TRACTION CONVERTING SUBSTATION FROM VIEWPOINT OF FEEDING INTERLOCKING PLANT AT CZECH RAILWAYS.

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Summary This paper presents analyses current and voltage harmonic in traction converting substation 3 kV. It researches their rise and influence to three-phase cable line 6 kV, 50 Hz that is used for feeding interlocking plant. Processing of this task is arisen from requirement practice for line Pěčky - Poříčany - Rostoklaty where happened to adverse ratio in particular transmission line of feeding system. It is meant especially about backward influence traction substation rectifier Pečky to three-phase cable line 6 kV, 50 Hz. At the determinate length of the cable line, when resonance frequency of circuit transformer 22 kV/ 6kV and the cable line 6 kV, 50 Hz is approached frequency 550 Hz and 650 Hz (i.e. 11 and 13 harmonic) are happened to so-called "annulations input reactance of this circuit". That is caused by the leakage of current resonance frequency from traction converting substation to cable line. That produces additional losses and deformation waveform of voltage too. This deformation can be reflected on how interlocking plant is working.

1. INTRODUCTION

At the present, influence of device toward electric surrounding is judged more than at last years. These problems deal with branch EMC (electromagnetic compatibility). In this paper problem of backward influence traction substation rectifier Pečky to three-phase cable line 6 kV, 50 Hz, which is intended for feeding track-interlocking plant to line Pečky - Poříčany - Rostoklaty is solved. The solution is transpose three-phase feeding system to single-phase that is created from single models as simplified substitute elements watched circuit. Situation is displayed (Fig.1).

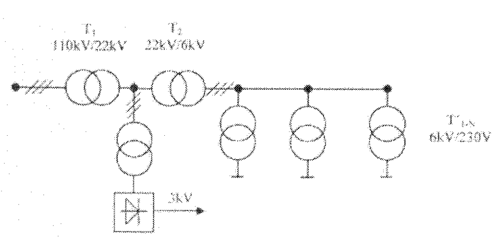


Fig.1. Wiring diagram of feeding system.

An appropriate algorithm is created from schematic for PSpice program where single signal analysis current and voltage in choice points of feeding system are performed. Acquired outputs values are processed in the form of data that are subsequently used as enter data for graphic representation. These data can be used to solution for prevention of creation of great distortion of current and also distortion of voltage that is undesirable for modern interlocking plant at Czech Railways.

2. THEORETICAL PART

2. 1. Traction transformer

We are issued from following principle [1] for harmonic when we are wanted to make-up alternative single-phase system for three-phase system:

- Harmonic current sources are considerated as ideal power supply except at fundamental harmonic.
- Fundamental harmonic current sources as well as consumer of fundamental harmonic current are replaced by their impedances.
- Impedance of all elements network are converted on frequency calculated harmonics.

The traction transformer has not self-resonance (i.e. it does not amplify and does not also damp current harmonics). It is basically current transformer, which transfer truly harmonics to the 2 kHz. It can be replaced by only longitudinal $\mathbf{L_T}$ for harmonic calculation. The traction transformer is replaced lengthwise impedance, which is calculated from fundamental parameters at linear dependence of leakage reactance on frequency.

$$X_T = \frac{u_k}{100} \frac{U_n^2}{S_n} . 10^3 \ [\Omega] \ , \qquad (1)$$

where $\mathbf{X_T}$ is alternate reactance transformer.

$\mathbf{u_k}$ is ratio voltage impedance transformer [%].

$\mathbf{U_n}$ is nominal voltage transformer [kV].

$\mathbf{S_n}$ is nominal power transformer [kVA].

Providing, that transformer are formed mainly inductive load then we is used for calculation $\mathbf{L_T}$ following relation.

$$\mathbf{Z_T = X_T = 2\pi f L_T} \ , \qquad (2)$$

where **f** is frequency [Hz].

Transformer T_1 (110 kV/22 kV):

$\mathbf{S_n}$ = 16.0 kVA; $\mathbf{u_k}$ = 11.0 %;

We have to calculated replaced $\mathbf{L_{T1}}$ according to relation (1) and (2) include gearing transformer

($\mathbf{p}$ = 3.667) because we have to convert all elements on the cables side with voltage 6 kV, so $\mathbf{L_{T1}}$ = 0.79 mH.

Transformer $\mathbf{T_2}$ (22 kV/6 kV):

$\mathbf{S_n}$ = 160.0 kVA; $\mathbf{u_k}$ = 4.05 %;

Calculated values are replaced $\mathbf{L_{T2}}$ according to relation (1) and (2): $\mathbf{L_{T2}}$ = 29 mH

Transformer $\mathbf{T'_1}$ to $\mathbf{T'_N}$ (6 kV/230 V):

$\mathbf{S_n}$ = 1.2 kVA; $\mathbf{L'_{T1}}$ = 159.2 H is set directly.

