Bitlis Eren Univ J Sci & Technol
5 (2), 57-61, 2015

E - ISSN 2146-7706

Research Article

Increasing of Switching Abilities of High Voltage Circuit Breakers

Sabir RUSTEMLI [1]

[1] *Bitlis Eren University, Department of Electrical and Electronics Engineering, Bitlis - Turkey*
srustemli@beu.edu.tr

Abstract

The most effective way of increasing switching abilities of high voltage circuit breakers in energy transmission systems is to influence around zero degree to short circuit currents (Maljkovic Z et al 2000; Gashimov, A.M et al. 2001; Antipov, K.M et al. 1985; Gashimov A.M 1991). For this reason, transformers neutral points should be grounded variously for limitation of asymmetric short circuit currents. But another way for this limitation is grounded of transformers neutral points over non-linear reactor. The non-linear reactor effects around zero degree to short circuit current. Therefore, the main purpose of non-linear reactor is to increase the switching abilities of the high voltage circuit breakers. This kind reactor does not necessitate the isolation exchange of transformer neutral points.

Non-linear reactors effect around zero degree to asymmetric short circuit current at the networks, which their neutral point, have been grounded with non-linear reactors. In addition, it also effects to changing speed of temporary recover of voltage, which occurred, between contacts of high voltage circuit breakers after removing of short circuit. So increasing switching abilities of the high voltage circuit breakers will be provided by these two ways.

Therefore, switching abilities of transformers neutral point the networks with 220 kV or higher can be increased by grounding over non-linear reactor.

Keywords: Short Circuit Current, Temporary Recovering Voltage, Reactor, Nonlinear Reactor

1. Scope of the Study

In this study, calculation of temporary recovering voltage between circuit breaker contacts and approaching to zero degree in short circuit currents have reviewed at the networks that its neutral point were grounded over non-linear reactor. Figure illustrates a network plane of this type. Short circuit statement at L_1 line after B circuit breaker interval vas investigated. C capacity and g_b permeability are for modelling the capacity at power distribution area region and leakage at isolation. Additionally, by means of g_b permeability, short circuit statement at bus system or at interval after the circuit breaker are modelled.

Calculations terms for each node are as follows.

Terms for I node:

Voltage and current at the sending-end are calculated from the following relationships.

$$\frac{di_{2S}}{dt} = L_2^{-1}(e(t) - U_{2S} - r_2 i_2)$$
$$U_{2S} = (Z + Z_s)_1 \, i_{2S} - V_{qS} \qquad (1)$$
$$V_{qS} = -U_{qS} + Z\, i_{2S}$$

Here, L_2, r_2: Inductance and resistant matrix of 2 blocks.

Indexes given in Fig. 1 are proper to the numbers of energy transmission line at the plane and node points.

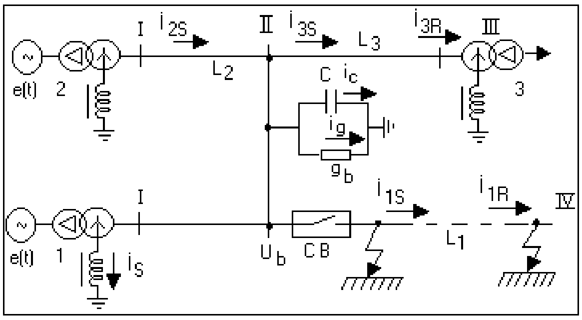

Figure 1. Network shema grounded over non-linear reactor

The current and voltage at interval points of L_1 energy transmission line can be determined by the following equations (Granelli G.P et al. 2001; Ragaller K 1981).

$$U_{L2} + (Z + Z_s)_2 \, i_{L2} = V_{p2}$$
$$-U_{L2} + (Z + Z_s)_2 \, i_{L2} = V_{q2} \qquad (2)$$

Where

$$V_{p2} = U_{p2} + Z\, i_{p2} + \sum_{k=1}^{n} \chi_{k2} \; i_{f2}$$

$$V_{q2} = -U_{q2} + Z\, i_{q2} + \sum_{k=1}^{n} \chi_{k2} \; i_{f2}$$

Terms for II node

Voltage in bus system and currents at bus branches can be calculated by the following equations.

