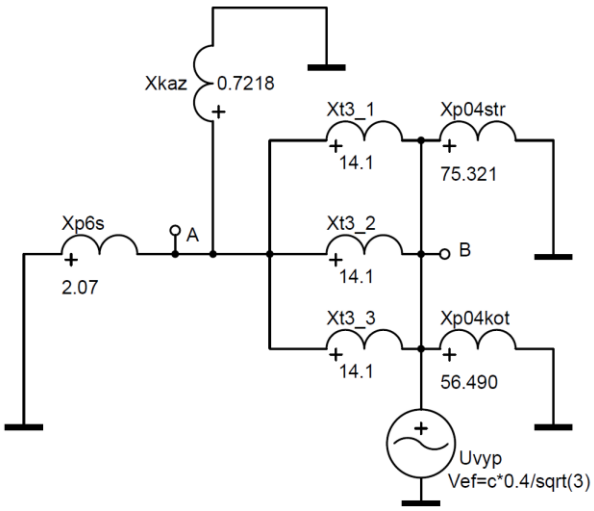
Xkazc=1/(1/Xkazks+1/Xkaz+1/Xp6s)
Skazc=c*Sv/Xkazc
Ikazc=Skazc/(sqrt(3)*Uv)
% alternatively
Ikazc=c*Uv/sqrt(3)*1/(Xkazc*Uv^2/Sv)

Xkazc = 0.52750
Skazc = 490.04
Ikazc = 47.155

Ikazcp=(Ikazc - Ikaz)/Ikazc*100

Ikazcp = 26.919

Calculation of short-circuit ratios at location "B" from the backup source with motor contributions:



Xkbks=1/(1/Xp04str+1/Xp04kot)
Xkbzc1=1/(1/Xp6s+1/Xkaz)+Xt3/3
Xkbzc=1/(1/Xkbzc1+1/Xkbks)
Ikbzc=c*Uv/(sqrt(3)*(Xkbzc*Uv^2/Sv))
Ikbzc04=Ikbzc*(Uv/0.4)
% alternatively
Skbzc=c*Sv/Xkbzc
Ikbzc=Skbzc/(sqrt(3)*Uv)

Xkbks = 32.280
Xkbzc1 = 5.2351
Xkbzc = 4.5046
Ikbzc = 5.5220
Ikbzc04 = 82.829

Skbzc = 57.386
Ikbzc = 5.5220

Table recapitulating the results of short circuit currents with motor contributions:

Short circuit location and power supply	**Designation and magnitude of short-circuit current (kA)**
"A", working source:	Iksoucta = 46.9
"B", working source:	Iksouctb = 32.1
"A", backup source:	Ikazc = 47.2
"B", backup source:	Ikbzc = 82.8

7 Exercise number 7 - 22-04-28

8 Control of the VS power supply of the power plant

1. The transformer must be able to transfer the required power according to the design load
2. Selection of transformer gearing to maintain rated voltage at continuous rated load.
3. Allowable voltage magnitude drop Δu under extreme loading shall not be greater than that which would affect the connected appliances. Two variations of the control are carried out:
    - the biggest engine starts up, when $\Delta u < 0.15$, thus $u_p > 0.85$
    - self-starting engines, where $\Delta u < 0.35$, thus $u_p > 0.65$

Must be done for both power supply variants (working power supply and reserve power supply).

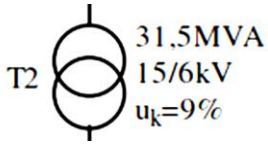
It is also necessary to determine the maximum values of the connectable power of the motor(s) that still satisfy the voltage limits as a supporting parameter for checking the self-tuning and optimizing the grouping.

The hardness of the power supply network is also checked, i.e. the magnitude of the short-circuit power of the network at the point of connection of the motors in relation to the minimum value of the short-circuit power of the network, which still guarantees compliance with the voltage conditions when starting the motors. This can also be seen as a determination of the limiting magnitude of the short-circuit impedance of the supply network.

