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ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

pag. Articole

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The Technological Information Centre helps in the innovation implementation in economy and society by the dissemination information of the R&D results, technological documentation and operators training in order to facilitate the capitalization results.

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- new ecological and biodegradable materials,
- medical equipment,
- IT applications, etc.

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Publicație trimestrială a ICPE

ISSN 1582-5175

vol. 65 nr. 3 iulie-septembrie 2017

Scopul revistei

Revista EEA își propune să publice numai acele articole care atât prin ideile noi, cât și prin rezultatele prezentate, să aducă contribuții importante la cercetarea românească de avangardă din electrotehnică, electronică, automatică, informatică și din celelalte domenii ale științelor inginerești.

Articolele, publicate în două versiuni pe suport de hârtie și online, sunt identice. Accesul liber online asigură o mare vizibilitate articolelor.

Prezentare

Revista EEA a fost fondată în anul 1950 sub numele de „Electricitatea" (ISSN 1220-2533; vol. 1-3) care, în 1953, și-a schimbat numele în „Electrotehnica" (ISSN 0013-5321; vol. 1-22), care, în 1975, după integrarea „Automatica și Electronica (ISSN 1220-2584) apare cu numele actual **Electrotehnică, Electronică, Automatică (EEA)** [ISSN 1582-5175; e-ISSN 2392-828X] (pentru detalii, a se naviga pe site-ul www.eea-journal.ro).

Încă de la primele numere, deși era unica revistă specializată din domeniul electrotehnicii, EEA a fost constant apreciată pentru nivelul științific ridicat al articolelor publicate.

În prezent, EEA este recunoscută ca lider printre publicațiile științifice, pentru calitatea și standardele înalte ale articolelor apărute în domeniul științelor inginerești. Printre autori se numără specialiști, cercetători și cadre didactice din Algeria, Belgia, R.P. China, Finlanda, Franța, Germania, Italia, Moldova, Serbia, Slovacia, Spania, Ungaria etc.

În paginile revistei, se regăsesc lucrări științifice originale care nu au mai fost publicate și care nu sunt luate în considerare pentru publicare în altă parte, cât și articolele prezentate la conferințe, cu condiția să nu fi fost publicate (parțial sau integral) în volumele manifestărilor științifice (min. 6 pagini-max. 16 pagini), sinteze ale unor proiecte de cercetare, dezbateri științifice și sinteze pe teme prioritare din cercetarea fundamentală și aplicativă (max. 20 pagini), recenzii / note de lectură ale celor mai recente apariții de cărți tehnico-științifice (max. 1 pagină), liste de resurse bibliografice comentate din domeniul științelor inginerești (max. 8 pagini).

Pentru a dovedi deschiderea către noile domenii de frontieră, Colegiul editorial a creat o secțiune-varia (*Miscellanea Section*), în care sunt publicate articole a căror tematică aparține altor domenii (matematică, științe socio-umane, științe economice, științele vieții și ale pământului (inclusiv mediul), științe agricole, științe medicale etc.) și care, *tangențial*, pot fi corelate cu domeniul științelor inginerești datorită viziunii, conexiunilor și al abordării inedite a subiectelor.

Revista are un *Colegiu de redacție* format din academicieni, profesori universitari și cercetători științifici din România și din străinătate — personalități recunoscute din domeniul științelor inginerești (în special, din electrotehnică, electronică, automatică și din celelalte domenii ale ingineriei).

Revista EEA este clasificată B⁺ de Consiliul Național al Cercetării Științifice din Învățământul Superior (CNCSIS) și este indexată în bazele internaționale de date: Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International. În prezent, este în proces de evaluare de Thomson Reuters - ISI.

Scope

The EEA Journal aims to publish only those papers that by the new ideas and the results shown to bring significant contributions to research in the Romanian avant-garde engineering as electrical engineering, electronics, automation and other engineering sciences.

The papers, published in two versions on paper and online, are identical. The online open access ensures a high visibility of the papers.

Description

The EEA Journal is founded in 1950 under the title „Electricitatea" (ISSN 1220-2533; vol. 1-3) that, in 1953, changed its title in „Electrotehnica" (ISSN 0013-5321; vol. 1-22) that, in 1975, after merging „Automatica și Electronica (ISSN 1220-2584) is published under the present title **Electrotehnica, Electronica, Automatica (EEA)** [ISSN 1582-5175; e-ISSN 2392-828X] (for further details, please navigate on the site www.eea-journal.ro).

Since the early issues, although it was the only scientific journal specialized in the field of electrical engineering, the EEA has been consistently highly rated for the level of its scientific papers.

At present, the EEA is recognized as a leader among the scientific publications for the quality and high standards of the papers belonging to the field of engineering sciences. The authors are specialists, researchers and academics from Algeria, Belgium, PR of China, Finland, France, Germany, Italy, Moldova, Serbia, Slovakia, Spain, Hungary, etc.

In the EEA, there are published original papers that haven't been previously published and are not under consideration for publication somewhere else, as well as papers presented at conferences, only if they have not been published (partially or fully) in the proceedings of that scientific event (min. 6 pages, max. 16 pages), syntheses of research projects, scientific debates and syntheses on priority themes of fundamental and applied research (max. 20 pages), reviews / reading notes of the latest scientific and technical books (max. 1 page), commented lists of bibliographic resources in engineering sciences (max. 8 pages).

To prove the openness to new frontier areas, the Editorial Board has created a *varia* section (*Miscellanea Section*) for papers belonging to other thematic areas (mathematics, social studies, economics, life and earth sciences (including the environment), agricultural sciences, medical sciences, etc.) and, *tangentially*, they are related to engineering sciences thanks to vision, connections and novel approach of the topics.

The *Editorial Board* includes academicians, university professors and researchers from Romania and abroad that are well-known personalities in the field of engineering sciences (especially, in electrical, electronics, automation, computer science and other fields of engineering).

The EEA journal is included in the B⁺ category by the National Council of Scientific Research in Higher Education (CNCSIS) and indexed in international data bases: Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International. Currently, EEA is under evaluation by Thomson Reuters - ISI.

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- to promote the reputation and the success of the Romanian scientific research in electrical engineering and other related or interdisciplinary fields;
- to support the creation, the innovation and the scientific research (fundamental, applied, quantitative, qualitative, results-oriented, etc.) and the trans-disciplinary and inter-disciplinary research;
- to encourage and promote the continuing professional training of its members in the various specialties of the electrical engineering;
- to support the young specialists for their professional training or specialization;
- to develop the bi- and multi-lateral scientific collaboration with specialists in engineering sciences and/or other related or interdisciplinary fields working in research centres and universities in Romania and abroad;
- to develop and promote the "clean" technologies by programmes and projects in the field of environmental sustainable development;
- to support the national and international scientific events, seminars, conferences and other meetings specialized in the field of electrical engineering.

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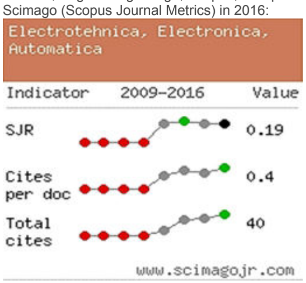

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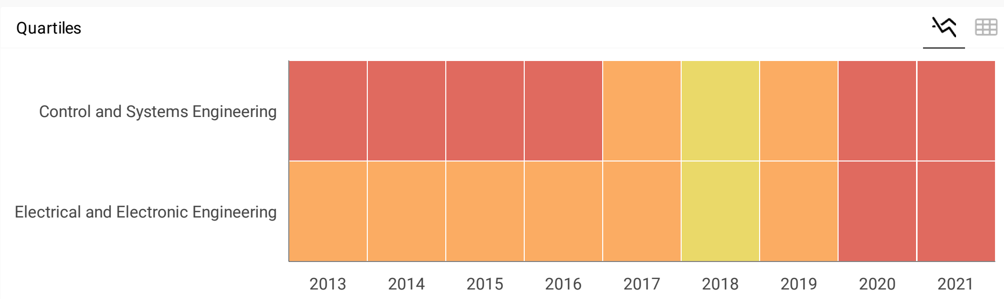

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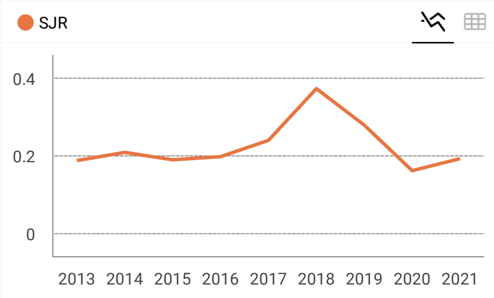