$$\frac{di_1}{dt} = L_1^{-1}(e(t) - GU_b - r_1 i_1)$$

Received 25 November 2015
Available online December 2015

$$\frac{dU_b}{dt} = C^{-1} i_C \qquad (3)$$

$$\frac{d\Psi}{dt} = U_N$$

$$i_\mu = a\varphi + b\varphi^n + c\varphi^m$$

Here, L, r, c, g_b -I and II node's inductance, resistant, capacity and permeability matrixes respectively. G are special and comparative matrix constants of the elements. They can be properly written by the following way.

$$G_s = [1 + L_0 F(\psi) + 3]^{-1}$$

$$G_m = [L_0 F(\psi) + 3]^{-1}$$

Where total capacity current

$$i_C = i_1 + i_{2R} - i_{3S} - i_{1S} + i_g$$

Where

$$i_{2R} = (Z + Z_s)_2^{-1}(V_{pK} - U_b)$$

$$i_{3S} = (Z + Z_s)_3^{-1}(V_{q3} + U_b)$$

$$i_{1S} = (Z + Z_s)_1^{-1}(V_{q1} + U_b)$$

$$i_g = g_b U_b$$

Short circuit statement after high voltage circuit breakers can be modelled by means of g_b capacity permeability. G_b has high value in case of short circuit statement current and voltage at intervals in L_1 and L_2 energy transmission line are determined by (2) relationship.

Terms for III node

Current and voltage in L_3 energy transmission line which charged by transformer, can be founded by the following equations

$$\frac{di_{3R}}{dt} = L_3^{-1}(U_{3R} - r_T i_{3R} - U_0)$$

$$U_{3R} = V_{pR} - (Z + Z_s)_3 i_{3R} \qquad (4)$$

$$V_{pR} = V_{p3} + Zi_{p3} + \sum_{k=1}^{n} \chi_{k3} i_{f3}$$

Here L_3, r_1-III nodes inductance and resistant matrixes respectively.

Terms for IV node

Voltage and current are founded by solving following equations

$$U_{1R} = 0\,,\ i_{1R} = (Z + Z_s)_1^{-1} V_{pR} \qquad (5)$$

$$V_{pR} = U_{p1} + Zi_{p1} + \sum_{k=1}^{n} \chi_{k1} i_{f1}$$

(1)-(5) terms provide a possibility for determination of voltage and current at p and q points for t+τ time in energy transmission line even for junction and interval point values of voltage and current. (Rustemov S.A 1995).

2. Calculation of Short Circuit Current in case of Aproaching Zero

Short circuit statement after circuit breaker is modelled by diagonal matrix. If there is not any short circuit, permeability of the element is equal to zero. In case of short circuit, diagonal element is accepted to have a value equal to permeability of phase in touch with floor. For example g_b short circuit statement at I phase will be as follows.

$$g_b = \begin{vmatrix} g_{kd} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{vmatrix}$$

Calculations were done by taking into consideration the reactor nominal voltage is equal to network's maximum phase voltage (U_{fm}) of 10% and 20 %. For each selected nominal voltage a various corresponding nominal currents (I_n) were accepted. After removing of short circuit statement, the number of working lines were determined as n=1,2and 4. Proper results of short circuit currents when approaching to zero are given in figure 2, figure 3 and figure 4.

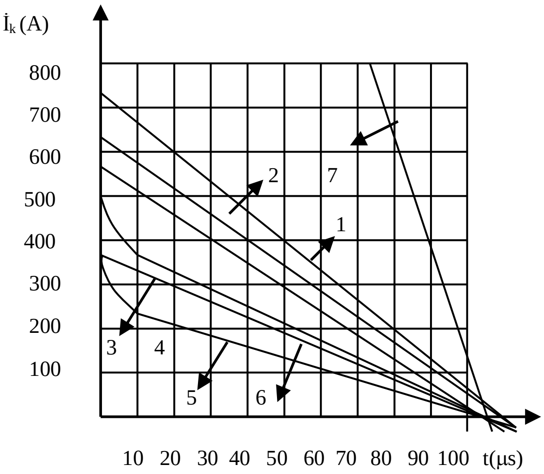

Figure 2. Approaching of short circuit currents to zero (n=1).