Relation for calculation partial transmission line (i. e. distance among power take-off places) is given:

$$\mathbf{P_{č}} = \frac{\mathbf{A}}{\mathbf{B}} \quad [-], \tag{3}$$

where **A** is distance transmission line Pěčky - Poříčany - Rostoklaty (i.e. 19.2 [km]). **B** is distance among power take-off places (i.e. 1.6 [km]). $\mathbf{P_{č}}$ = 12 is count – "Π- network", see below.

2. 2. Cable line 6 kV, 50 Hz

The line can be replaced according to [1] for calculations current of harmonics for running common feeding point to open distribution network and their suppression (i.e. amplification), this way:

The lines are replaced by common element and lumped parameters are direved from waves relation for a long transmission. In case of three-phase cable line 6 kV, 50 Hz, which cannot be counted as a long line because there are sorted transformers $\mathbf{T'_{T1}}$ to $\mathbf{T'_{TN}}$ in feeding system, which are replaced by inductance $\mathbf{L'_T}$. After this model is changed to element " Π " (Fig. 2).

The values parameters of three-phase cable line 6 kV, 50 Hz should be converted on section 1.6 km because it is length among simple supply points.

R'_k = 1.376 Ω; L'_k = 0.352 mH; C'_k = 0.624 μF

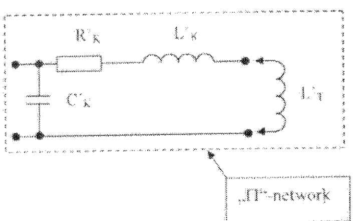


Fig.2. Substitution diagram of cable line 6 kV, 50Hz.

2. 3. Characteristics of substitation traction rectifier from the view of feeding 22kV

We have to brought in conditions for resulting simplification for analyses traction rectifier as the source of higher harmonic current:

- Feeding system is symmetric.
- Input voltage rectifier is symmetric.
- Inductivity in direct-current circuit Lss → ∞.
- Short-circuit power feeding system S_{NS} → ∞.
- Ignore losses of rectifier.

We are gone out from three-phase rectifier in bridge circuit and transformer in connection Y/y for constructive values of higher harmonic currents. Current contain except fundamental harmonic and higher harmonic. Those are given by relation:

$$\mathbf{n} = \mathbf{k\,p} \pm \mathbf{1} \tag{4}$$

Where **n** is harmonic from 2 to n.

k is whole number.

p is count pulses of rectifier.

The harmonic, that satisfy conditions for relation (4) are called -"characteristic harmonic", the others are not given in current.

Amplitudes of higher harmonic currents $\mathbf{I_n}$ are decreased with number of harmonic by relation called as " Principle of amplitude" [2].

$$\mathbf{I_n} = \frac{\mathbf{I_1}}{\mathbf{n}} \tag{5}$$

Where $\mathbf{I_n}$ is amplitude current number of harmonic.

$\mathbf{I_1}$ is amplitude current fundamental harmonic.

n is number of harmonic.

It follows relation (4) and (5) that rectifier with increasing count pulses positive by affect form of output current (i.e. less content harmonic). It is advantaged because higher harmonics produce additive losses and they brought on deformation voltage.

2. 4. Spectral primari current rectifier of substation

There are valide relation (4) for 12-pulses rectifier This relation shows that current has except fundamental harmonic the others harmonic number in spectral of primary n = 11, 13, 23, 25 etc. In our case, it is necessary to use values of 11 and 13 harmonics (We do not reflect the others values because their values amounting by relation (5) maximum 4.3% of fundamental harmonic), which is counted as arithmetic average. It is not come about case only with power load not ever case ideal smoothed.

Supply point with nominal power $\mathbf{P_n}$ = 5 MW (i.e. point for feeding interlocking plant) are responded at primary site bus bar **U** = 22 kV with ignored losses current $\mathbf{I_1}$ fundamental harmonic. It is counted on base of relation (6).

$$\mathbf{P_n} = \sqrt{3}\mathbf{U}\mathbf{I_1} \Rightarrow \mathbf{I_1}\frac{\mathbf{P_n}}{\sqrt{3}\mathbf{U}} = \mathbf{131.21} \quad [A] \tag{6}$$

We are count values of 11 and 13 harmonic by help of this current.

$$\mathbf{I}_{11} = \mathbf{I}_1(8{,}95\ \%) = \mathbf{11.74} \quad [\mathrm{A}] \tag{7}$$

$$\mathbf{I}_{13} = \mathbf{I}_1(7{,}45\ \%) = \mathbf{9.78} \quad [\mathrm{A}] \tag{8}$$

The rectifier behave as current source toward site 22 kV (source of current => **I** = constant, it is independent on voltage site 3 kV as source of voltage (R_i = 0 theoretic; U = constant, it is independent on load). We make substation diagram with utilize above conclusions. This is displayed in (Fig.3).

