COMPLEX ASYMMETRIC REGIMES IN THE 110 KV NETWORK DUE TO RAR AUTOMATION

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Abstract: This paper analyzes a particularly case of complex asymmetric which appears in the 110 kV radial networks when monophase RAR works. It is determined working equations and they are solving for a numerical example. Finally, it is shown influence of impedance above fault place and success conditions for monophase RAR.

Keywords: asymmetric regime, short circuit, calculus

1. INTRODUCTION

Calculation of the complex asymmetric regimes is laboriously. The same calculus for a situation which has a very little realization probability is presented in [1]. This situation is due to biphase short circuit interplay with transversal asymmetry – break of two phases, due to inadequate working of the IUP breaker. Practical, there are, currently, situations generated by the asymmetric fault followed by the action of the RAR automation. The same situations appear in case of monophase fault followed by the RAR on the 110 kV lines which have one supply. It is necessary as network to contain at least a 110/MT transformer with bonder on 110 kV site. Use of 110 kV monophase breakers can lead to the same situations. The problems are much complicate when in the radial networks there are electrical generators. In the same situations, in order to maintain synchronism of generator with system, monophase RAR must be successfully.
In this paper there are analyzed the calculation methods of the complex asymmetric regimes in the same situations.

2. THE EQUATIONS OF THE ASYMMETRIC REGIME

We consider a typical situation for these asymmetric regimes (figure 1).

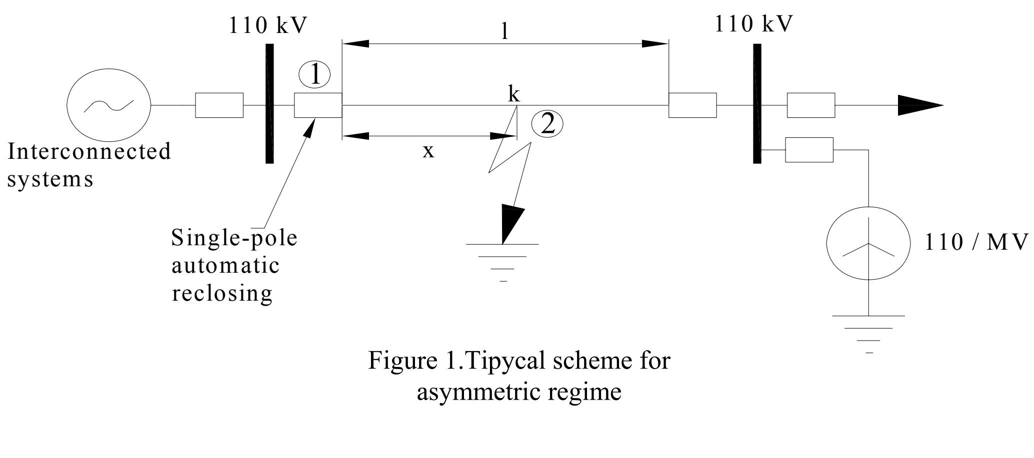

Figure 1.Tipycal scheme for asymmetric regime

The schemes for direct and homopolar sequences are shown in the figures 2 and 3.

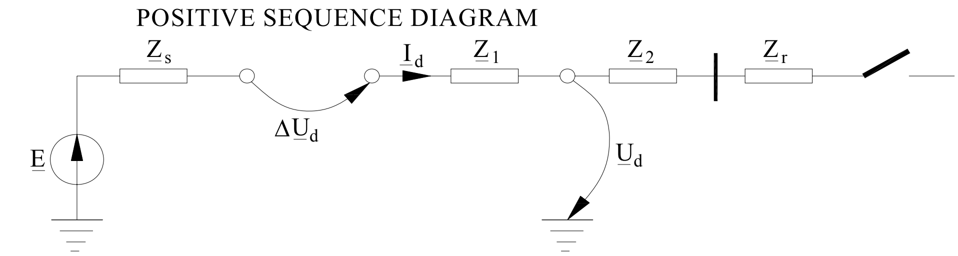

Fig. 2
Positive
sequence
scheme

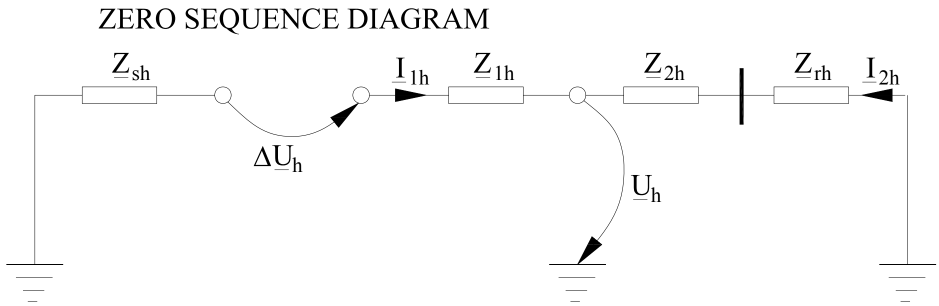

Fig. 3
Zero
sequence
scheme

In the figures 2 and 3 notations have following meaning:

- $\underline{E}$ – equivalent voltage of source, on phase
- $\underline{Z}_s$, $\underline{Z}_{sh}$ – sequence impedance of the system
- $\underline{Z}_1$, $\underline{Z}_{1h}$ – sequence impedance of the line from source to the fault place (length of line is *x*)
- $\underline{Z}_2$, $\underline{Z}_{2h}$ – sequence impedance of the line from fault place to the end (length of line is *l-x*)
- $\underline{Z}_r$, $\underline{Z}_{rh}$ – equivalent sequence impedance of the downstream radial network

Note, in the equivalent, influence of the network load was neglected.
The conditions on phase for the two asymmetries, longitudinal (1) and transversal (2), result from figure 4.

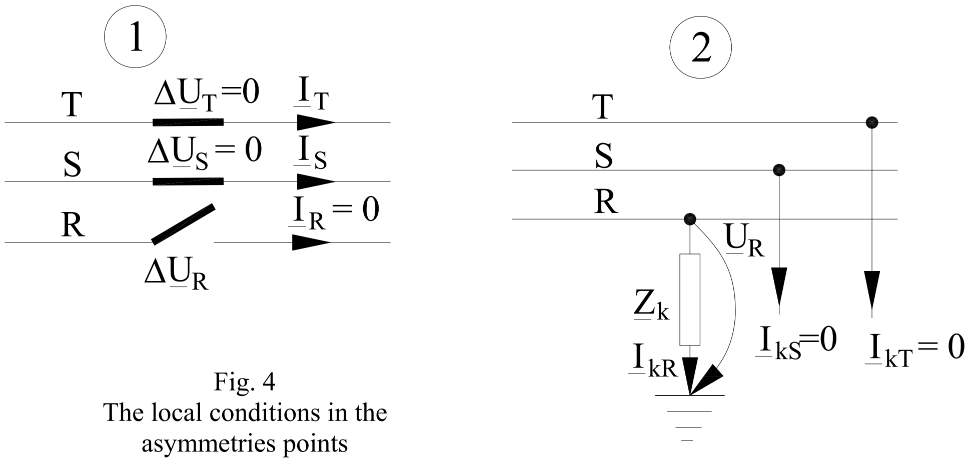

Fig. 4
The local conditions in the
asymmetries points

In the figure 4, $\underline{Z}_k$ is impedance on the monophase short circuit place (usually impedance of the arc).
The conditions for the asymmetries points can be written as:

$$\begin{aligned} &\underline{I}_R = 0 \\ &\Delta\underline{U}_S = 0 \\ &\Delta\underline{U}_T = 0 \end{aligned} \tag{1}$$

$$\begin{aligned} &\underline{U}_R = Z_k \cdot \underline{I}_{kR} \\ &\underline{I}_{kS} = 0 \\ &\underline{I}_{kT} = 0 \end{aligned} \tag{2}$$

Calculation of the working regime means calculation of the voltages and currents in the triphase network. The calculus is made in the sequence quantities. Passing from the phase quantities to the sequence quantities is made with following relations:

$$\begin{bmatrix} \underline{V}_R \\ \underline{V}_S \\ \underline{V}_T \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \cdot \begin{bmatrix} \underline{V}_h \\ \underline{V}_d \\ \underline{V}_i \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} \underline{V}_h \\ \underline{V}_d \\ \underline{V}_i \end{bmatrix} = \frac{1}{3} \cdot \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} \underline{V}_R \\ \underline{V}_S \\ \underline{V}_T \end{bmatrix} \tag{4}$$

where $a = e^{j \cdot \frac{2 \cdot \pi}{3}}$ and quantities V can be currents or voltages.

In this situation, the currents in the asymmetry point (1) can be determined easy. Therefore, we have as unknown quantities: sequence voltages in the point (1), $\Delta\underline{U}_d$, $\Delta\underline{U}_i$, $\Delta\underline{U}_h$, voltages in the point (2), $\underline{U}_d$, $\underline{U}_i$, $\underline{U}_h$ and currents $\underline{I}_d$, $\underline{I}_i$, $\underline{I}_{1h}$, $\underline{I}_{2h}$.