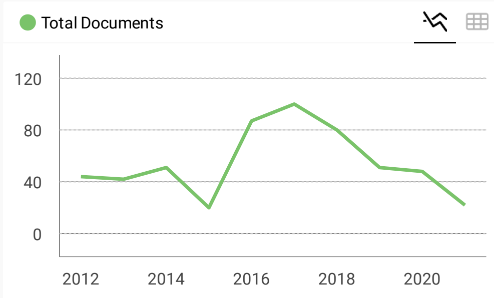

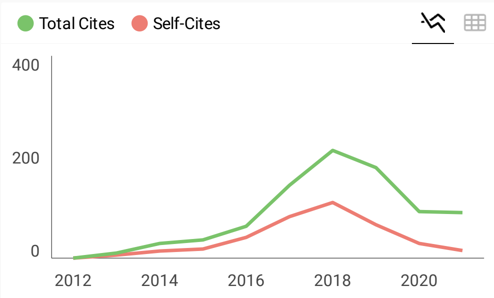

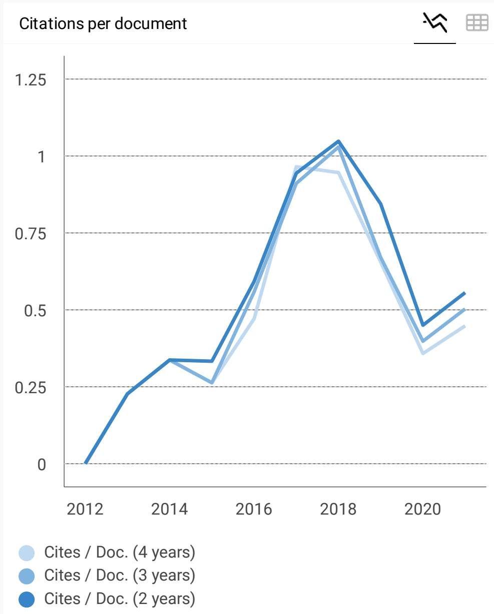

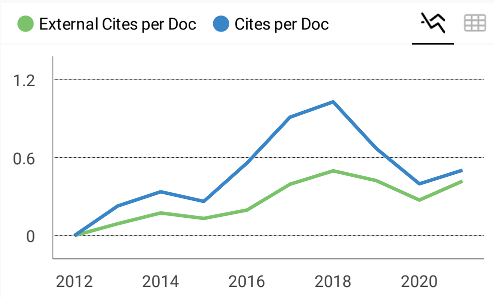

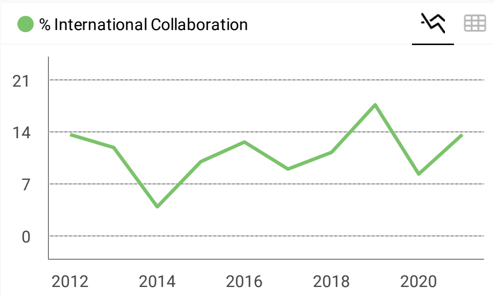

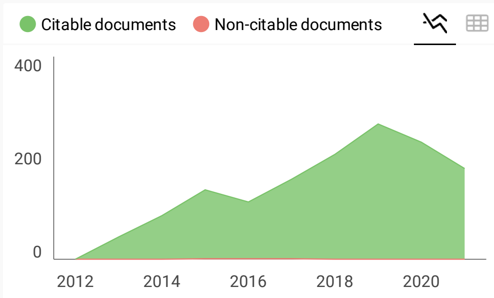

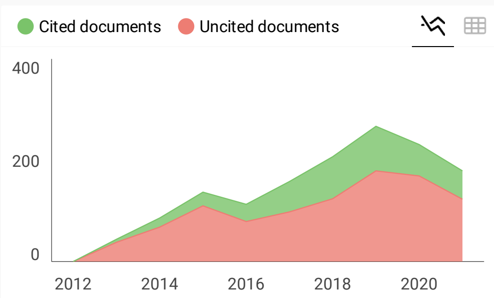

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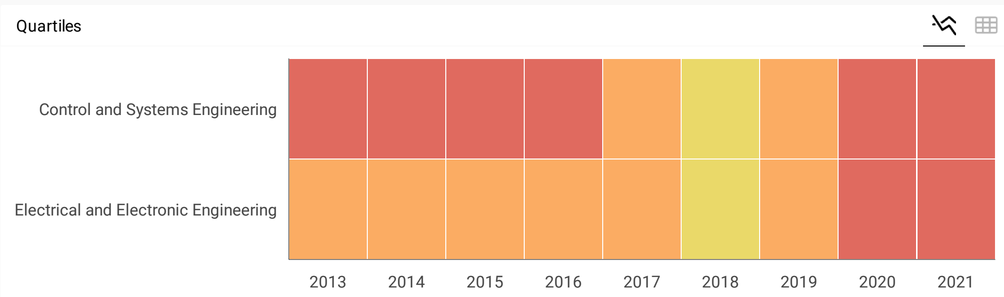

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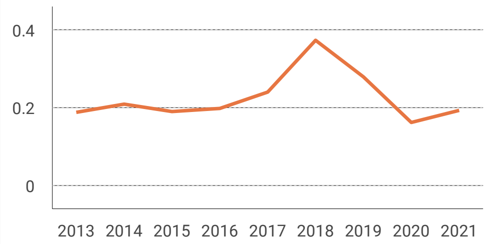

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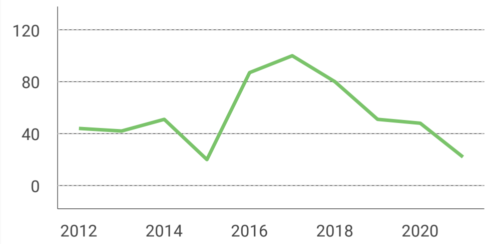

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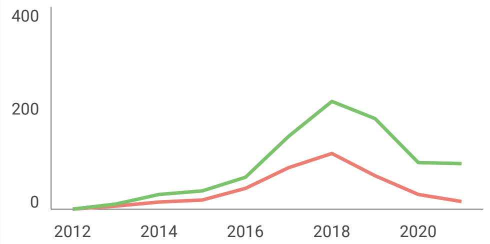

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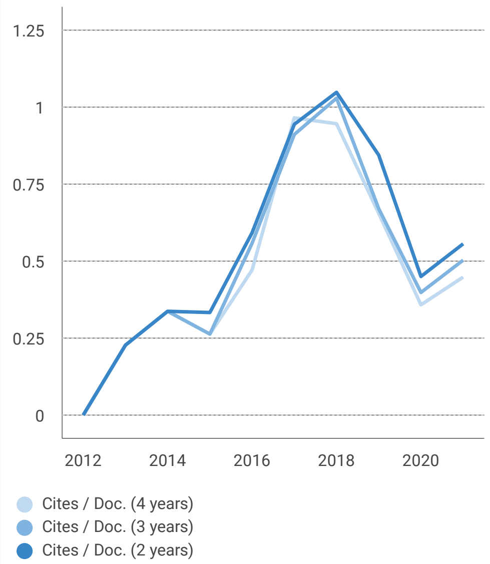

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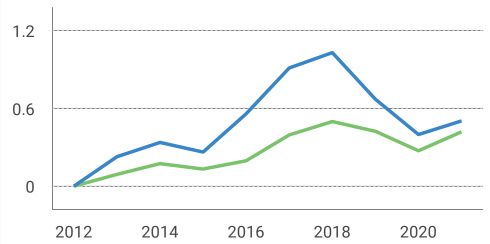

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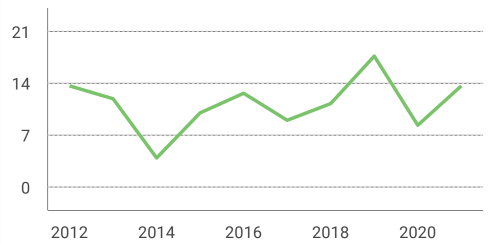

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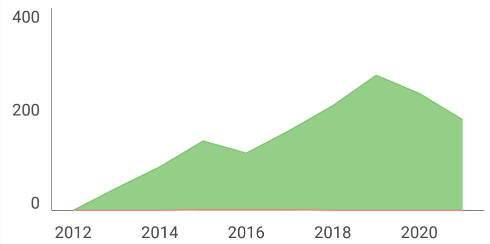

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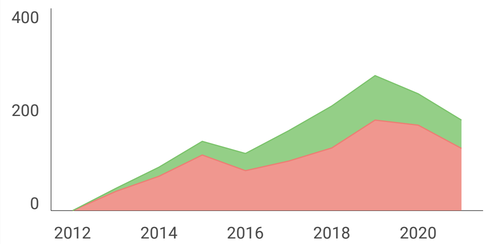

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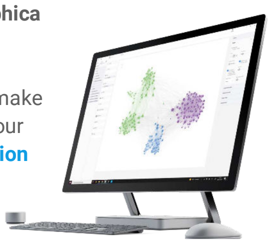

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Keywords: *asymmetrical short circuit, feeder, current, medium voltage, relay*

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Asymmetrical Short-Circuit of 20 kV Medium Voltage Feeders

(Full text in English)

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Abstract

An electrical system quality is very important to develop and maintain for distributing the electrical energy to consument. The 20 kV medium voltage distribution system provides electrical energy to supply to the consument. However, but in the practical applications, there are many disturbances to supply to consument. The impact of short circuit disturbance on distribution network is too large, that could broke the equipment in distribution network, the losses on consument who live upon the electrical system, and can harm the people and make fire. This research was to calculate the asymmetrical short circuit currents that could occurred on the feeders and then the results would be compared to the simulations. They would also be used to set an OCR relay, to protect the feeders. The asymmetrical short circuit current calculation results were lower than those the simulations, with 403.9 A (9.24%) average difference, for two phase and 48.4 (12.53%) for one phase faults. The different of relay working times between the calculation and simulation results were 0.1913 s (45.98%) for the two and 0.0997 s (35.68%) for the one phase faults, where the latters were longer than those the formers.

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1. Introduction

The system short circuit current has increased where many sources of power are available to feed. The majority of power system faults occur in transmission lines, constitute 85-87% of overall power system fault. Fault analysis is an integral part of power system analysis. The impact of faults is generally considered very critical for power system operation. During short circuit fault, voltage magnitude at faulty buses reduced and current flow in the lines increases. Short circuit (sc) current normally takes on asymmetrical characteristics during the first few cycles of duration [1-5].

Faults can be classified as symmetrical (three phase) and asymmetrical (one, two-phase), where short-circuit to ground can also occur for both types. Positive sequence is for both symmetrical and asymmetrical faults, whereas negative and zero sequences are for asymmetrical faults. Symmetrical components are commonly used to analyze unsymmetrical faults in three phase power system. The models were in several fault conditions, such as three phase and single phase short circuits, or symmetrical and asymmetrical fault conditions. It was used to determine the magnitude of short circuit current [6-10].

A familiarization with the asymmetry can be a valuable tool in an analyzation of disturbance on power system, and become the deciding factor between breakers of different interrupting ratings. Some particular aspects of short-circuit currents will be addressed three-phase and single-phase fault currents, DC-time constants, peak values, contributions from transformers and distributed generators. The fault level represents the maximum short-circuit current. A fault repair of power distribution network is one of important task, which affects to safety and reliable operation [11-15].

A short-circuit calculation in the reduced network gives the same results for the original distribution network. Based on ANSI and IEC standards, a fault current was influenced by the intervening reactance of power system components [16-17].

To protect the system, it was conducted to detect the short circuit current and prevent it from flowing through the transmission line. The calculations of short circuit currents also protect the system from damage, fire and other physical hazards. The seriousness of single-phase fault emphasizes the importance to escaping it as soon as possible via protective control actions. Short circuit studies are done for calculating the withstanding capability normal and abnormal (fault) conditions. They calculate the ratings of switchgear and settings for protection. A circuit breaker used in power network is close in a normal situation but must be opened to protect network if there is an abnormal event [18-22].