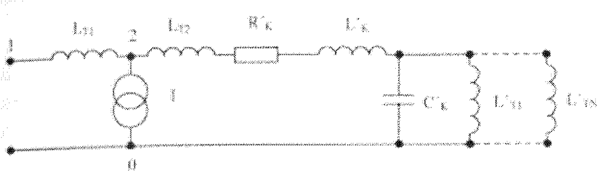


Fig. 3. Substitution diagram of feeding system.

Where $\mathbf{L_{T1}}$ is transformer $\mathbf{T_1}$ 110 kV/22 kV.

$\mathbf{L_{T2}}$ is transformer $\mathbf{T_2}$ 22 kV/6 kV.

$\mathbf{L'_{T1}}$ is transformer from $\mathbf{T_1}$ to $\mathbf{T_N}$ 6 kV/ 230V.

$\mathbf{R'_k}, \mathbf{L'_k}, \mathbf{C'_k}$ are values of cable line.

I is ideal source of current (i.e. rectifier).

Values of amplitude 11 and 13 harmonics are counted from relations (7) and (8)

$$\mathbf{I}_{11} = \mathbf{I}_1\sqrt{2} = \mathbf{16.6} \quad [\mathrm{A}] \tag{9}$$

$$\mathbf{I}_{13} = \mathbf{I}_1\sqrt{2} = \mathbf{13.8} \quad [\mathrm{A}] \tag{10}$$

The substation is given by those values $\mathbf{I_{11}}$ and $\mathbf{I_{13}}$ to point 2 because reactance of transformer $\mathbf{T_1}$ is less than reactance of cable line.

3. ANALYSIS

3.1. Load traction rectifier – spectrum primary current characteristic

Load of rectifier traction substation has effected to spectrum primary current so that higher harmonic are increased with increasing load approximately. It can be found [3] and [4].

3.2. Effecting impedance of feeding network

The higher harmonic voltages are smaller in case „hard network". It is the most ideal state. When impedance of feeding network is increased than effect of higher harmonic voltage is increased. It is meant that 11 and 13 harmonics are function of load.

3.3. Current and voltage ration in chosen points of cable line 6 kV, 50 Hz

We make calculation spectrum current and spectrum voltage of cable line for two cases:

a) Section Pečky - Rostoklaty (distance 19.2 km)

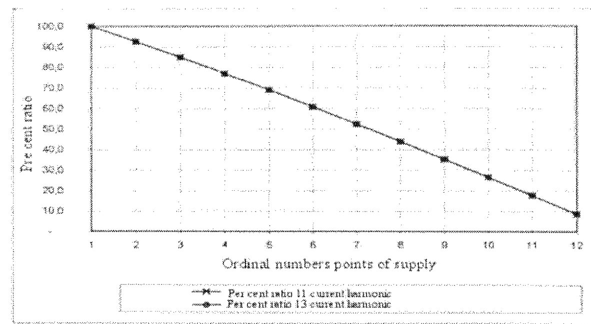


Fig.4. Per cent ratio 11 and 13 current harmonics in respect of the first point of supply feeding system.

Ordinal numbers points of supply are awayed with each other 1.6 km because values for per cent ratio 11 and 13 current harmonics in respect of the first point of supply are exactly identical. Result from (Fig. 4) is: Per cent ratio 11 and 13 current harmonics for this section are decreased to size 8.9 %.

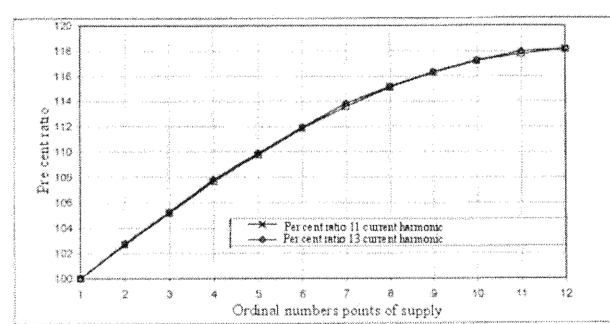


Fig.5. Per cent ratio 11 and 13 voltage harmonics in respect of the first point of supply feeding system.

