ESF II project of the University of West Bohemia in Pilsen
reg. number: CZ.02.2.69/0.0/0.0/18_056/0013239



EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education



THEORY OF TRANSMISSION AND DISTRIBUTION OF ELECTRIC ENERGY

4th lecture - theory

2

Content

- **Creation of substitution schema of the EPS part**
  - Prerequisites
  - Conversion to one voltage level
  - Conversion between ratio variables and variables in named (real) units
  - Calculation of longitudinal impedances (reactance) of individual network elements

3

Creation of simplified substitute schema of the ES part (1)

- When solving networks (design, operation, failures) it is needed to perform calculations for:
  - steady state and transient processes (closer in subject KEE/PJS)
  - symmetrical and asymmetrical states
- Before it is **necessary to define networks** (even if we use mathematical simulation and computer technology)

4

Creation of simplified substitute schema of the EPS part (2)

- **Defining of EPS part** = **compilation of substitute schema**
  - here is solved **simplified** one, i.e. substitution of elements is created only by **longitudinal parameters,** so that
    - as faithfully as possible to copy the reality
    - it was possible to solve it as easily as possible

    → it is important to optimally introduce **simplifying assumptions**

5

Creation of substitute schema (1)

We assume:

- **Symmetrical network (three-phase)**
  - passive parameters (R, L, C, G) – same for each phase
  - active parameters ($\bar{U}$,$\bar{I}$) – equally large, offset by 120°, 240°
    - → in operating states we assume that it is valid
    - → for fault conditions
      - symmetrical – again valid (3ph short circuit)
      - asymmetric – decompose into symmetrical component systems (∃ various options – e.g. Fortescue method)
- **! The equivalent circuit can be formed for 1 phase !**

6

Creation of substitute schema (2)

1) Conversion to one voltage level

- Part of multi-voltage EPS – schema **for one voltage level** → recalculation of element parametrers to this voltage
- We recalculate to the voltage level where we are interested in some problem (e.g. short-circuit conditions)
- We recalculate **using transformers conversion**, which connect individual networks

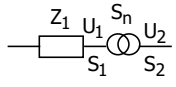


7

Creation of substitute schema (3)

- Transformer is divided for calculation into two parts:
  - its impedance (admittance) – here Z_1
  - ideal transformer characterized by conversion p ($p = U_1/U_2$) → applies - input and output power is the same, it is $S_1 = S_2$

$$S_1 = \frac{U_1^2}{Z_1} = S_2 = \frac{U_2^2}{Z_1^{(2)}}$$



$$Z_1^{(2)} = Z_1\left(\frac{U_2}{U_1}\right)^2 = Z_1\frac{1}{p^2}$$

impedance $\mathbf{Z_1}$ recalculated to the level $\mathbf{U_2}$

8

Creation of substitute schema (4)

- transformer impedance (here $\mathbf{Z_1}$) **we include in the substitute network schema**
- conversion $p = U_1/U_2$ (usually $U_1 > U_2$ → not for block transformers, so that better according to active power flow direction)
- we use in impedance recalculation usually $(1/p)^2$, but it can also be p^2 - it depends on the place where we recalculate
- recalculation through real conversions – only with physical values, i.e. with variables in named units

9

Creation of substitute schema (5)

Different way of expressing the conversion (for different calculations – different conversion):

a) Actual conversion p_s (= immediate ratio of input and output windings)

- we have regulatory transformer (regulation alway at higher voltage) with the stated label value:

e. g.: $p = 110 \pm 8 \times 2\% / 23$



it is e.g. when setting the 10th tap (+2%) of the controller → $p_s = 112{,}2 / 23$

- **It is used** for the appropriate regulation of the taps
  - solution is computationally hard ← for each conversion change the recalculation of many parame-ters is necessary

10

Creation of substitute schema (6)

b) Nominal conversion p_n (= regulator in basic position, i.e. at middle tap)

- output voltage increased - after load (⇒ incurrence of losses) on the secondary the nominal voltage respectively network (about 5% of U_n)
  - e. g.: $p_n = 110/23$ – increased voltage
- **Use**:
  - in less loaded networks
  - calculations sufficiently accurate
  - it is constant → transfers made once do not change

11

Creation of substitute schema (7)

c) Fictional conversion p_f (= ratio of nominal input and output voltages)

- e. g.: $p_f = 110/22$

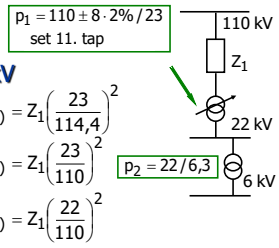
- **Use:**
  - for orientation calculations
  - in a cursory calculation of short-circuit currents
  - the simplest recalculations
  - for these calculations the accuracy of the results is sufficient