The effect of short circuit faults was also to electronic converter and rotor phases on overall behavior of system. It was analyzed demanding current and voltage required capability concerned with the short circuit current which experienced by generator circuit breaker. The comparative experimental and theoretical results are given for line-to-line, a single line-to-ground and a double line-to-ground short circuits [23-25].

The symmetrical component method is used in the calculations associated with the state that not balanced on three phase system, particularly for unbalanced short circuit calculations [26].

According fortescure theorem, three unbalanced phasors of three phase system can be outlined into three balanced phasor system. It is also to show that each phase of three-phase unbalanced system can be broken down into three sets of components [23].

The purposes of of study were to calculate the effective maximum short circuit current on the asymmetrical conditions on 20 kV distribution feeders, determine the setting times and current transformer (CT) rating and to get the short-circuit current of the fault location on the long distance feeders.

2. Materials and Methods

The process to analyze the problem in the study was divided into several stages. In the short-circuit current calculation, the zero phase sequence reactance generally differ essentially with positive and negative sequence. Operator is a unit vector that is shaping up to 120 degrees with positive ignition [27].

Multiplying the vector with a yield of 120 degree rotation, multiply by producing a 240 degree rotation for positive, negative and zero sequences respectively.

In some cases where the zero sequence impedance is smaller than the positive one, the phase disturbance to the ground resulting in higher currents [28]. The consequences of short circuit are reduced stability limits and damage for the power system as well as explosions [29].

The usefulness of the analysis of short circuit includes to determine the maximum and minimum, fault currents, investigation operating protection relays, and power breaker capacity [30].

For a phase to ground short-circuit, it is as I_b=0, I_c=0, V_a=I_a.Z_f. The current equations were obtained from the symmetrical components of currents [27, 29-30,31-34].

$$I_{a0} = I_{a1} = I_{a2} = \frac{V_{phase}}{Z_0 + Z_1 + Z_2 + 3Z_f} \tag{1}$$

$$\begin{bmatrix} I_{af} \\ I_{bf} \\ I_{cf} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} \tag{2}$$

A phase fault current would be obtained as

$$I_{af} = I_{a0} + I_{a1} + I_{a2} \tag{3}$$

$$I_{af} = 3I_{a0} = 3I_{a1} = 3I_{a2} \tag{4}$$

$$I_{1phase} = 3.I_0 = \frac{3.V_{phase}}{Z_1 + Z_2 + Z_0} \tag{5}$$

According to Gonen [35], the formula for single phase to ground disturbance is as

$$I_{f1L-G} = \frac{V_{phase}}{Z_G} \tag{6}$$

$$Z_G = \frac{2Z_1 + Z_0}{3} \tag{7}$$

where:

$$I_{f1L-G} = \frac{3.V_{phase}}{2Z_1 + Z_0} \tag{8}$$

The single phase short circuit to ground was obtained as

$$I_{a1} = \tfrac{1}{3} I_a = \frac{V_f}{Z_1 + Z_2 + Z_0 + Z_f} \tag{9}$$

$$I_a = I_f = \frac{3V_f}{Z_1 + Z_2 + Z_0 + 3Z_f} \tag{10}$$

Most of the distribution line is a type of radial, with only one source and one line for fault current. The equation to calculate the current fault in a distribution line is as

$$I_A = \frac{V_{LN}}{\frac{(2Z_1 + Z_0)}{3} + R_F} \tag{11}$$

The two phase short-circuit disturbance occurred in phase **b** and phase **c**, it was used the equations as $I_a = 0; I_b = -I_c; V_b - V_c = Z_f.I_b$, so that the components of symmetric is as below [35].

$$Ia = 0$$
$$I_{a1} = -I_{a2} = \frac{V_{phase}}{Z_1 + Z_2 + Z_f} \tag{12}$$

If

F = 0

$$Ia = 0$$
$$I_{a1} = -I_{a2} = \frac{V_{phase}}{Z_1 + Z_2} \tag{13}$$

$$Ia = 0$$
$$I_{bf} = -I_{cf} = \sqrt{3}\, I_{a1} \angle -90^o \tag{14}$$

According to Gonen [35], the two-phase disturbance formula is as below.

$$I_{f.L} = \frac{j\sqrt{3}.V_{L-N}}{Z_1 + Z_2} \tag{15}$$

Furthermore, it was obtained as

$$I_{a1} = \frac{V_f}{Z_1 + Z_2 + Z_f} \tag{16}$$

So that, the two phase fault current is:

$$I_{bf} = -j\sqrt{3}\, I_{a1} \tag{17}$$

$$I_{a0} = -\frac{V_f - Z_1 I_{a1}}{Z_0 + 3Z_f} \tag{18}$$

$$I_{a2} = -\frac{V_f - Z_1 I_{a1}}{Z_2} \tag{19}$$

$$I_{a1} = \frac{V_f}{Z_1 + \frac{Z_2 (Z_0 + 3Z_f)}{Z_2 + Z_0 + 3Z_f}} \tag{20}$$

$$I_F = I_b + I_c = 3 I_{a0} \tag{21}$$

$$I_A = -j\sqrt{3}\,\frac{Z_0 + a Z_1}{Z_1 (Z_1 + 2Z_0)} V_{LN} \tag{22}$$

$$I_B = j\sqrt{3}\,\frac{Z_0 - a^2 Z_1}{Z_1 (Z_1 + 2Z_0)} V_{LN} \tag{23}$$

$$I_G = \frac{-V_{LN}}{(Z_1 + 2Z_0)/3} \tag{24}$$

Table 1 lists the frequency persentage of fault type occurences [32, 35].

Table 1. Overhead line disturbance frequency

No	Fault types	Occurences (%)
1	L-G	70
2	L-L	15
3	L-L-G	10
4	L-L-L	5

OCR is a device which indicated the existence overcurrent, whether caused by the short circuit or overload which can probably damage the equipment. It is used in almost all patterns of power system protection, as the main or backup. OCR can open power circuit breakers on low or high voltage side of power transformer. It types can be defenite time or inverse time. Time–current characteristics of relay are classified into normal inverse, very inverse, long inverse and extremly inverse.

In this research, the case study was used 6 units of 60 MVA, 150/20 kV power transformer and 20 kV distribution line feeders to be analyzed. Nevertheless, it was used only three points of impedance. The transformer positive and negative sequence impedances are as follow.

$$Z_1 = Z_T = R_T + jX_T \tag{25}$$

To calculate the short-circuit current on cables, the positive and negative sequence impedances were ignored. However, the zero sequence impedance of grounding system was payed to consider. Short circuit phase to phase and single phase to ground are as below respectively.

$$I_{2\,phase} = \frac{V_n}{2.Z_{equiv}} \tag{26}$$

$$I_{1\,phase} = \frac{3.\frac{V_n}{\sqrt{3}}}{2.Z_{equiv1} + Z_{equiv0}} \tag{27}$$

A short circuit peak value (I_p) was calculated by using the formula as follow [36-37].

$$I_p = \sqrt{2}\, k\, I_k'' \tag{28}$$

where k is function of the **R/X** system on the fault locations.
Table 2 lists the voltage factor method C.

Table 2. Voltage factor methods C

	Nominal Voltage (U_n)	For maximum sc calculations (C_{max})	For minimum sc calculations (C_{min})
LV	100-1000 V 30-400 V	1.00	0.95
	Other Voltage	1.05	1.00
MV	1KV-35 KV	1.10	1.00
HV	35KV-230 KV	1.10	1.00

Conductors used in a power systems are vary depending on the technical and economic calculation needs. The 20 kV underground cables were used as N2XSEFGBY, i.e. Cu/XLPE/CTS/AWA/PVC 3.6/6 kV, 6/10 kV, 12/20 kV, 18/30kV-3 Core. The distribution lines have three radial feeders, where one line is for stand-by feeder, when disturbance existence.

Tables 3-9 list the power transformer data, distribution transformer data and cable data for the investigations.

Table 3. Power transformer data

No	Transformer name	Rating Power (MVA)	Primary Voltage (kV)	Secondary Voltage (kV)	Z (%)	R(%)
1	Main Trafo III	60	150	20	13.93	12
2	Main Trafo V	60	150	20	14.6	11.6

Table 4. Distribution transformer data of USB feeder

No	Transformer name	Rating Power (kVA)	Primary Voltage (kV)	Secondary Voltage (V)	Z (%)	R(%)
1	UZB-LIKA 12	250	20	400	3.93	3.09
2	UZB-LIK 13	400	20	400	3.93	3.15
3	UZB-PRA 14	630	20	400	4.12	3.96
4	UZB-ALT 15	250	20	400	3.93	3.09
5	UZB-CWI 16	400	20	400	3.93	3.15
6	UZB-VPI 17	2770	20	400	7.0	10.67
7	UZB-VTX 18	400	20	400	3.93	3.15
8	UZB-GKSII 19	630	20	400	4.12	3.96
9	UZB-PCN 110	250	20	400	3.93	3.09
10	UZB-GMS 111	414	20	400	3.93	3.15
11	UZB-MSG 112	555	20	400	4	3.96
12	UZB-PIK 113	250	20	400	3.93	3.09
13	UZB-OGA 114	630	20	400	4.12	3.96

Table 5. Distribution transformer data of USM feeder

No	Transformer name	Rating Power (kVA)	Primary Voltage (kV)	Secondary Voltage (V)	Z (%)	R(%)
1	UZM-CBU 12	630	20	400	4.12	3.96
2	UZM-TRC 13	250	20	400	3.93	3.09
3	UZM-ATM 14	400	20	400	3.93	3.15
4	UZM-ATM 14	400	20	400	3.93	3.15

5	UZM-BKB 15	250	20	400	3.93	3.09
6	UZM-DS 16	400	20	400	3.93	3.15
7	UZM-GRUB 17	240	20	400	3.93	3.09
8	UZM-OG 18	630	20	400	4.12	3.96
9	UZM-OGC 19	630	20	400	4.12	3.96
10	UZM-BTR 110	250	20	400	3.93	3.09
11	UZM-BTZ 111	1730	20	400	6.25	6