We introduce simplifying assumptions for the calculation:

- we consider only the longitudinal reactances of the individual elements
- neglect voltage drops on the supply lines (between the generator and the self-consumption transformer)
- we consider the current to be purely reactive (in fact, it is $cos\varphi$ in the range of 0.2 to 0.3 at the start of the run)
- we consider motors as if they were standing still, i.e. we neglect the gradual reduction of starting current with decreasing slip

8.1 Checking and optimization of V.S. T2 transformer gear ratio



The short-circuit power on the T2 side of the 6 kV level transformer corresponds to the rectance:

Xst2= Xka - Xt2
% alternatively
Xst2= 1/(1/Xc + 1/Xg)

Xst2=0.053886
Previously defined:
CosFi = 0.75000
Spvn = 24.170

Relative reactive power and relative reactive current:
Qt2jp= Spvn * sin(acos(CosFi))/Sv
It2jp = Qt2jp

Qt2jp = 15.987It2jp
= 0.068028

$u_E = (x_S + x_T)i_j + u_P$ $\qquad \frac{U_E}{p \cdot U_V} - X_S \frac{S_V}{p^2 {U_V}^2} i_j - x_T i_j = u_P$

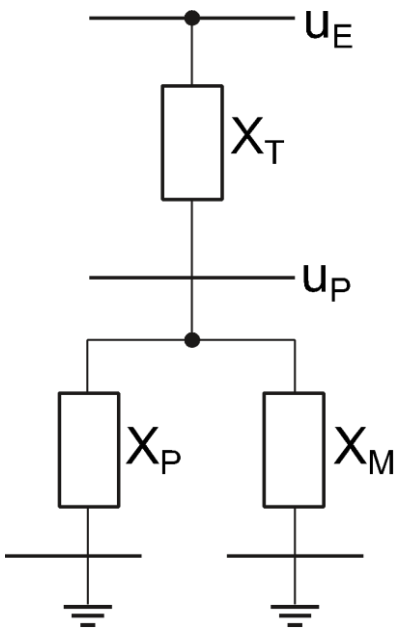
$(x_T i_j + u_P)p^2 - \frac{U_E}{U_V} p + X_S \frac{S_V}{{U_V}^2} i_j = 0$ $\qquad x_S = \frac{X_S}{p^2 Z_V} = X_S \frac{S_V}{p^2 {U_V}^2}$

$(x_{T2} i_{T2j} + u_P)p^2 - \frac{U_E}{U_V} p + x_{ST2} \cdot i_{T2j} = 0$ $\qquad a \cdot p^2 + b \cdot p + c = 0$

Ue=15
Up=1
a1=Xt2*It2jp + Up
b1=-Ue/Uv
c1=Xst2*It2jp
p=(-b1-sqrt(b1^2-4*a1*c1))/(2*a1)
p=(-b1+sqrt(b1^2-4*a1*c1))/(2*a1)
a1 = 1.0457
b1 = -2.5000
c1 = 0.0036658
p = 0.0014672
p = 2.3893

```
p0=Ue/Uv
Uep = Ue/(p*Uv)
% alternative
Uep=(Xst2/p^2+Xt2)*It2jp+Up
```
p0 = 2.5000
Uep = 1.0463

8.2 Checking the start-up of the largest drive




```
CosFiM=0.95
EtaM=0.98
Pm=4.25
Sm=Pm/CosFiM/EtaM
Spp=Spvn-Sm
```
Sm = 4.5650
Spp = 19.605

```
Ik=5
Xm=(1/Ik*Uv^2/Sm)/Zv
% alternatively
Xm=1/Ik*Sv/Sm
Xp=1/sin(acos(CosFi))*Sv/Spp
% alternatively
Qpp=Spp*sin(acos(CosFi))
Xp=(Uv^2/Qpp)*Sv/Uv^2
```