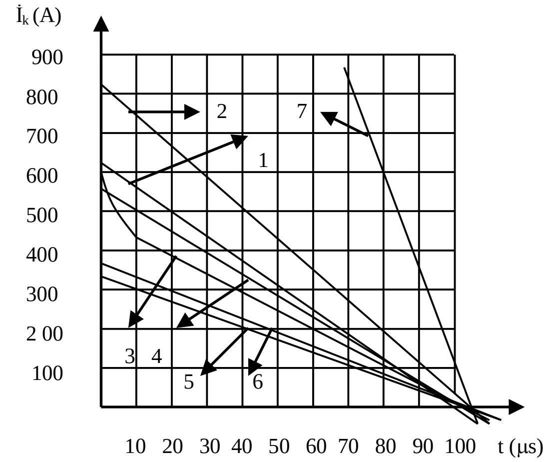

Figure 3. Approaching of short circuit currents to zero (n=2).

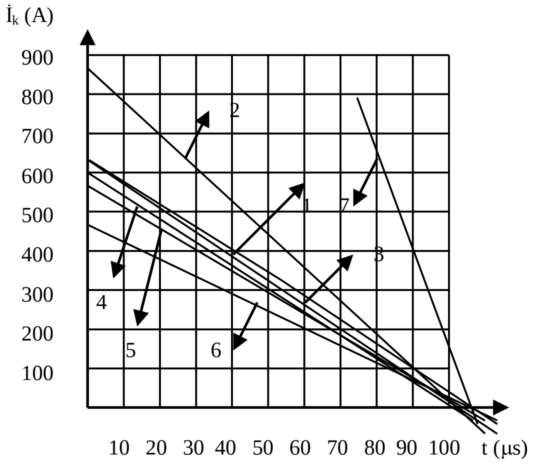

Figure 4. Approaching of short circuit currents to zero (n=4).

Curve 7 in figures represents that transformer's neutral point was directly grounded. 1,2,3,4,5 and 6 curves on the other hand represent that transformer's neutral points were grounded over reactor. The curve 1 states linear reactor and remain curves states non-linear reactor grounded. U_N and I_N parameters were handled as shown below Table 1.

Table 1. Non-linear reactor parameters

Curve number	U_N	I_N
2	%10 U_{fm}	600 A
3	%10 U_{fm}	20 kA
4	%20 U_{fm}	20 kA
5	%10 U_{fm}	12 kA
6	%20 U_{fm}	12 kA

Calculations have showed that as line numbers in power distributing area increase, reactor efficiency also increases. If last 70 μs of short circuit current when approaching to zero was considered there is no important difference between line numbers if they are 1 and 2 in power distributing area and approaching speed of short circuit current to zero. Whereas if line numbers in power distributing area is n=21, comparison with first variance lead to an important decrease in speed of approaching zero for short circuit current. The most important difference was seen in comparison of neutral points grounded over non-linear reactor and neutral points grounded directly.

Short circuit current's approaching zero speed in case of increasing nominal current of reactor does not mainly depend on nominal voltage of reactor nor line numbers at distributing area. This statement provides optimum parameters selection for reactor. The most suitable variation among all is the parameter with U_N = %10U_{fm}, I_N=20 kA.

3. Temporary Ground Valtage after Circuit Breaker when Short Circuit Statement Removed

In bus system or removing of short circuit statement, the mentioned relationship terms remain unchanged. Opening of short circuits is characterized by g_b permeability. All diagonal elements g_b are accepted to have the highest value of permeability at first and calculations are partly done by general way, then three phases short circuit statement is achieved.

$$g_b = \begin{vmatrix} g_{sc} & 0 & 0 \\ 0 & g_{sc} & 0 \\ 0 & 0 & g_{sc} \end{vmatrix}$$

Calculation step are decreased to 10^{-6} second and methods are used to increase the calculation speed so short circuit current characteristic in case of approaching zero and temporary recovering voltage are conducted at determined statement.

The permeability of a phase is accepted as equal to zero if current of any phases in network is passed in zero value.

In our calculation passing of current in zero value and opening order are as follows.

I. Phase:

$$g_b = \begin{vmatrix} g_{sc} & 0 & 0 \\ 0 & g_{sc} & 0 \\ 0 & 0 & g_{sc} \end{vmatrix}$$

II. Phase:

$$g_b = \begin{vmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{vmatrix}$$

III. Phase:

$$g_b = \begin{vmatrix} 0 & 0 & 0 \\ 0 & g_{sc} & 0 \\ 0 & 0 & 0 \end{vmatrix}$$

Here variations in case of zero approaching of short circuit current were considered. The characteristic of temporary voltage recovering according to obtained results is illustrated in Table's 2,3 and 4.