Table 6. Distribution transformer data of UZU feeder

No	Transformer name	Rating Power (kVA)	Primary Voltage (kV)	Secondary Voltage (V)	Z (%)	R(%)
1	UZU-DPA 12	630	20	400	4.12	3.96
2	UZU-IPT 13	250	20	400	3.93	3.09
3	UZU-FTX 14	5540	20	400	7	12.85
4	UZU-SIJU 15	400	20	400	3.93	3.15
5	UZU-IDX 16	400	20	400	3.93	3.15
6	UZU-TBA 161	250	20	400	3.93	3.09
7	UZU-MWR17	555	20	400	4	3.96
8	UZU-HRX 18	555	20	400	4	3.96
9	UZU-GPP 19	250	20	400	3.93	3.09
10	UZU-LIP 110	250	20	400	3.93	3.09
11	UZU-LRR 111	250	20	400	3.93	3.09
12	UZU-JPX 112	400	20	400	3.93	3.15
13	UZU-BKK 113	250	20	400	3.93	3.09
14	UZU-BMU 114	400	20	400	3.93	3.15

Tabel 7. Cable data of UZB feeder

Feeder	Load Name	Length (mc)	Load Name	A (mm^2)
UZB	UZM	3,600	LIKA	150
	LIKA	1,000	LIK	150
	LIK	800	PRA	150
	PRA	200	ALT	150
	ALT	300	CWI	150
	CWI	400	VPI	150
	VPI	250	VTX	150
	VTX	600	GKSI	150
	GKSI	1,500	PCN	150
	PCN	700	GMS	150
	GMS	400	MSG	150
	MSG	300	PIK	150
	PIK	1,000	OGA	150
Total		11,050 mc		

Tabel 8. Cable data of UZM feeder

Feeder	Load Name	Length (mc)	Load Name	A (mm^2)
UZM	UZM	1,500	CBU	150
	CBU	350	TRC	150
	TRC	400	ATM1	150
	ATM1	240	ATM2	150
	ATM2	300	BKB	150
	BKB	500	DS	150
	DS	800	GRUB	150
	GRUB	1,200	OG	150
	OG	500	OGC	150
	OGC	450	BTR	150
	BTR	150	BTZ	150
Total		6,390 mc		

Table 9. Cable data of UZU feeder

Feeder	Load Name	Length (mc)	Load Name	A (mm^2)
UZU	UZU	1,200	DPA	150
	DPA	2,210	IPT	150
	IPT	425	FTX	150
	FTX	521	SIJU	150
	SIJU	1,400	IDX	150
	IDX	670	TBA	150
	TBA	325	MWR	150
	MWR	1,100	HRX	150
	HRX	160	GPP	150
	GPP	50	LIP	150
	LIP	2,500	LRR	150
	LRR	100	JPX	150
	JPX	210	BKK	150
	BKK	40	BMU	150
Total		10,911 mc		

For short-circuit calculation of UZB feeder, it might be occured as asymmetrical two phases and one phase to ground. The calculations were based on the length of feeders, which were assumed to occur on 25%, 50%, 75%, and 100% of feeder lengths as shown in Figure 1.

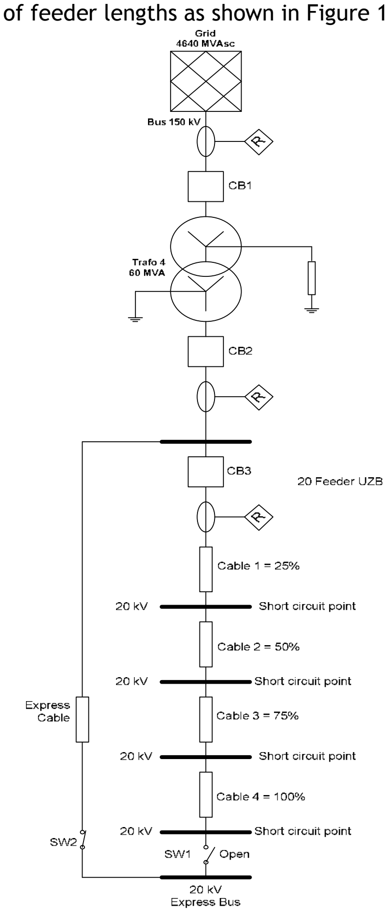

Figure 1. Calculation scenario of short circuit

The source impedance on 150 kV side was X_{s150kV} as 5.28 Ω, and on 20 kV side X_{s20kV} as 0.093 Ω, the transformer impedance Z_B as 6.66 Ω, positive dan negative sequence reactance of power transformer $X_{t1}=X_{t2}$ 1.15+j1.02 Ω and the zero sequence reactance of power transformer (Ynyn0 to feeder UZB) X_{t0} as j11.832 Ω.

The modelling of point location in the 0%-100% with a total length of feeder UZB 11.05 kmc Z_{kpos}=0.152+j0.102 and Z_{kzero}=0.314+j2.076.

Table 10 lists the positive, negative and zero sequence impedances of UZB feeder.

Table 10. Positive, negative and zero sequence impedances of UZB feeder

Fault location (%)	(+)and (−) sequence impedances (Ω)	(0) sequence impedance (Ω)
0	0	0
25	0.419+j0.281	0.866+j5.729
50	0.875+j0.587	1.802+j11.902
75	1.256+j0.844	2.591+j17.11
100	1.678+j1.127	3.45+j22.834

The positive or negative sequence equivalent impedance was used by the formula as

$$Z_{1equiv} = Z_{S1} + Z_{T1} + Z_{1feeder} \tag{29}$$

The zero sequence impedance obtained from the sum of zero sequence impedance transformer, the value of 3 R_N (neutral resistance) and zero sequence impedance of feeder, as

$$Z_{0equiv} = Z_{0T} + 3R_N + Z_{0feeder} \tag{30}$$

Table 11 lists the positive, negative and zero sequence equivalent impedances of UZB feeder.

Table 11. Equivalent impedances on UZB feeder

Fault location (%)	(+)and (–) sequence equivalent impedances (Ω)	(0) sequence equivalent impedances (Ω)
0	1.15+j1.113	34.8 + j 11.832
25	1.569+j1.394	35.666 + j 17.561
50	2.025+j1.7	36.602 + j 23.734
75	2.406+j1.957	37.391 + j 28.942
100	2.828+j2.24	38.25 + j 34.666

For the sc calculation of UZM feeder, it might occured in some conditions as above. The feeder length was 6.39 kmc.

The source impedance (or reactance) on 150 kV and 20 kV sides were X_{s150kV} as 5.28 Ω and X_{s20kV}=0.093 Ω respectively. Transformer impedance Z_B was 6.66 Ω. The positive, negative and zero sequence impedances of power transformer were $Z_{t1}=Z_{t2}$=1.15+j1.02 Ω and X_{t0}=11.832 Ω.

The positive (or negative) of UZM feeder with 6.39 kmc was Z_{kpos}=0.152+j0.102. While the zero sequence impedance of UZM feeder was Z_{kzero}=0.314+j2.076.

Table 12 lists the positive, negative and zero sequence mpedances of UZM feeder.

Table 12. Positive, negative and zero sequence impedances of UZM feeder

Fault location (%)	(+)and (–) sequence impedances (Ω)	(0) sequence impedance (Ω)
0	0	0
25	0.241+j0.162	0.866+j3.3
50	0.485+j0.325	1.003+j6.632
75	0.728+j0.488	1.504+j9.949
100	0.971+j0.651	2.006+j13.265

The neutral grounding resistance was 11.6 Ohm.

Table 13 lists the positive, negative and zero sequence equivalent impedances of UZM feeder.

Table 13. Equivalent impedances on UZM feeder

Fault location (%)	(+) or (–) equivalent impedance (Ω)	(0) equivalent impedance (Ω)
0	1.15+j1.113	34.8+j11.832
25	1.391+j1.275	35.686+j15.132
50	1.635+j1.438	36.689+j18.464
75	1.878+j1.601	38.193+j21.781
100	2.121+j1.764	40.199+j25.097

The feeder length was 10.911 kmc, source impedance (or reactance) on 150 kV and 20 sides were X_{s150kV}=5.28 Ω and X_{s20kV}=0.093 Ω respectively, the transformer impedance Z_B was 6.66 Ω, and the positive and negative impedances of power transformer were $Z_{t1}=Z_{t2}$=1.15+j1.02 Ω. Furthermore, the zero sequence reactance was X_{t0} =11.832 Ω.

Total length of feeder UZU was 10.911 kmc, so that the impedance was Z_{kpos}=0.152+j0.102 Ω.

Table 14 lists the positive, negative and zero sequence mpedances of UZU feeder.

Table 14. Positive, negative and zero sequence impedances on UZU feeder

Position (%)	(+)and (–)sequence impedances (Ω)	(0) sequence impedance (Ω)
0	0	0
25	0.413+j0.277	0.854+j5.646
50	0.828+j0.555	1.711+j11.314
75	1.243+j0.834	2.568+j16.981
100	1.658+j1.119	3.42+j22.651

The total length of feeder was 11.05 kmc, and Z_{kzero}=0.314+j2.076.

Table 15 lists the positive, negative and zero sequence equivalent impedances of UZU feeder.

Table 15. Equivalent impedances on UZU feeder

Position (%)	(+) and (–) sequence equivalent impedances (Ω)	(0) sequence equivalent impedance (Ω)
0	1.15+j1.113	34.8+j11.832
25	1.563+j1.39	35.654+j17.478
50	1.978+j1.668	36.511+j23.146
75	2.393+j1.947	37.368+j28.813
100	2.808+j2.232	38.22+j34.483

The neutral grounding resistance was 11.6 Ω. The overcurrent relay setting on feeders of UZB, UZM and UZU is used the installed current transformer of 600/5 A ratio, the basis for the calculation of the maximum current. For the inverse relays, the usual settings are 1.05 up to 1.1 times of maximum current, while the setting definite relays are 1.2 up to 1.3 times of maximum current. Other requirements that should be met were for adjustment of the minimum time overcurrent relays (especially in the feeders) as not less than 0.3 seconds. This decision was taken so as not to trip relays again due to inrush currents of distribution transformers those already connected in the network. The load current was I_{load}= 657.142 A, CT ratio was 600/5 A, $I_{set(primary)}$=1.05 x I_{load} was 690 A and $I_{set(secondary)}$ was 5.75 A.

The nominal load current on the 20 kV incoming feeder I_{load} was 1732 A, CT ratio was 2000/5 A, $I_{set(primary)}$ was 1.05 x I_{load} = 1818.6 A and $I_{set(secondary)}$ was 4.547 A.

4. Results and Discussion

From the calculation results of short circuit currents above, it can be seen in the Table 16 below which the results obtained have been compared to the results of the simulation for UZB feeder.