If we write equations 2 and 3 from the systems (1) and (2) in the sequences quantities, result easily:

$$\Delta\underline{U}_d = \Delta\underline{U}_i = \Delta\underline{U}_h \tag{5}$$

$$\underline{I}_d = \underline{I}_i = \underline{I}_h \tag{6}$$

with

$$\underline{I}_h = \underline{I}_{1h} + \underline{I}_{2h} \tag{7}$$

The first equations from the systems (1) and (2) can be written in the sequence quantities as:

$$\begin{aligned} &\underline{I}_d + \underline{I}_i + \underline{I}_{1h} = 0 \\ &\underline{U}_d + \underline{U}_i + \underline{U}_h = \left(\underline{I}_d + \underline{I}_i + \underline{I}_h\right) \cdot \underline{Z}_k \end{aligned} \tag{8}$$

From the direct, inverse and homopolar sequence schemes (figures 3 and 4, inverse sequence is like direct sequence) result:

$$\begin{aligned} &\underline{E} = \left(\underline{Z}_s + \underline{Z}_1\right) \cdot \underline{I}_d + \Delta\underline{U}_d + \underline{U}_d \\ &0 = \left(\underline{Z}_s + \underline{Z}_1\right) \cdot \underline{I}_i + \Delta\underline{U}_i + \underline{U}_i \\ &0 = \left(\underline{Z}_{sh} + \underline{Z}_{1h}\right) \cdot \underline{I}_{1h} + \Delta\underline{U}_h + \underline{U}_h \\ &\underline{U}_h = -\left(\underline{Z}_{2h} + \underline{Z}_{rh}\right) \cdot \underline{I}_{2h} \end{aligned} \tag{9}$$

If we replace (5), (6) in (7), (8) and (9), result following equation system:

$$\begin{aligned} &\underline{I}_d = \underline{I}_{1h} + \underline{I}_{2h} \\ &2 \cdot \underline{I}_d + \underline{I}_{1h} = 0 \\ &\underline{U}_d + \underline{U}_i + \underline{U}_h = 3 \cdot \underline{I}_d \cdot \underline{Z}_k \\ &\underline{E} = \left(\underline{Z}_s + \underline{Z}_1\right) \cdot \underline{I}_d + \Delta\underline{U}_d + \underline{U}_d \\ &0 = \left(\underline{Z}_s + \underline{Z}_1\right) \cdot \underline{I}_d + \Delta\underline{U}_d + \underline{U}_i \\ &0 = \left(\underline{Z}_{sh} + \underline{Z}_{1h}\right) \cdot \underline{I}_{1h} + \Delta\underline{U}_d + \underline{U}_h \\ &\underline{U}_h = -\left(\underline{Z}_{2h} + \underline{Z}_{rh}\right) \cdot \underline{I}_{2h} \end{aligned} \tag{10}$$

where $\underline{I}_d$, $\underline{I}_{1h}$, $\underline{I}_{2h}$, $\Delta\underline{U}_d$, $\underline{U}_d$, $\underline{U}_i$, $\underline{U}_h$ are unknown quantities.
The linear system in complex quantities (10) can be solved using matrices methods or numerical methods.
After solving system (10) the voltages and currents, on phase, in the asymmetry points are determined using relation (3).

3. NUMERICAL RESULTS FOR A TEST NETWORK

We consider a network like as figure 1. There is one 110/MT transformer connected to the 110 kV bus-bar. The characteristic quantities of the network are following:

A. System

The short circuit power: $S_k = 1500$ [MVA]

$\underline{Z}_s = 0.81+j8.07$ [Ω]

$\underline{Z}_{sh} = 2.82+j28.23$ [Ω]

$$\underline{E} = \frac{115}{\sqrt{3}} \cdot e^{j\cdot 0} \text{ [kV]}$$

B. LEA 110 kV – 3 x 185 mm^2+90 mm^2 OL-AL

l = 20 km

$\underline{Z}_0 = 0.157 + j\,0.394$ [Ω/km]

$\underline{Z}_{0h} = 0.386 + j\,1.342$ [Ω/km]

$\underline{Z}_1 = \underline{Z}_0 \cdot x$

$\underline{Z}_2 = \underline{Z}_0 \cdot (l - x)$

$\underline{Z}_{1h} = \underline{Z}_{0h} \cdot x$

$\underline{Z}_{2h} = \underline{Z}_{0h} \cdot (l - x)$

C. Transformer 110/20 kV, connexity Y_0/D

$S_n = 16$ [MVA]

$u_k = 10.36$ [%]