Table 2. Opening time of 3 phase distance short circuit after the high voltage circuit breaker. Transformer's neutral point is grounded over the linear and non-linear reactor.(Remaining lines number after the opening of short circuit for n=1)

Array No:	Kind of reactor and its parameter	Variation speed of temporary recover voltage kV/μs			Amplitude of temporary recover voltage		
		Opening phase			Opening phase		
		I	II	III	I	II	III
1	Linear reactor; x_r=2.4Ω	1.45	1.34	0.87	1.28	1.26	1
2	Non-linear reactor U_N=%10U_{fm}; I_N=600A	1.38	0.97	0.74	1.48	0.9	0.88
3	Non-linear reactor U_N=%10U_{fm} ; I_N=12 kA	1.38	1.01	0.8	1.37	0.9	1
4	Non-linear reactor U_N=%10U_{fm} ; I_N=20 kA	1.2	0.98	0.95	1.3	0.9	0.98

5	Non-linear reactor U_N=%20U_{fm} ; I_N=12 kA	1.39	0.81	0.8	1.43	0.9	0.97
6	Non-linear reactor U_N=%20U_{fm} ; I_N=20 kA	1.3	0.95	0.8	1.39	0.91	1

Table 3. Opening time of 3-phase distance short circuit after the high voltage circuit breaker. Transformer's neutral point is grounded over the linear and non-linear reactor.(Remaining lines number after the opening of short circuit for n=2)

Array No:	Kind of reactor and its parameter	Variation speed of temporary recover voltage kV/μs			Amplitude of temporary recover voltage		
		Opening phase			Opening phase		
		I	II	III	I	II	III
1	Linear reactor; x_r=2.4Ω	0.62	0.67	0.7	1.28	1.25	1
2	Non-linear reactor U_N=%10U_{fm}; I_N=600A	0.53	0.73	0.42	1.48	0.9	0.88
3	Non-linear reactor U_N=%10U_{fm} ; I_N=12 kA	0.6	0.83	0.55	1.37	0.9	0.98
4	Non-linear reactor U_N=%10U_{fm} ; I_N=20 kA	0.8	0.6	0.4	1.27	0.9	0.97
5	Non-linear reactor U_N=%20U_{fm} ; I_N=12 kA	0.64	0.7	0.53	1.43	0.9	0.94
6	Non-linear reactor U_N=%20U_{fm} ; I_N=20 kA	0.63	0.71	0.32	1.38	0.9	0.97

Table 4. Opening time of 3-phase distance short circuit after the high voltage circuit breaker. Transformer's neutral point is grounded over the linear and non-linear reactor.(Remaining lines number after the opening of short circuit for n=4)

Array No:	Kind of reactor and its parameter	Variation speed of temporary recover voltage kV/μs			Amplitude of temporary recover voltage		
		Opening phase			Opening phase		
		I	II	III	I	II	III
1	Linear reactor; x_r=2.4Ω	0.38	0.68	0.42	1.28	1.22	0.97
2	Non-linear reactor U_N=%10U_{fm}; I_N=600A	0.55	0.43	0.38	1.46	0.89	0.71
3	Non-linear reactor U_N=%10U_{fm} ; I_N=12 kA	0.4	0.49	0.35	1.3	0.88	0.94
4	Non-linear reactor U_N=%10U_{fm} ; I_N=20 kA	0.4	0.52	0.35	1.25	0.89	0.97
5	Non-linear reactor U_N=%20U_{fm} ; I_N=12 kA	0.4	0.55	0.3	1.4	0.88	0.87
6	Non-linear reactor U_N=%20U_{fm} ; I_N=20 kA	0.39	0.35	0.3	1.35	0.89	0.8

Here, it is possible to ground neutral point over non-linear reactor without any change on its isolation.