Figure 3 shows the comparisons of fault currents between the caculation and simulation results for double and single phase on feeder UZB.

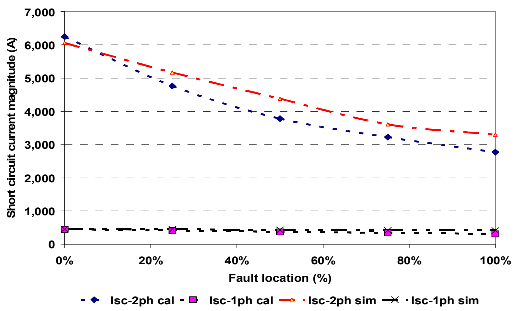

Figure 3. Comparison of fault currents on feeder UZB

From Table 16, the differences between the calculation and simulation results of asymmetrical short circuit current on UZB feeder might caused by that the simulation taking into account voltage drops and impedance difference of calculation methods.

Table 16. Asymmetrical short circuit currents on UZB feeder

Fault location	Calculation		Simulation	
	2 phase	1 phase	2 phase	1 phase
0%	6248.4	451.6	6060	455
25%	4764.6	413.8	5170	446
50%	3782.2	374.4	4380	430
75%	3224.3	343.8	3610	419
100%	2771.9	313.6	3300	414

At the distance of 25% -100%, the feeder currents were big difference in the results.

For UZM feeder, the comparison short circuit currents between the calculation and simulation results can be seen in the Table 17, for both double and single phase faults.

Table 17. Asymmetrical short circuit currents on UZM feeder

Fault location	Calculation (A)		Simulation (A)	
	2 phase	1 phase	2 phase	1 phase
0%	6248.4	451.6	6060	455
25%	5299.6	426.1	5860	453
50%	4592.6	400.5	5390	449
75%	4052.2	373.0	4610	440
100%	3624.9	345.4	3690	427

At UZM feeder, they have differences that resembles the UZB feeder, this is because the method used for the calculation and analysis of the same.

Figure 4 shows the comparisons of fault currents between the caculation and simulation results for double and single phase on feeder UZM.

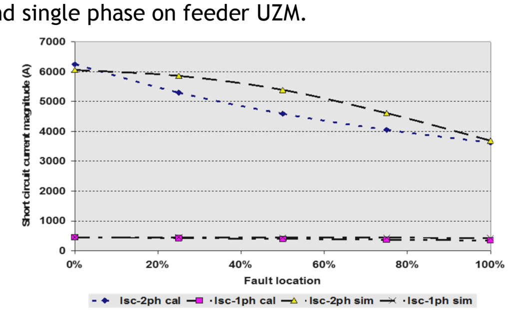

Figure 4. Curve Comparison feeder fault current at UZM

For UZU feeder, the comparison short circuit currents between the calculation and simulation results can be seen in Table 18, for both double and single phase faults.

Table 18. Asymmetrical short circuit currents on UZU feeder

Fault location	Calculation (A)		Simulation (A)	
	2 phase	1 phase	2 phase	1 phase
0%	6248.4	451.6	6080	455
25%	4780.9	414.4	5340	436
50%	3864.9	378.0	4410	426
75%	3241.5	344.5	3480	413
100%	2787.8	314.6	3060	405

In UZU feeders there is a difference current of calculation and simulation results were significantly high. This case was probably caused by the longer of feeder UZM compared to another feeder. The short circuit currents at the point of 25%-100% interruptions were also obtained by the simulations.

Figure 5 shows the comparisons of fault currents between the caculation and simulation results for double and single phase on feeder UZU.

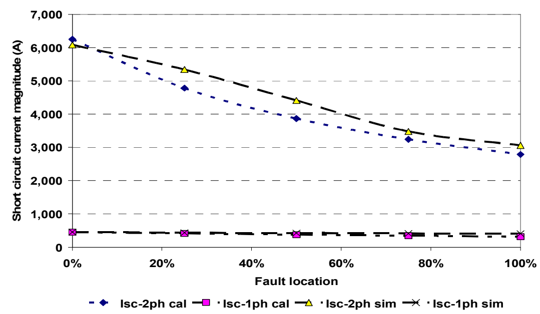

Figure 5. Curve Comparison feeder fault current at UZU

Table 19 lists the contribution current of simulation results on UZB feeder. It was assumed that the motor load was 60%.

Table 19. Contribution current of simulation on UZB feeder

Special customer UZB feeder			Contributing current (A)
Name of Load	Load (kVA)	60% motor load (kVA)	
PRA 14	550	330	72
CWI 16	350	210	46
VPI 17	2 560	1 536	303
VTX 18	380	228	49
GMS 11	390	234	51
MSG 12	460	276	61

Table 20 lists the contribution current of simulation results on UZM feeder. It was assumed that the motor load was 60%.

Table 20. Contribution current of simulation results on UZM feeder

Special customer UZM feeder			Contributing current (A)
Name of Load	Load (kVA)	60% motor load (kVA)	
GRUB 17	220	132	29
BTZ 11	1690	1014	204

Table 21 lists the contribution current of simulation results on UZU feeder. It was assumed that the motor load was 60%.

Table 21. Contribution current of simulation results on UZU feeder

Special customer UZU feeder			Contributing current (A)
Name of Load	Load (kVA)	60% motor load (kVA)	
FTX 14	5450	3 270	637
MWR 17	350	210	46
HRX 18	510	186	66
JPX 12	520	312	68
JPX 12	385	231	50

From the simulation results, the current contribution of each load feeder was dynamic. There were two categories of load, namely general and special loads. In this study, they were assumed that 60% of loads were motors.

Table 22-24 list the relay working times on UZB, UZM and UZU respectivley.

Table 22. Relay working time on UZB feeder

Fault location	Time to relay work on UZB feeder				Existing data
	Calculation (s)		Simulation (s)		
	2 phases	1 phase	2 phases	1 phase	
25%	0.362	0.266	0.536	0.348	0.2 second
50%	0.412	0.277	0.600	0.377	
75%	0.456	0.288	0.669	0.400	
100%	0.506	0.299	0.703	0.412	

Table 23. Relay working time on UZM feeder

Fault location	Time to relay work on UZM feeder				Existing data
	Calculation (s)		Simulation (s)		
	2 phases	1 phase	2 phases	1 phase	
25%	0.343	0.263	0.475	0.334	0.2 second
50%	0.369	0.269	0.509	0.342	
75%	0.396	0.277	0.564	0.358	
100%	0.423	0.286	0.642	0.384	

Table 24. Relay working time on UZU feeder

Location fault	Relay working time of UZM feeder				Existing data
	Calculation (s)		Simulation (s)		
	2 phase	1 phase	2 phase	1 phase	
25%	0.361	0.266	0.535	0.363	0.2 second
50%	0.407	0.276	0.608	0.384	
75%	0.454	0.287	0.697	0.414	
100%	0.504	0.298	0.751	0.432	

Of the three tables, there are differences in relay working times between the calculation and simulation results. Nevertheless, they were still within the normal working times.

Based on Tables 16-18, and Figures 3-5, the magnitudes of asymmetrical short circuit currents would reduce as the distance increased. Of course, they were caused by the impedances would increase. The magnitudes for the two phase faults were significantly higher than the one phase faults. These phenomena were caused by the voltage which were only one phase and the fault impedances were higher than those the two phase ones. If they were compared between the calculation and simulation results of asymmetrical short circuit currents, generally, the latters were higher than those the former ones. The average difference was 403.9 A or 9.24% for two phase faults and 48.4 or 12.53% for one phase faults, for the three feeders. These differences were probably caused by the some value of reactance(s) involved in the simulations, however, they could not be involved in the manual caculations, or due to slightly differences of feeder parameters, not exacly same, depend on the library existence. Among three feeders, the asymmetrical short circuit currents on UZM feeder was the highest compared to the remaining feeders. This case was caused by the shortest distance of UZM feeder.

Based on Tables 22-24, the relay working times would be longer as the positions of faults increased from the substation on each feeder. The relay working times on on the transformer incomings were longer than the working times on the feeders. These cases were caused by the impedances increased due to both the feeder fault distance rose and the transformer incomings. Nevertheless, the relay working times on the feeders for double phase faults were longer than the single phase ones. These cases were caused by the determination of relay settings, which were different between the single phase and double phase faults. Among the three feeders, UZB, UZM and UZU, the longest of relay working time was on UZB feeder, due to the longestin distance, i.e. 0.506 seconds for the feeder and 2.23 seconds for the transformer incoming, both for the double phasefaults and for the fault pistion of 100%. While for the single phase faults were 0.299 seconds and 0.7 seconds for the same case. However, if they were compared between the calculation and simulation results, usually the latters were longer than those the formers with the average differences were 0.1913 or 45.98% for the two phase faults and 0.0997 or 35.68% for the one phase faults, for the three feeders. These differences were probably caused by some value of reactance(s) involved in the simulations, however, they could not be involved in the manual calculations.

5. Conclusions

Based on the calculations, simulations and analysis of 20 kV feeder asymmetrical short circuits, it could be concluded as follows. The magnitudes of asymmetrical short circuit currents would reduce as the distance increased due to the impedances rose. The short circuit current magnitudes for the two phase faults were significantly higher than the one phase faults. The calculation results of asymmetrical short circuit currents were lower than those the simulations, where the average difference was 403.9 A (9.24%) for two phase faults and 48.4 (12.53%) for one phase faults.

The relay working times would be longer as the positions of faults increased from the substation. The relay working times on the feeders for double phase faults were longer than the single phase ones. The different between the calculation and simulation results were 0.1913 seconds or 45.98% for the two phase faults and 0.0997 seconds or 35.68% for the one phase faults, where usually the latters were longer than those the formers.

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Asymmetrical Short-Circuit of 20 kV Medium Voltage Feeders

(Full text in English)

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Abstract

An electrical system quality is very important to develop and maintain for distributing the electrical energy to consument. The 20 kV medium voltage distribution system provides electrical energy to supply to the consument. However, but in the practical applications, there are many disturbances to supply to consument. The impact of short circuit disturbance on distribution network is too large, that could broke the equipment in distribution network, the losses on consument who live upon the electrical system, and can harm the people and make fire. This research was to calculate the asymmetrical short circuit currents that could occurred on the feeders and then the results would be compared to the simulations. They would also be used to set an OCR relay, to protect the feeders. The asymmetrical short circuit current calculation results were lower than those the simulations, with 403.9 A (9.24%) average difference, for two phase and 48.4 (12.53%) for one phase faults. The different of relay working times between the calculation and simulation results were 0.1913 s (45.98%) for the two and 0.0997 s (35.68%) for the one phase faults, where the latters were longer than those the formers.