Xm = 10.296
Xp = 18.123
Qpp = 12.967
Xp = 18.123

Xz=1/(1/Xp+1/Xm)
Xz = 6.5657

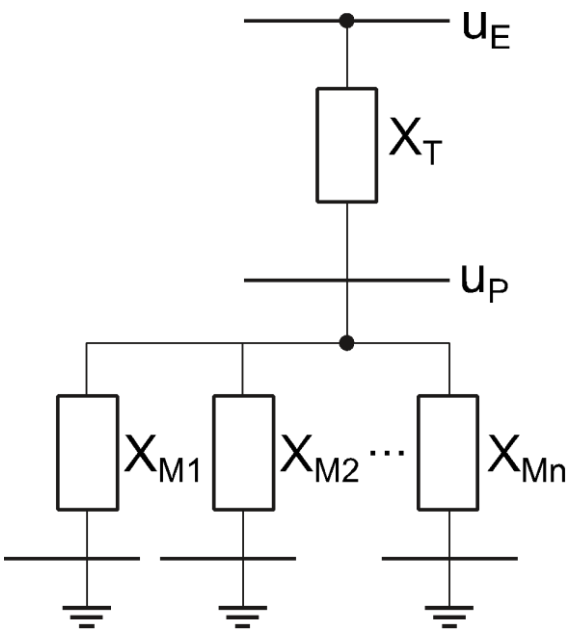
Assuming $u_E = 1$ and without respecting x_{ST2} :
Uproz=1/(Xt2+Xz)*Xz
Uproz = 0.90722

Alternatively, with reasoning x_{ST2} and with an increase in voltage u_E with optimised gearing

Uproz2=Uep/(Xst2/p^2+Xt2+Xz)*Xz
Uproz2 = 0.94801

9 Exercise number 8 - 22-05-05

9.1 Running of all drives (preload and maximum load) as a group



Ikpz=6

Xpz2=1/Ikpz*Sv/Spp
Xz2=1/(1/Xpz2+1/Xm)
Xpz2 = 1.9978
Xz2 = 1.6732

A very indicative average value of the current draw
Ikprum=(Ik+Ikpz)/2
Xz2=1/Ikprum*Sv/(Sm+Spp)
Ikprum = 5.5000
Xz2 = 1.7678

Weighted average current draw value
Ikprum2=(Ik*Sm+Ikpz*Spp)/(Sm+Spp)
Xz2=1/Ikprum2*Sv/(Sm+Spp)
Ikprum2 = 5.8111
Xz2 = 1.6732

Assuming $u_E = 1$ and without respecting x_{ST2} :
Uproz3=1/(Xt2+Xz2)*Xz2

Uproz3 = 0.71363

Alternatively, with reasoning x_{ST2} and with an increase in voltage u_E with optimised gearing
Uproz4=Uep/(Xst2/p^2+Xt2+Xz2)*Xz2
Uproz4 = 0.74369

9.2 Check for transformer overload current

When starting the largest drive

Snt=31.5
It= 1/(Xt2+Xz)*Sv/Snt
It = 1.0308
It2=Uep/(Xst2/p^2+Xt2+Xz)*Sv/Snt
It2 = 1.0772

When starting the largest group of drives

It4= 1/(Xt2+Xz2)*Sv/Snt
It4 = 3.1819
It3=Uep/(Xst2/p^2+Xt2+Xz2)*Sv/Snt
It3 = 3.3160

Corrective measures for failure to meet voltage limits

Generally always either on the network side (we influence the impedance of the power network, i.e. the hardness of the power supply) or on the load side (we limit the current load)

- Measures on the network side
  - increase S_n of the power transformer
  - choice of transformer with lower u_K
- Load-side measures
  - Reduction of inrush currents
  - Reduction of preload in case of starting the largest engine
  - In the case of self-propulsion, division of the motors into two groups that will run sequentially, first the important drives (self-propulsion), then the other drives (re-propulsion only after completion of self-propulsion with a delay)

9.3 Short-circuit power required to maintain the desired bus voltage

Up=0.8

The actual short-circuit power on the busbars must be:

$$S_{KM} = c \cdot S_V \frac{u_E}{x_{EP}} = c \cdot S_V \frac{u_E}{u_E - u_P} i_T = c \cdot S_V \frac{u_E}{u_E - u_P} \cdot \frac{u_P}{x_Z} = c \cdot S_V \frac{u_E \cdot u_P}{u_E - u_P} \left(\frac{S_P sin\varphi_P}{S_V} + i_K \frac{S_M}{S_V} \right)$$

$$S_{KM} = c \frac{u_E \cdot u_P}{u_E - u_P} (S_P sin\varphi_P + i_K \cdot S_M)$$

Skm = (Uep*Up)/(Uep-Up) * (Spp * sin(acos(CosFi))+ Ik*Sm)
Skm = 121.63
% alternative
Skm = Sv * Uep/(Uep-Up) * Up/Xz

This power must be less than the real short-circuit power at point "A", i.e. $S_{kA} = c \frac{S_V}{x_{kA}}$.