Result from (Fig.5) is: Per cent ratio 11 and 13 voltage harmonics for this section are increased to size 118.2 % in respect of the first point of supply.

b) Section Pečky - Poříčany (distance 8.0 km)

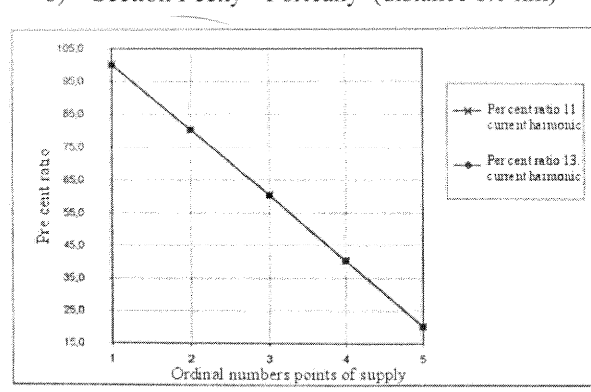


Fig.6. Per cent ratio 11 and 13 current harmonics in respect of the first point of supply feeding system.

Result from (Fig.6) is: Per cent ratio 11 and 13 current harmonics for this section are decreased to size 20.2 % in respect of the first point of supply.

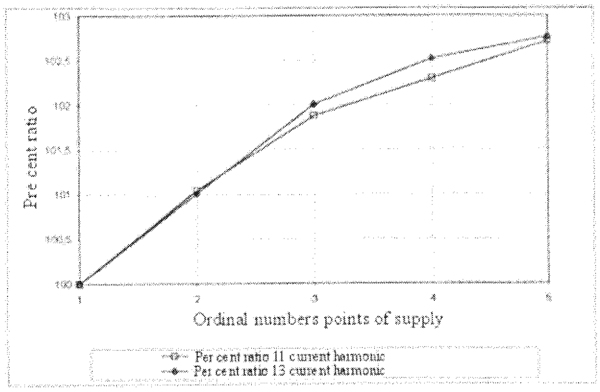


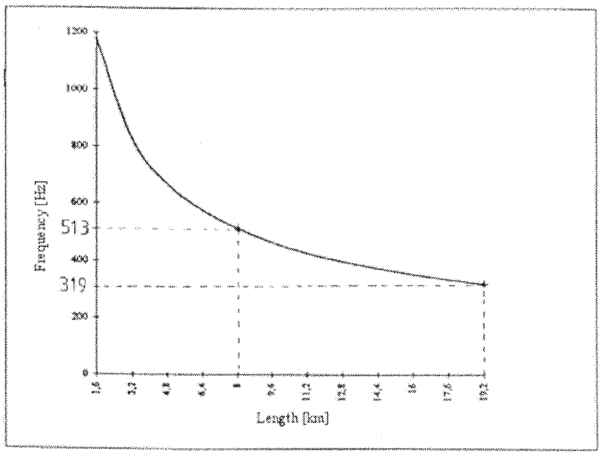
Fig.7. Per cent ratio 11 and 13 voltage harmonics in respect of the first point of supply feeding system.

Result from (Fig.7) is: Per cent ratio 11 and 13 voltage harmonics for this section are slightly increased to size 102.8 % in respect of the first point of supply.

3.4. Points of eventual presence of distortion voltage and current at cable line

Thomson relation for resonance frequency:

$$\mathbf{f} = \frac{1}{2\pi\sqrt{LC}} \tag{12}$$



Obr.8. Resonance frequency-length cable line characteristic.

Points of eventual presence of resonance in cable line 6 kV, 50 Hz for 11 and 13 harmonics are out of analyzed sections (Pečky – Poříčany - distance 8 km; Pečky – Rostoklaty - distance 19.2 km). This situation is displayed in (Fig.8) [3].

4. CONCLUSION

Analyzed currents and voltages harmonics in cable line show, that length of this line with corresponding resonance frequency of combination elements (transformer 22 kV/6 kV and cable line 6 kV, 50 Hz) have effect on spectrum harmonic current and voltage. The least positive case is getting for this combination elements, when their resonance frequency is near to frequency 11 and 13 harmonics. At these frequencies (f_{11} = 550Hz a f_{13} = 650Hz) so-called situation annulations input reactance of this combination elements come on. Than current and voltage harmonics these frequencies are transparenced to cable line.

Voltage harmonics (11 and 13) have trend to increase with length line (section Pečky - Rostoklaty to 18.2%, section Pečky - Poříčany to 2.8% compared to begin of feeding section).

Distortion of current and voltages, which are desirable for a new interlocking plant, they should be prohibit using these ways:

Feeding bus bar of transformer 22 kV/ 6 kV from others source which would not be influence of effect of rectifier.

Filtration circuits LC, which are parallel connected to bus bar 22 kV, reduce harmonics.

Resonance circuits modified through serial inductor inset circuit for shortcut section Pečky - Poříčany (e.i. solution parallel connection single-phase compensators connected to Y).

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