$\Delta P_{cu} = 97$ [kW]

$$R_T = \Delta P_{cu} \cdot \frac{U_n^2}{S_n} \cdot 10^{-3} = 4.58 \text{ [Ω]}$$

$$Z_T = \frac{u_k}{100} \cdot \frac{U_n^2}{S_n} = 78.35 \text{ [Ω]}$$

$$X_T = \sqrt{Z_T^2 - R_T^2} = 78.21 \text{ [Ω]}$$

$$\underline{Z}_r = \underline{Z}_T = 4.58 + j \cdot 78.21 \text{ [Ω]}$$

$$\underline{Z}_{rh} = \underline{Z}_T = 4.58 + j \cdot 78.21 \text{ [Ω]}$$

In the table 1 there are presented results obtained for different fault places (x variable) and for the more values of the impedance on the fault place, $\underline{Z}_k$.
In this table was shown and monophase short circuit current in the point k, before working of RAR, I'_{kR}, which is calculated with relation:

$$\underline{I'}_{kR} = \frac{3 \cdot \underline{E}}{2 \cdot \underline{Z}_s + 2 \cdot \underline{Z}_1 + \underline{Z}_h + 3 \cdot \underline{Z}_k} \tag{11}$$

where

$$\underline{Z}_h = \frac{\left(\underline{Z}_{sh} + \underline{Z}_{1h}\right) \cdot \left(\underline{Z}_{2h} + \underline{Z}_{rh}\right)}{\underline{Z}_{sh} + \underline{Z}_{1h} + \left(\underline{Z}_{2h} + \underline{Z}_{rh}\right)} \tag{12}$$

Table 1
Results obtained for the test network

No. crt.	$\underline{Z}_k$ [Ω]/ x [km]	I_{kR} [A]	$\Delta U_R \cdot \sqrt{3}$ [kV]	$U_R \cdot \sqrt{3}$ [kV]	$U_S \cdot \sqrt{3}$ [kV]	$U_T \cdot \sqrt{3}$ [kV]	I'_{kR} [A]
1	10 10	194.40	121.3	3.37	110.3	109.7	3046
2	10 1	184.54	119.1	3.19	111.3	111.7	3776
3	10 19	205.38	123.8	3.56	109.2	107.4	2622
4	1 10	195.03	121.7	0.34	110.5	109.4	3691
5	1 1	185.13	119.5	0.32	111.5	111.6	4903
6	1 19	206.03	124.2	0.36	109.6	107.1	3062
7	0 10	195.09	121.7	0	110.5	109.4	3730
8	0 1	185.19	119.5	0	111.5	111.6	4957
9	0 19	206.09	124.2	0	109.7	107.0	3092

In the table 1, voltages are multiplied with $\sqrt{3}$ in order to compare with nominal voltage, 110 kV and system voltage, 115 kV. Note, the values of the monophase short circuit current, in case of the double asymmetry, varies insignificant due to varies of the impedance in the fault place, 10,1 or 0 Ω. Thus, for x = 10 km, its values are 194.4, 195.03, respectively 195.09 A. The explanation is that value of homopolar impedance of the transformer (78 Ω) is much more than impedance on the fault place.
Note, also, the fault place does not influence too much value of the fault current. Thus, for Z_k = 10 Ω and x = 1, x=10, x=19 km, values of the monophase fault current are 184.54, 194.4, 205.38 A. The explanation is the same: vary of the line homopolar impedance is small given the transformer homopolar impedance. The value of the current is bigger for the faults that are much far from the source. This is due to fact that fault is supplied through 110/20 kV transformer which is located to the end opposite of the source.
The monophase short circuit current decreases function to far from the source, before working of the monophase RAR. For example, for Z_k=10 Ω, and x=1, 10, 19 km, the values of the fault currents are 3776, 3046, 2622 A and it increases when impedance in the fault place decreases. For example, for x = 10 km and Z_k = 10, 1, 0 Ω, values of the currents are 3046, 3691, 3730 A.
The voltage on the phase with monophase fault is small. It is proportional to value of the impedance on the fault place. The voltage on the phase unaffected varies insignificant function to impedance of the fault place and location of the fault place.

4. CONCLUSION

In conclusion, from the data presented up, it can be said:

- Calculation of the complex asymmetric regime due to working of the monophase RAR from one end, in case of a monophase fault, is difficult. It involves solving a system with 7 complex linear equations.
- In the situations presented, working of the monophase RAR isn't efficiently because fault remains supplied from the 110/MT transformers. But, value of the fault current decreases significantly.
- Location of the fault doesn't influence significantly value of the monophase fault current. For the fault near the 110/MT transformers, values of the fault currents are bigger.
- Value of the impedance on the fault place does not influence value of the monophase short circuit current.

- In case of the monophase short circuit current which is supplied from the source (before working of the monophase RAR), this decreases when distance from the source increases and when impedance on the fault place increases.

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