Similarly for the group start-up:
Up = 0.65

$$S_{KM} = c \cdot S_V \frac{u_E}{x_{EP}} = c \cdot S_V \frac{u_E}{u_E - u_P} i_T = c \cdot S_V \frac{u_E}{u_E - u_P} \cdot \frac{u_P}{x_{Z2}} = c \cdot S_V \frac{u_E \cdot u_P}{u_E - u_P} \left(i_{KP} \frac{S_{PP}}{S_V} + i_K \frac{S_M}{S_V} \right)$$

$$S_{KM} = c \frac{u_E \cdot u_P}{u_E - u_P} (i_{KP} \cdot S_{PP} + i_K \cdot S_M)$$

Up = 0.65
Skm2 = Uep*Up/(Uep-Up) * (Ikp*Spp + Ik*Sm)
% alternative
Skm2 = Sv * Uep/(Uep-Up) * Up/Xz2
Skm2 = 241.03

This power must again be less than the real short-circuit power at point "A", i.e. $S_{kA} = c \frac{S_V}{x_{kA}}$.

9.4 Design of the maximum possible concurrently executable group power

$$i_{MAX} = \frac{u_E - u_{MIN}}{x_{T2}} \qquad x_{Z\,MIN} = \frac{u_P}{i_{MAX}} \qquad S_{SKUP\,MAX} = \frac{1}{i_{K\,PRUM}} \cdot \frac{S_V}{x_{Z\,MIN}}$$

Umin=0.65

Imax=(Uep-Umin)/Xt2
Xzmin=Umin/Imax
Sskupmax=1/Ikprum*Sv/Xzmin
Imax = 0.59026
Xzmin = 1.1012
Sskupmax = 36.723

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10 Exercise number 9 - 22-05-05

10.1 Alternator operating point and phase diagram

The alternator has the basic characteristic of de schematic:

$S_N = 235\ MVA$ $U_N = 15\ kV$ $x_d'' = 17.6\ \%$

Parameters of conventional turbolters:

P_N [MW]	1000	500	220	200	110	50
S_N [MVA]	1111.0	588.0	259.0	235.0	137.0	62.5
cos(ϕ) [-]	0.90	0.85	0.85	0.85	0.80	0.80
U_N [kV]	24.00	20.00	15.75	15.75	13.80	10.50
I_N [A]	26726	17000	9500	8615	5753	3437
U_{FN} [V]	505	465	332	310	320	290
I_{FN} [A]	7120	3620	2400	2230	1200	625
U_{F0} [V]	109	110	102	102	85	80
I_{F0} [A]	2000	1090	900	900	400	225
U_{FN} / U_{F0} [V]	4.63	4.23	3.25	3.04	3.76	3.63
I_{FN} / I_{F0} [V]	3.56	3.32	2.67	2.48	3.00	2.78

x_d [%]	280.00	266.00	191.00	173.00	218.00	196.00
x_q [%]	257.60	256.00	182.00	165.00	206.00	184.00
x_d' [%]	38.0	35.2	26.7	24.2	24.7	24.7
x_d'' [%]	26.0	25.8	19.9	18.1	15.3	15.3
x_q'' [%]	26.4	27.0	20.4	18.5	15.6	15.5
R [Ω]	0.00110	0.00120	0.00144	0.00144	0.00236	0.00346
$FROM_N$ [Ω]	0.51845	0.68027	0.95777	1.05559	1.39007	1.76400
r [%]	0.212	0.176	0.150	0.136	0.170	0.196
x_d / r [-]	1320	1508	1270	1268	1284	999
x_d'' / r [-]	123	146	132	133	90	78
x_2 [%]	26.2	26.5	20.9	19.0	16.6	16.2
R_F [Ω]	0.05618	0.0996	0.112	0.112	0.21	0.35
R_D [Ω]		0.0207	0.0198	0.0198	0.0312	0.0409