Keywords: asymmetrical short circuit, feeder, current, medium voltage, relay

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1. Introduction

The system short circuit current has increased where many sources of power are available to feed. The majority of power system faults occur in transmission lines, constitute 85-87% of overall power system fault. Fault analysis is an integral part of power system analysis. The impact of faults is generally considered very critical for power system operation. During short circuit fault, voltage magnitude at faulty buses reduced and current flow in the lines increases. Short circuit (sc) current normally takes on asymmetrical characteristics during the first few cycles of duration [1-5].

Faults can be classified as symmetrical (three phase) and asymmetrical (one, two-phase), where short-circuit to ground can also occur for both types. Positive sequence is for both symmetrical and asymmetrical faults, whereas negative and zero sequences are for asymmetrical faults. Symmetrical components are commonly used to analyze unsymmetrical faults in three phase power system. The models were in several fault conditions, such as three phase and single phase short circuits, or symmetrical and asymmetrical fault conditions. It was used to determine the magnitude of short circuit current [6-10].

A familiarization with the asymmetry can be a valuable tool in an analyzation of disturbance on power system, and become the deciding factor between breakers of different interrupting ratings. Some particular aspects of short-circuit currents will be addressed three-phase and single-phase fault currents, DC-time constants, peak values, contributions from transformers and distributed generators. The fault level represents the maximum short-circuit current. A fault repair of power distribution network is one of important task, which affects to safety and reliable operation [11-15].

A short-circuit calculation in the reduced network gives the same results for the original distribution network. Based on ANSI and IEC standards, a fault current was influenced by the intervening reactance of power system components [16-17].

To protect the system, it was conducted to detect the short circuit current and prevent it from flowing through the transmission line. The calculations of short circuit currents also protect the system from damage, fire and other physical hazards. The seriousness of single-phase fault emphasizes the importance to escaping it as soon as possible via protective control actions. Short circuit studies are done for calculating the withstanding capability normal and abnormal (fault) conditions. They calculate the ratings of switchgear and settings for protection. A circuit breaker used in power network is close in a normal situation but must be opened to protect network if there is an abnormal event [18-22].

The effect of short circuit faults was also to electronic converter and rotor phases on overall behavior of system. It was analyzed demanding current and voltage required capability concerned with the short circuit current which experienced by generator circuit breaker. The comparative experimental and theoretical results are given for line-to-line, a single line-to-ground and a double line-to-ground short circuits [23-25].

The symmetrical component method is used in the calculations associated with the state that not balanced on three phase system, particularly for unbalanced short circuit calculations [26].

According fortescure theorem, three unbalanced phasors of three phase system can be outlined into three balanced phasor system. It is also to show that each phase of three-phase unbalanced system can be broken down into three sets of components [23].

The purposes of of study were to calculate the effective maximum short circuit current on the asymmetrical conditions on 20 kV distribution feeders, determine the setting times and current transformer (CT) rating and to get the short-circuit current of the fault location on the long distance feeders.

2. Materials and Methods

The process to analyze the problem in the study was divided into several stages. In the short-circuit current calculation, the zero phase sequence reactance generally differ essentially with positive and negative sequence. Operator is a unit vector that is shaping up to 120 degrees with positive ignition [27].

Multiplying the vector with a yield of 120 degree rotation, multiply by producing a 240 degree rotation for positive, negative and zero sequences respectively.

In some cases where the zero sequence impedance is smaller than the positive one, the phase disturbance to the ground resulting in higher currents [28]. The consequences of short circuit are reduced stability limits and damage for the power system as well as explosions [29].

The usefulness of the analysis of short circuit includes to determine the maximum and minimum, fault currents, investigation operating protection relays, and power breaker capacity [30].

For a phase to ground short-circuit, it is as I_b=0, I_c=0, V_a=I_a.Z_f. The current equations were obtained from the symmetrical components of currents [27, 29-30,31-34].

$$I_{a0} = I_{a1} = I_{a2} = \frac{V_{phase}}{Z_0 + Z_1 + Z_2 + 3Z_f} \quad (1)$$

$$\begin{bmatrix} I_{af} \\ I_{bf} \\ I_{cf} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} \quad (2)$$

A phase fault current would be obtained as

$$I_{af} = I_{a0} + I_{a1} + I_{a2} \quad (3)$$

$$I_{af} = 3I_{a0} = 3I_{a1} = 3I_{a2} \quad (4)$$

$$I_{1phase} = 3.I_0 = \frac{3.V_{phase}}{Z_1 + Z_2 + Z_0} \quad (5)$$

According to Gonen [35], the formula for single phase to ground disturbance is as

$$I_{f1L-G} = \frac{V_{phase}}{Z_G} \quad (6)$$

$$Z_G = \frac{2Z_1 + Z_0}{3} \quad (7)$$

where:

$$I_{f1L-G} = \frac{3.V_{phase}}{2Z_1 + Z_0} \quad (8)$$

The single phase short circuit to ground was obtained as

$$I_{a1} = \tfrac{1}{3} I_a = \frac{V_f}{Z_1 + Z_2 + Z_0 + Z_f} \quad (9)$$

$$I_a = I_f = \frac{3V_f}{Z_1 + Z_2 + Z_0 + 3Z_f} \quad (10)$$

Most of the distribution line is a type of radial, with only one source and one line for fault current. The equation to calculate the current fault in a distribution line is as

$$I_A = \frac{V_{LN}}{\frac{(2Z_1 + Z_0)}{3} + R_F} \quad (11)$$

The two phase short-circuit disturbance occurred in phase **b** and phase **c**, it was used the equations as $I_a = 0; I_b = -I_c; V_b - V_c = Z_f.I_b$, so that the components of symmetric is as below [35].

$$Ia = 0$$
$$I_{a1} = -I_{a2} = \frac{V_{phase}}{Z_1 + Z_2 + Z_f} \quad (12)$$

If

F = 0

$$Ia = 0$$
$$I_{a1} = -I_{a2} = \frac{V_{phase}}{Z_1 + Z_2} \quad (13)$$

$$Ia = 0$$
$$I_{bf} = -I_{cf} = \sqrt{3} I_{a1} \angle -90^o \quad (14)$$

According to Gonen [35], the two-phase disturbance formula is as below.

$$I_{f.L} = \frac{j\sqrt{3}.V_{L-N}}{Z_1 + Z_2} \quad (15)$$

Furthermore, it was obtained as

$$I_{a1} = \frac{V_f}{Z_1 + Z_2 + Z_f} \quad (16)$$

So that, the two phase fault current is:

$$I_{bf} = -j\sqrt{3}\, I_{a1} \quad (17)$$

$$I_{a0} = -\frac{V_f - Z_1 I_{a1}}{Z_0 + 3Z_f} \quad (18)$$

$$I_{a2} = -\frac{V_f - Z_1 I_{a1}}{Z_2} \quad (19)$$

$$I_{a1} = \frac{V_f}{Z_1 + \frac{Z_2 (Z_0 + 3Z_f)}{Z_2 + Z_0 + 3Z_f}} \quad (20)$$

$$I_F = I_b + I_c = 3 I_{a0} \quad (21)$$

$$I_A = -j\sqrt{3}\,\frac{Z_0 + a Z_1}{Z_1 (Z_1 + 2Z_0)} V_{LN} \quad (22)$$

$$I_B = j\sqrt{3}\,\frac{Z_0 - a^2 Z_1}{Z_1 (Z_1 + 2Z_0)} V_{LN} \quad (23)$$

$$I_G = \frac{-V_{LN}}{(Z_1 + 2Z_0)/3} \quad (24)$$

Table 1 lists the frequency persentage of fault type occurences [32, 35].

Table 1. Overhead line disturbance frequency

No	Fault types	Occurences (%)
1	L-G	70
2	L-L	15
3	L-L-G	10
4	L-L-L	5

OCR is a device which indicated the existence overcurrent, whether caused by the short circuit or overload which can probably damage the equipment. It is used in almost all patterns of power system protection, as the main or backup. OCR can open power circuit breakers on low or high voltage side of power transformer. It types can be defenite time or inverse time. Time–current characteristics of relay are classified into normal inverse, very inverse, long inverse and extremly inverse.

In this research, the case study was used 6 units of 60 MVA, 150/20 kV power transformer and 20 kV distribution line feeders to be analyzed. Nevertheless, it was used only three points of impedance. The transformer positive and negative sequence impedances are as follow.

$$Z_1 = Z_T = R_T + jX_T \quad (25)$$

To calculate the short-circuit current on cables, the positive and negative sequence impedances were ignored. However, the zero sequence impedance of grounding system was payed to consider. Short circuit phase to phase and single phase to ground are as below respectively.

$$I_{2phase} = \frac{V_n}{2.Z_{equiv}} \quad (26)$$

$$I_{1phase} = \frac{3.\frac{V_n}{\sqrt{3}}}{2.Z_{equiv1} + Z_{equiv0}} \quad (27)$$

A short circuit peak value (I_p) was calculated by using the formula as follow [36-37].

$$I_p = \sqrt{2}\, k\, I_k^{"} \quad (28)$$

where k is function of the **R/X** system on the fault locations.
Table 2 lists the voltage factor method C.

Table 2. Voltage factor methods C

	Nominal Voltage (U_n)	For maximum sc calculations (C_{max})	For minimum sc calculations (C_{min})
LV	100-1000 V 30-400 V	1.00	0.95
	Other Voltage	1.05	1.00
MV	1KV-35 KV	1.10	1.00
HV	35KV-230 KV	1.10	1.00

Conductors used in a power systems are vary depending on the technical and economic calculation needs. The 20 kV underground cables were used as N2XSEFGBY, i.e. Cu/XLPE/CTS/AWA/PVC 3.6/6 kV, 6/10 kV, 12/20 kV, 18/30kV-3 Core. The distribution lines have three radial feeders, where one line is for stand-by feeder, when disturbance existence.

Tables 3-9 list the power transformer data, distribution transformer data and cable data for the investigations.