4. Temporary Recovery Voltage in case of Short Circuit Interval Statement

The heavy work duty for circuit breaker is short interval circuit statements. In order to investigate the effects of non-linear reactor short interval circuit on temporary recovery voltage after removal of short circuit, number of lines from bus and each phase openings were considered. Opening orders are thought as like short circuit after circuit breaker statement. First opening phase will be "C" phase and its i_{LC}=0 due to zero current passing. Here I_L is current at the sending-end L_1. The current is represented by i_{1S} in the Fig.1. "S" and "R" indexes at the sending-end and receiving-end of energy transmission line in second node do not given here for easy calculation. Lets find i_C and i_L current by using equations (1) and (2).

$$\begin{vmatrix} i_{ca} \\ i_{cb} \end{vmatrix} = \begin{vmatrix} i_{1a} \\ i_{1b} \end{vmatrix} + \begin{vmatrix} i_{2a} \\ i_{2b} \end{vmatrix} - \begin{vmatrix} i_{3a} \\ i_{3b} \end{vmatrix} - \begin{vmatrix} i_{La} \\ i_{Lb} \end{vmatrix} + \begin{vmatrix} i_{ga} \\ i_{gb} \end{vmatrix} \quad (6)$$

$$i_{cc} = i_{2c} + i_{1c} - i_{3c} - i_{gc}$$

Here

$$\begin{vmatrix} i_{2a} \\ i_{2b} \end{vmatrix} = \begin{vmatrix} (Z+Z_S)_{2_{11}} & (Z+Z_S)_{2_{12}} \\ (Z+Z_S)_{2_{21}} & (Z+Z_S)_{2_{22}} \end{vmatrix} \begin{vmatrix} V_{pa} \\ V_{pb} \end{vmatrix} - \begin{vmatrix} U_{bq} \\ U_{bb} \end{vmatrix}$$

$$\begin{vmatrix} i_{3a} \\ i_{3b} \end{vmatrix} = \begin{vmatrix} (Z+Z_S)_{3_{11}} & (Z+Z_S)_{3_{12}} \\ (Z+Z_S)_{3_{21}} & (Z+Z_S)_{3_{22}} \end{vmatrix} \begin{vmatrix} V_{qq} \\ V_{qb} \end{vmatrix} + \begin{vmatrix} U_{bq} \\ U_{bb} \end{vmatrix}$$

$$\begin{vmatrix} i_{La} \\ i_{Lb} \end{vmatrix} = \begin{vmatrix} (Z+Z_S)_{1_{11}} & (Z+Z_S)_{1_{12}} \\ (Z+Z_S)_{1_{21}} & (Z+Z_S)_{1_{22}} \end{vmatrix} \begin{vmatrix} V_{qq} \\ V_{qb} \end{vmatrix} + \begin{vmatrix} U_{bq} \\ U_{bb} \end{vmatrix}$$

$$\begin{vmatrix} i_{ga} \\ i_{gb} \end{vmatrix} = \begin{vmatrix} g_q & 0 \\ 0 & g_b \end{vmatrix} \begin{vmatrix} U_{bq} \\ U_{bb} \end{vmatrix}$$

Voltage in the sending-end L_1 line can be computed by the following relationships.

$$\begin{vmatrix} U_{Lq} \\ U_{Lb} \end{vmatrix} = \begin{vmatrix} (Z+Z_S)_{1_{11}} & (Z+Z_S)_{1_{12}} \\ (Z+Z_S)_{1_{21}} & (Z+Z_S)_{1_{22}} \end{vmatrix} \begin{vmatrix} i_{Lq} \\ i_{Lb} \end{vmatrix} - \begin{vmatrix} V_{qq} \\ V_{qb} \end{vmatrix}$$

$$U_{Lc} = (Z+Z_s)_{1_{13}}\, i_{La} + (Z+Z_s)\, i_{Lb} - V_{qc}$$

Current at second phase opening (we assume a phase) is $i_{La}=0$. In that case i_{CB} current is defined by the following equations.

$$i_{cb} = i_{2a} + i_{1b} - i_{3c} - i_{gb}$$

Where

$$i_{2b} = (Z+Z_s)^{-1}_{2_{22}}\,(V_{pb} - U_{bb})$$

$$i_{3b} = (Z+Z_s)^{-1}_{3_{22}}\,(V_{pb} - U_{bb})$$

$$i_{Lb} = (Z+Z_s)^{-1}_{1_{22}}\,(V_{gb} + U_{bb})$$

$$i_{gb} = g_b U_{bb}$$

Voltage in the head of L_1 line can be computed by the following relationships.