12

Creation of substitute schema (8)

Ex.: Recalculate impedance Z_1 from 110 kV voltage levels to 22 kV and 6 kV, using all of **conversions**, i.e.:

a) actual
b) nominal
c) fictional



- Recalculation on 22 kV

ad a) $p_1 = \frac{114,4}{23}$ $Z_{1(22kV)} = Z_1\left(\frac{23}{114,4}\right)^2$

ad b) $p_1 = \frac{110}{23}$ $Z_{1(22kV)} = Z_1\left(\frac{23}{110}\right)^2$

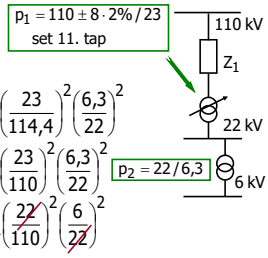
ad c) $p_1 = \frac{110}{22}$ $Z_{1(22kV)} = Z_1\left(\frac{22}{110}\right)^2$

13

Creation of substitute schema (9)

Ex.: Recalculate impedance Z_1 from 110 kV voltage levels to 22 kV and 6 kV, using **conversions**, i.e.:

a) actual
b) nominal
c) fictional



- Recalculation on 6 kV

ad a) $p_2 = \frac{22}{6,3}$ $Z_{1(6kV)} = Z_1\left(\frac{23}{114,4}\right)^2\left(\frac{6,3}{22}\right)^2$

ad b) $p_2 = \frac{22}{6,3}$ $Z_{1(6kV)} = Z_1\left(\frac{23}{110}\right)^2\left(\frac{6,3}{22}\right)^2$

ad c) $p_2 = \frac{22}{6}$ $Z_{1(6kV)} = Z_1\left(\frac{22}{110}\right)^2\left(\frac{6}{22}\right)^2$

14

Creation of substitute schema (10)

2) We have two options for solving the substitution schema:

a) in **physical** values, it is with named units - all network elements in **[Ω], [S]** ⇒ results **[A], [V], [W], ...**

b) in **relative** (percent) values:

- all network elements in relative units **[r.u.]** or percentage units **[%]** (percentage = relative x 100)

⇓

- Before the problem solution – it is necessary to choose whether we want the result in **a)** or **b)**

15

Creation of substitute schema (11)

- Input values of impedances (admittances) are for:
  - line in [Ω] ([S])
  - other network elements (alternator, transformer, appliance, reactor) in [%] or directly v [r.u.]

⇓

- **Need to unify !!!**

16

Creation of substitute schema (12)

ad b) variables **in relative units** could be:

- related to **nominal value** → relative value = $= \frac{\text{real}}{\text{nominal}}$
  - e.g. **for impedance:**

$$z = \frac{Z_\Omega}{Z_n} \qquad Z_\Omega = z \cdot Z_n$$

  - nominal impedance calculation

$$S = \sqrt{3} \cdot U \cdot I = \sqrt{3} \cdot U \cdot \frac{U_f}{Z} = \sqrt{3} \cdot U \cdot \frac{U}{\sqrt{3} \cdot Z} = \frac{U^2}{Z}$$ (it's about size)

$$S_n = \frac{U_n^2}{Z_n} \Rightarrow Z_n = \frac{U_n^2}{S_n}$$

  - after substitution $z = Z_\Omega \frac{S_n}{U_n^2} \qquad Z_\Omega = z \frac{U_n^2}{S_n}$ **(*)**

17

Creation of substitute schema (13)

ad b) variables **in ratio units** could be:

- related to **reference value** → relative value = $= \frac{\text{real}}{\text{reference}}$
  - e.g. **for impedance:**

$$z = \frac{Z_\Omega}{Z_v} \qquad Z_\Omega = z \cdot Z_v$$

  - the calculation is same only with using of reference value S_v and U_v:

$$z = Z_\Omega \frac{S_v}{U_v^2} \qquad Z_\Omega = z \frac{U_v^2}{S_v}$$ **(**)**

18

Creation of substitute schema (14)

- We usually use both (it is (*), (**)) ⇒ **a combination of both calculations**
  - specified variables in r. u. (or %) characterizing the specific element to be related to nominal values of this element
  - for calculation we need all the elements related to the same values (reference) → we choose:
    - S_V … reference apparent power
    - U_V … reference voltage

→ of them can be determined $I_V = \frac{S_V}{\sqrt{3}U_V}$ … reference current

19

Creation of substitute schema (15)