Table 3. Power transformer data

No	Transformer name	Rating Power (MVA)	Primary Voltage (kV)	Secondary Voltage (kV)	Z (%)	R(%)
1	Main Trafo III	60	150	20	13.93	12
2	Main Trafo V	60	150	20	14.6	11.6

Table 4. Distribution transformer data of USB feeder

No	Transformer name	Rating Power (kVA)	Primary Voltage (kV)	Secondary Voltage (V)	Z (%)	R(%)
1	UZB-LIKA 12	250	20	400	3.93	3.09
2	UZB-LIK 13	400	20	400	3.93	3.15
3	UZB-PRA 14	630	20	400	4.12	3.96
4	UZB-ALT 15	250	20	400	3.93	3.09
5	UZB-CWI 16	400	20	400	3.93	3.15
6	UZB-VPI 17	2770	20	400	7.0	10.67
7	UZB-VTX 18	400	20	400	3.93	3.15
8	UZB-GKSII 19	630	20	400	4.12	3.96
9	UZB-PCN 110	250	20	400	3.93	3.09
10	UZB-GMS 111	414	20	400	3.93	3.15
11	UZB-MSG 112	555	20	400	4	3.96
12	UZB-PIK 113	250	20	400	3.93	3.09
13	UZB-OGA 114	630	20	400	4.12	3.96

Table 5. Distribution transformer data of USM feeder

No	Transformer name	Rating Power (kVA)	Primary Voltage (kV)	Secondary Voltage (V)	Z (%)	R(%)
1	UZM-CBU 12	630	20	400	4.12	3.96
2	UZM-TRC 13	250	20	400	3.93	3.09
3	UZM-ATM 14	400	20	400	3.93	3.15
4	UZM-ATM 14	400	20	400	3.93	3.15

5	UZM-BKB 15	250	20	400	3.93	3.09
6	UZM-DS 16	400	20	400	3.93	3.15
7	UZM-GRUB 17	240	20	400	3.93	3.09
8	UZM-OG 18	630	20	400	4.12	3.96
9	UZM-OGC 19	630	20	400	4.12	3.96
10	UZM-BTR 110	250	20	400	3.93	3.09
11	UZM-BTZ 111	1730	20	400	6.25	6

Table 6. Distribution transformer data of UZU feeder

No	Transformer name	Rating Power (kVA)	Primary Voltage (kV)	Secondary Voltage (V)	Z (%)	R(%)
1	UZU-DPA 12	630	20	400	4.12	3.96
2	UZU-IPT 13	250	20	400	3.93	3.09
3	UZU-FTX 14	5540	20	400	7	12.85
4	UZU-SIJU 15	400	20	400	3.93	3.15
5	UZU-IDX 16	400	20	400	3.93	3.15
6	UZU-TBA 161	250	20	400	3.93	3.09
7	UZU-MWR17	555	20	400	4	3.96
8	UZU-HRX 18	555	20	400	4	3.96
9	UZU-GPP 19	250	20	400	3.93	3.09
10	UZU-LIP 110	250	20	400	3.93	3.09
11	UZU-LRR 111	250	20	400	3.93	3.09
12	UZU-JPX 112	400	20	400	3.93	3.15
13	UZU-BKK 113	250	20	400	3.93	3.09
14	UZU-BMU 114	400	20	400	3.93	3.15

Tabel 7. Cable data of UZB feeder

Feeder	Load Name	Length (mc)	Load Name	A (mm^2)
UZB	UZM	3,600	LIKA	150
	LIKA	1,000	LIK	150
	LIK	800	PRA	150
	PRA	200	ALT	150
	ALT	300	CWI	150
	CWI	400	VPI	150
	VPI	250	VTX	150
	VTX	600	GKSI	150
	GKSI	1,500	PCN	150
	PCN	700	GMS	150
	GMS	400	MSG	150
	MSG	300	PIK	150
	PIK	1,000	OGA	150
Total		11,050 mc		

Tabel 8. Cable data of UZM feeder

Feeder	Load Name	Length (mc)	Load Name	A (mm^2)
UZM	UZM	1,500	CBU	150
	CBU	350	TRC	150
	TRC	400	ATM1	150
	ATM1	240	ATM2	150
	ATM2	300	BKB	150
	BKB	500	DS	150
	DS	800	GRUB	150
	GRUB	1,200	OG	150
	OG	500	OGC	150
	OGC	450	BTR	150
	BTR	150	BTZ	150
Total		6,390 mc		

Table 9. Cable data of UZU feeder

Feeder	Load Name	Length (mc)	Load Name	A (mm^2)
UZU	UZU	1,200	DPA	150
	DPA	2,210	IPT	150
	IPT	425	FTX	150
	FTX	521	SIJU	150
	SIJU	1,400	IDX	150
	IDX	670	TBA	150
	TBA	325	MWR	150
	MWR	1,100	HRX	150
	HRX	160	GPP	150
	GPP	50	LIP	150
	LIP	2,500	LRR	150
	LRR	100	JPX	150
	JPX	210	BKK	150
	BKK	40	BMU	150
Total		10,911 mc		

For short-circuit calculation of UZB feeder, it might be occured as asymmetrical two phases and one phase to ground. The calculations were based on the length of feeders, which were assumed to occur on 25%, 50%, 75%, and 100% of feeder lengths as shown in Figure 1.

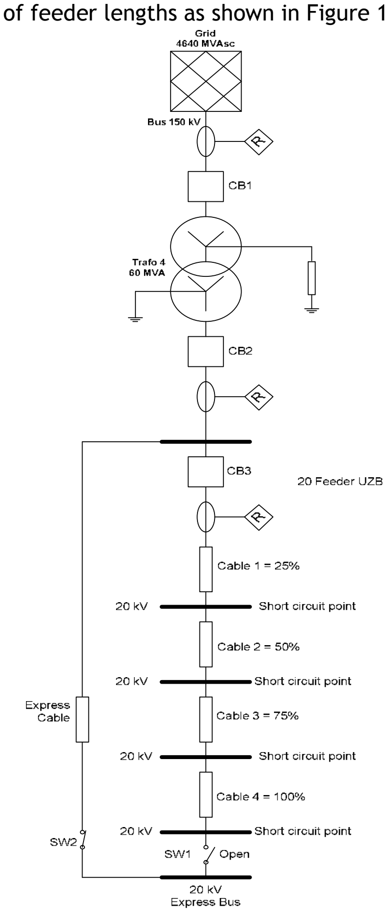

Figure 1. Calculation scenario of short circuit

The source impedance on 150 kV side was $\mathbf{X_{s150kV}}$ as 5.28 Ω, and on 20 kV side $\mathbf{X_{s20kV}}$ as 0.093 Ω, the transformer impedance Z_B as 6.66 Ω, positive dan negative sequence reactance of power transformer $X_{t1}=X_{t2}$ 1.15+j1.02 Ω and the zero sequence reactance of power transformer (Ynyn0 to feeder UZB) X_{t0} as j11.832 Ω.

The modelling of point location in the 0%-100% with a total length of feeder UZB 11.05 kmc Z_{kpos}=0.152+j0.102 and Z_{kzero}=0.314+j2.076.

Table 10 lists the positive, negative and zero sequence impedances of UZB feeder.

Table 10. Positive, negative and zero sequence impedances of UZB feeder

Fault location (%)	(+)and (−) sequence impedances (Ω)	(0) sequence impedance (Ω)
0	0	0
25	0.419+j0.281	0.866+j5.729
50	0.875+j0.587	1.802+j11.902
75	1.256+j0.844	2.591+j17.11
100	1.678+j1.127	3.45+j22.834

The positive or negative sequence equivalent impedance was used by the formula as

$$Z_{1equiv}=Z_{S1}+Z_{T1}+Z_{1feeder} \quad (29)$$

The zero sequence impedance obtained from the sum of zero sequence impedance transformer, the value of 3 R_N (neutral resistance) and zero sequence impedance of feeder, as

$$Z_{0equiv}=Z_{0T}+3R_N+Z_{0feeder} \quad (30)$$

Table 11 lists the positive, negative and zero sequence equivalent impedances of UZB feeder.

Table 11. Equivalent impedances on UZB feeder

Fault location (%)	(+)and (–) sequence equivalent impedances (Ω)	(0) sequence equivalent impedances (Ω)
0	1.15+j1.113	34.8 + j 11.832
25	1.569+j1.394	35.666 + j 17.561
50	2.025+j1.7	36.602 + j 23.734
75	2.406+j1.957	37.391 + j 28.942
100	2.828+j2.24	38.25 + j 34.666

For the sc calculation of UZM feeder, it might occured in some conditions as above. The feeder length was 6.39 kmc.

The source impedance (or reactance) on 150 kV and 20 kV sides were X_{s150kV} as 5.28 Ω and X_{s20kV}=0.093 Ω respectively. Transformer impedance Z_B was 6.66 Ω. The positive, negative and zero sequence impedances of power transformer were $Z_{t1}=Z_{t2}$=1.15+j1.02 Ω and X_{t0}=11.832 Ω.

The positive (or negative) of UZM feeder with 6.39 kmc was Z_{kpos}=0.152+j0.102. While the zero sequence impedance of UZM feeder was Z_{kzero}=0.314+j2.076.

Table 12 lists the positive, negative and zero sequence mpedances of UZM feeder.

Table 12. Positive, negative and zero sequence impedances of UZM feeder

Fault location (%)	(+)and (–) sequence impedances (Ω)	(0) sequence impedance (Ω)
0	0	0
25	0.241+j0.162	0.866+j3.3
50	0.485+j0.325	1.003+j6.632
75	0.728+j0.488	1.504+j9.949
100	0.971+j0.651	2.006+j13.265

The neutral grounding resistance was 11.6 Ohm.

Table 13 lists the positive, negative and zero sequence equivalent impedances of UZM feeder.

Table 13. Equivalent impedances on UZM feeder

Fault location (%)	(+) or (–) equivalent impedance (Ω)	(0) equivalent impedance (Ω)
0	1.15+j1.113	34.8+j11.832
25	1.391+j1.275	35.686+j15.132
50	1.635+j1.438	36.689+j18.464
75	1.878+j1.601	38.193+j21.781
100	2.121+j1.764	40.199+j25.097

The feeder length was 10.911 kmc, source impedance (or reactance) on 150 kV and 20 sides were X_{s150kV}=5.28 Ω and X_{s20kV}=0.093 Ω respectively, the transformer impedance Z_B was 6.66 Ω, and the positive and negative impedances of power transformer were $Z_{t1}=Z_{t2}$=1.15+j1.02 Ω. Furthermore, the zero sequence reactance was X_{t0} =11.832 Ω.