T_{d0}' [s]	9.208	7.9	7.7	7.7	7.4	7.9
T_{d0}'' [s]	0.0477	0.037	0.040	0.040	0.060	0.033
T_d' [s]	1.20	0.85	0.84	0.84	0.70	0.85
T_d'' [s]	0.033	0.027	0.030	0.030	0.025	0.020
T_{q0}' [s]		2.7	2.3	2.3	2.6	2.7
T_{q0}'' [s]		0.034	0.037	0.037	0.033	0.027
T_q' [s]		0.43	0.42	0.42	0.35	0.42
T_q'' [s]		0.019	0.020	0.020	0.015	0.013
T_a [s]	0.339	0.40	0.37	0.37	0.30	0.18
T_m [s]	8.265	5.85	9.89	6.56	7.05	7.70

```
% Operating point and phasor diagram
Sng=235
Ung=15
CosFiG=0.85
Png=Sng*CosFiG
Ungf=Ung/sqrt(3)
Fi=acos(CosFiG)
Ing=Sng/(sqrt(3)*Ung)*exp(j*Fi)
Ingabs=Sng/(sqrt(3)*Ung)
Ingc=real(Ing)
Ingj=imag(Ing)
```

Png = 199.75
Ungf = 8.6603
Fi = 0.55481
Ing = 7.6884 - 4.7648i
Ingabs = 9.0452
Ingc = 7.6884
Ingj = -4.7648

```
Zng=Ungf/Ingabs
Xd=173*Zng/100
Xq=165*Zng/100
Rs=0.00144
```

Zng = 0.95745
Xd = 1.6564
Xq = 1.5798
Rs = 0.0014400

```
Pt=Png
Evabs=2.5*Ungf
Theta=asin(Pt*Xd/(3*Evabs*Ungf))
Iq=Ingabs*cos(Theta+Fi)*exp(j*Theta)
Id=Ingabs*sin(Theta+Fi)*exp(j*(Theta-pi/2))
Ev=Ungf + Rs*Ing + j*Xd*Id + i*Xq*Iq
% pro zcela hladky rotor
Ev2=Ungf + Rs*Ing + j*Xd*Ing
```

Pt = 199.75
Evabs = 21.651
Theta = 0.62883
Iq = 2.7618 + 2.0087i
Id = 4.9266 - 6.7736i
Ev = 16.718 + 12.517i
Ev2 = 16.564 + 12.728i

To display the phasors, it is necessary to first define the following auxiliary function:

```
function displayfazor(Start, Delta, MyColor, MyArrowSize, MyCoordinate);
  h= quiver(real(Start),imag(Start),real(Delta),imag(Delta),0);
  set (h,  'maxheadsize', MyArrowSize);
  set (h,  'color', MyColor);
  if MyCoordinate
    text(real(Start+Delta), imag(Start+Delta), sprintf('(%f,%f)',[abs(Start+Delta)
angle(Start+Delta)]));
  end
end
```

Then the entire phasor diagram can be plotted:

```
VelSipky=0.03;
clf;
hold on;
displayfazor(0, Ungf, 'r', VelSipky, 0)
displayfazor(0, Ev, 'r', VelSipky, 0)
displayfazor(Ungf, Rs*Ing, 'k', 0.0, 0)
displayfazor(Ungf + Rs*Ing, j*Xd*Id, 'b', 0.0, 0)
displayfazor(Ungf + Rs*Ing + j*Xd*Id, i*Xq*Iq, 'b', 0.0, 0)
displayfazor(0, Ing, 'g', VelSipky, 0)
displayfazor(0, Ingc, 'c', VelSipky, 0)
displayfazor(0, Ingj*j, 'c', VelSipky, 0)
displayfazor(0, Id, 'm', VelSipky, 0)
displayfazor(0, Iq, 'm', VelSipky, 0)
displayfazor(0, Ev2, 'y', VelSipky, 0)
displayfazor(0, Evabs*exp(j*Theta), 'k', VelSipky, 0)
hold off;
axis('equal')
grid on;
```