$$U_{La} = (Z+Z_s)_{1_{12}}\, i_{Lb} - U_{qq}$$

$$U_{Lb} = (Z+Z_s)_{1_{22}}\, i_{Lb} - U_{qb}$$

$$U_{Lc} = (Z+Z_s)_{1_{32}}\, i_{Lb} - U_{qc}$$

Current at third phase opening (we assume b phase) is $i_{La}= i_{Lb}= i_{Lc}=0$. In that case current matrix and voltage on the sending-end of the L_1 energy transmission line are obtained from Eq.(1) and Eq.(4) . Sending-end voltage is defined by the following equations.

$$\begin{vmatrix} U_{La} \\ U_{Lb} \\ U_{Lc} \end{vmatrix} = \begin{vmatrix} V_{qd} \\ V_{qb} \\ V_{qc} \end{vmatrix}$$

Variation of temporary recovering voltage in case of removing of short interval circuit statement is shown in figure 5. Here, curve 1 has taken when number of lines are 2 after short circuit opened, neutral points of transformer U_N=%10 U_{fm}, I_N=20 kA during grounded over non-linear reactor and maximum short circuit current and curve 2 and curve 3 consist of %75, %60 and %30 currents respectively.

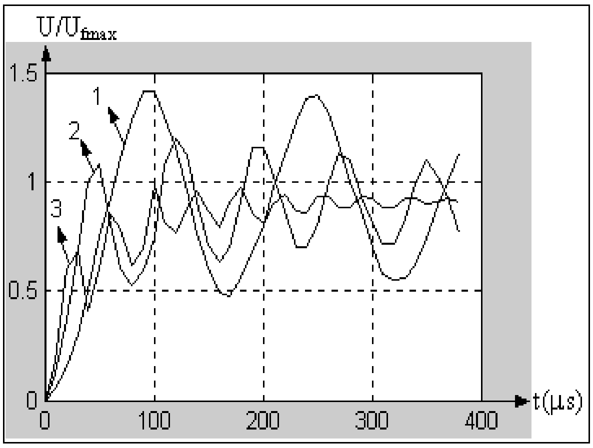

Figure. 5. Variation of temporary recovering voltage

After removing of three phases short circuit, three phases formed here and only ones opening time considered for temporary recovering voltage calculation, because this value is the same for all phases. Results from calculation of short interval circuit opening during temporary recovering voltage, network's neutral point is grounded over non-linear reactor, opening time of three phases have shown increases at switch abilities of circuit breaker.

5. Conclusion

Complex analysis were carried out on approaching speed of short circuit current to zero degree under circumstance at electrical networks when transformers neutral points were grounded over non-linear reactor. The method was examined whether it is suitable for limitation of approaching speed of short circuit current to zero degree. Results have showed that: it is applicable. Complex analysis were also carried out on temporary recovering voltage between contacts of circuit breaker at transformers neutral point is grounded over non-linear reactor. It is possible to be grounded neutral point over non-linear reactor after opening short circuit and limitation of changing speed and spreading interval of temporary recovery voltage formed between circuit breaker contacts. All of the conclusions provide possibility for increasing switch abilities of high voltage circuit breakers.

References

Maljkovic Z, Uglesic I, Kuteravic LJ, Vrkic I, Vucak S, (2000) Voltage Increase in Hydrogenerator Circuit due to Failures and Disturbances. Cigre:Session, Electrotechnical broushers, Ref. No:11-200.

Granelli G.P, Montagne M, Pasini G.L (2001). Worst Case Short Circuit Calculation by Genetic Algorithms. UPEC 2001.

Ragaller K (1981). Opening of Current Circuits at High Voltage Networks. Moscow.

Gashimov A.M, Dimitriev E.V, Rustemov S.A (1994) Single-phase Short Circuit at Network of which Transformer Grounded over Non-linear Reactor. Electrophysics and Electroenergetica on topic of periodical papers, Baku, Elm. pp:176-181

Antipov K.M, Juvarlı C.M, Dimitriev E.V, Gashimov, A.M (1985). List of Condition Concerning with Limitation of Short Circuit Currents at Electrical Network with 110-220 kV. Moscow.

Rustemov S.A (1995). Modelling the Non-linear Reactor Voltage Restoration after the Grounding of the Network Transformer Neutral. Ph.D Thesis, Azebaycan State Oil Academy, Baku.

Gashimov A.M, Juvarlı C.M, Dimitriev E.V (1991). Subprograms for calculating of Wave Phenomenon in Multi Conductors Energy Transmission Lines Considering the Corana Effect, Numerical Analysis of Transient and Exact Regime at power station. Baku. pp:5-37.