- ***Recalculation:*** (summary)
  - from physical to relative value:

$$u = \frac{U}{U_V} \qquad s = \frac{S}{S_V} \qquad i = \frac{I}{I_V} = I\frac{\sqrt{3}U_V}{S_V}$$

$$z = \frac{Z}{Z_V} = Z\frac{S_V}{U_V^2} \qquad y = \frac{Y}{Y_V} = Y\frac{U_V^2}{S_V}$$

  - from relative to physical value:

$$U = u \cdot U_V \qquad S = s \cdot S_V \qquad I = i \cdot I_V = i\frac{S_V}{\sqrt{3}U_V}$$

$$Z = z \cdot Z_V = z\frac{U_V^2}{S_V} \qquad Y = y \cdot Y_V = y\frac{S_V}{U_V^2}$$

20

The procedure for creation of substitute schema – summary (1)

ad a) **in physical values**

- we create a substitute schema
- we recalculate variables (generally impedance, more often reactance) specified like relative to variables in real units

$$X = x\frac{U_n^2}{S_n}$$ … when R is neglected

- we recalculate variables through transformer conversions to one voltage level $X' = X\frac{1}{p^2}$

21

The procedure for creation of substitute schema – summary (2)

ad b) in relative values

- everything as with physical values
- recalculation of all parameters **to relative values** relative to the chosen one S_v a U_v

⇓

- All together:

$$x' = x \cdot \frac{U_n^2}{S_n} \cdot \frac{1}{p^2} \cdot \frac{S_v}{U_v^2}$$

Recalculation to [Ω] = physical values

Recalculation to one voltage level

Recalculation to relative value related to reference S_v a U_v

22

Creation of substitute schema

- to the impedance of individual network elements (1)

- **Alternator:**
  - represented by **reactance**

x''_d, x''_q … shock
x'_d, x'_q … transient
x_d, x_q … synchronous

longitudinal transverse

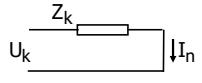
- calculating operating states – $x \approx 200\text{-}250\ \%$
- for failure states (short circuits) – $x'' \approx 12\ \%$

23

Creation of substitute schema

- to the impedance of individual network elements (2)

- **Transformer:**
  - represented by **short-circuit impedance z_k** (= longitudinal element in relative value)
  - the transverse element is neglected (very small against the longitudinal, especially for vvn/vvn a vvn/vn)



z_k can be replaced short-circuit voltage u_k
$z_k = u_k \approx 10\%$

- u_k – voltage at the terminals, if by connection secondary short the nominal current flows through the circuit

Derivation: $U_k = Z_k I_n$, $u_k = U_k / U_n = Z_k I_n / Z_n I_n = z_k$

24

Creation of substitute schema
- to the impedance of individual network elements (3)

- **Line:**
  - usually represented by X_Ω
    - for overhead lines vn, vvn
      $X_\Omega \approx 0{,}4\ \Omega/km$
    - for cables vn
      $X_\Omega \approx 0{,}1\ \Omega/km$
    - we need to know the length of the line

25

Creation of substitute schema - general relations for calculation of individual elements

in values

	physical	relative
line:	$X_v = X_\Omega \frac{1}{p^2}$	$x_v = X_\Omega \frac{1}{p^2}\frac{S_v}{U_v^2}$
transformator:	$X_t = \frac{u_{k\%}}{100}\frac{U_{nt}^2}{S_{nt}}\frac{1}{p^2}$	$x_t = \frac{u_{k\%}}{100}\frac{U_{nt}^2}{S_{nt}}\frac{1}{p^2}\frac{S_v}{U_v^2}$
alternator:	$X_g = \frac{x''_{d\%}}{100}\frac{U_{ng}^2}{S_{ng}}\frac{1}{p^2}$	$x_g = \frac{x''_{d\%}}{100}\frac{U_{ng}^2}{S_{ng}}\frac{1}{p^2}\frac{S_v}{U_v^2}$
network (system):	$X_s = \frac{c\cdot U_{ns}}{\sqrt{3} I_k''}\frac{1}{p^2}$	$x_s = \frac{c\cdot U_{ns}}{\sqrt{3} I_k''}\frac{1}{p^2}\frac{S_v}{U_v^2}$

where: c = 1,1 (for system) ... constant see tab. textbook

I_k'' ... initial impact short-circuit current

26

Next time

- **Solutions of voltage, current and power output conditions in the electric network**
  - Voltage and current conditions on power line
  - Determination power output flows in branch, branch losses

27