Total length of feeder UZU was 10.911 kmc, so that the impedance was Z_{kpos}=0.152+j0.102 Ω.

Table 14 lists the positive, negative and zero sequence mpedances of UZU feeder.

Table 14. Positive, negative and zero sequence impedances on UZU feeder

Position (%)	(+)and (–)sequence impedances (Ω)	(0) sequence impedance (Ω)
0	0	0
25	0.413+j0.277	0.854+j5.646
50	0.828+j0.555	1.711+j11.314
75	1.243+j0.834	2.568+j16.981
100	1.658+j1.119	3.42+j22.651

The total length of feeder was 11.05 kmc, and Z_{kzero}=0.314+j2.076.

Table 15 lists the positive, negative and zero sequence equivalent impedances of UZU feeder.

Table 15. Equivalent impedances on UZU feeder

Position (%)	(+) and (–) sequence equivalent impedances (Ω)	(0) sequence equivalent impedance (Ω)
0	1.15+j1.113	34.8+j11.832
25	1.563+j1.39	35.654+j17.478
50	1.978+j1.668	36.511+j23.146
75	2.393+j1.947	37.368+j28.813
100	2.808+j2.232	38.22+j34.483

The neutral grounding resistance was 11.6 Ω. The overcurrent relay setting on feeders of UZB, UZM and UZU is used the installed current transformer of 600/5 A ratio, the basis for the calculation of the maximum current. For the inverse relays, the usual settings are 1.05 up to 1.1 times of maximum current, while the setting definite relays are 1.2 up to 1.3 times of maximum current. Other requirements that should be met were for adjustment of the minimum time overcurrent relays (especially in the feeders) as not less than 0.3 seconds. This decision was taken so as not to trip relays again due to inrush currents of distribution transformers those already connected in the network. The load current was I_{load}= 657.142 A, CT ratio was 600/5 A, $I_{set(primary)}$=1.05 x I_{load} was 690 A and $I_{set(secondary)}$ was 5.75 A.

The nominal load current on the 20 kV incoming feeder I_{load} was 1732 A, CT ratio was 2000/5 A, $I_{set(primary)}$ was 1.05 x I_{load} = 1818.6 A and $I_{set(secondary)}$ was 4.547 A.

4. Results and Discussion

From the calculation results of short circuit currents above, it can be seen in the Table 16 below which the results obtained have been compared to the results of the simulation for UZB feeder.

Figure 3 shows the comparisons of fault currents between the caculation and simulation results for double and single phase on feeder UZB.

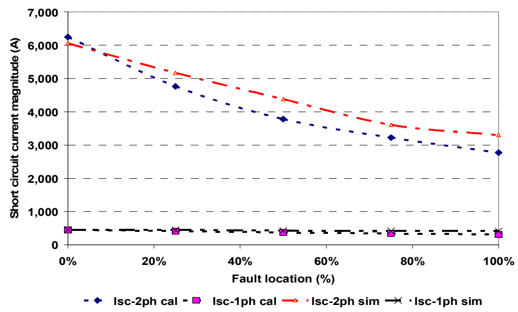

Figure 3. Comparison of fault currents on feeder UZB

From Table 16, the differences between the calculation and simulation results of asymmetrical short circuit current on UZB feeder might caused by that the simulation taking into account voltage drops and impedance difference of calculation methods.

Table 16. Asymmetrical short circuit currents on UZB feeder

Fault location	Calculation 2 phase	Calculation 1 phase	Simulation 2 phase	Simulation 1 phase
0%	6248.4	451.6	6060	455
25%	4764.6	413.8	5170	446
50%	3782.2	374.4	4380	430
75%	3224.3	343.8	3610	419
100%	2771.9	313.6	3300	414

At the distance of 25% -100%, the feeder currents were big difference in the results.

For UZM feeder, the comparison short circuit currents between the calculation and simulation results can be seen in the Table 17, for both double and single phase faults.

Table 17. Asymmetrical short circuit currents on UZM feeder

Fault location	Calculation (A) 2 phase	Calculation (A) 1 phase	Simulation (A) 2 phase	Simulation (A) 1 phase
0%	6248.4	451.6	6060	455
25%	5299.6	426.1	5860	453
50%	4592.6	400.5	5390	449
75%	4052.2	373.0	4610	440
100%	3624.9	345.4	3690	427

At UZM feeder, they have differences that resembles the UZB feeder, this is because the method used for the calculation and analysis of the same.

Figure 4 shows the comparisons of fault currents between the caculation and simulation results for double and single phase on feeder UZM.

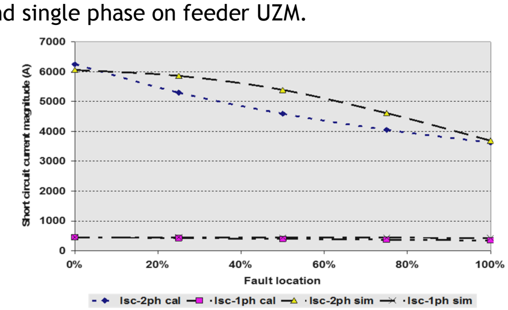

Figure 4. Curve Comparison feeder fault current at UZM

For UZU feeder, the comparison short circuit currents between the calculation and simulation results can be seen in Table 18, for both double and single phase faults.

Table 18. Asymmetrical short circuit currents on UZU feeder

Fault location	Calculation (A) 2 phase	Calculation (A) 1 phase	Simulation (A) 2 phase	Simulation (A) 1 phase
0%	6248.4	451.6	6080	455
25%	4780.9	414.4	5340	436
50%	3864.9	378.0	4410	426
75%	3241.5	344.5	3480	413
100%	2787.8	314.6	3060	405

In UZU feeders there is a difference current of calculation and simulation results were significantly high. This case was probably caused by the longer of feeder UZM compared to another feeder. The short circuit currents at the point of 25%-100% interruptions were also obtained by the simulations.

Figure 5 shows the comparisons of fault currents between the caculation and simulation results for double and single phase on feeder UZU.

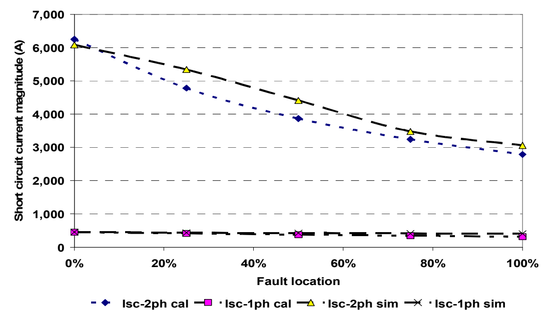

Figure 5. Curve Comparison feeder fault current at UZU

Table 19 lists the contribution current of simulation results on UZB feeder. It was assumed that the motor load was 60%.

Table 19. Contribution current of simulation on UZB feeder

Special customer UZB feeder			Contributing
Name of Load	Load (kVA)	60% motor load (kVA)	current (A)
PRA 14	550	330	72
CWI 16	350	210	46
VPI 17	2 560	1 536	303
VTX 18	380	228	49
GMS 11	390	234	51
MSG 12	460	276	61

Table 20 lists the contribution current of simulation results on UZM feeder. It was assumed that the motor load was 60%.

Table 20. Contribution current of simulation results on UZM feeder

Special customer UZM feeder			Contributing
Name of Load	Load (kVA)	60% motor load (kVA)	current (A)
GRUB 17	220	132	29
BTZ 11	1690	1014	204

Table 21 lists the contribution current of simulation results on UZU feeder. It was assumed that the motor load was 60%.

Table 21. Contribution current of simulation results on UZU feeder

Special customer UZU feeder			Contributing current (A)
Name of Load	Load (kVA)	60% motor load (kVA)	
FTX 14	5450	3 270	637
MWR 17	350	210	46
HRX 18	510	186	66
JPX 12	520	312	68
JPX 12	385	231	50

From the simulation results, the current contribution of each load feeder was dynamic. There were two categories of load, namely general and special loads. In this study, they were assumed that 60% of loads were motors.

Table 22-24 list the relay working times on UZB, UZM and UZU respectivley.

Table 22. Relay working time on UZB feeder

Fault location	Time to relay work on UZB feeder				Existing data
	Calculation (s)		Simulation (s)		
	2 phases	1 phase	2 phases	1 phase	
25%	0.362	0.266	0.536	0.348	0.2 second
50%	0.412	0.277	0.600	0.377	
75%	0.456	0.288	0.669	0.400	
100%	0.506	0.299	0.703	0.412	

Table 23. Relay working time on UZM feeder

Fault location	Time to relay work on UZM feeder				Existing data
	Calculation (s)		Simulation (s)		
	2 phases	1 phase	2 phases	1 phase	
25%	0.343	0.263	0.475	0.334	0.2 second
50%	0.369	0.269	0.509	0.342	
75%	0.396	0.277	0.564	0.358	
100%	0.423	0.286	0.642	0.384	

Table 24. Relay working time on UZU feeder

Location fault	Relay working time of UZM feeder				Existing data
	Calculation (s)		Simulation (s)		
	2 phase	1 phase	2 phase	1 phase	
25%	0.361	0.266	0.535	0.363	0.2 second
50%	0.407	0.276	0.608	0.384	
75%	0.454	0.287	0.697	0.414	
100%	0.504	0.298	0.751	0.432	

Of the three tables, there are differences in relay working times between the calculation and simulation results. Nevertheless, they were still within the normal working times.

Based on Tables 16-18, and Figures 3-5, the magnitudes of asymmetrical short circuit currents would reduce as the distance increased. Of course, they were caused by the impedances would increase. The magnitudes for the two phase faults were significantly higher than the one phase faults. These phenomena were caused by the voltage which were only one phase and the fault impedances were higher than those the two phase ones. If they were compared between the calculation and simulation results of asymmetrical short circuit currents, generally, the latters were higher than those the former ones. The average difference was 403.9 A or 9.24% for two phase faults and 48.4 or 12.53% for one phase faults, for the three feeders. These differences were probably caused by the some value of reactance(s) involved in the simulations, however, they could not be involved in the manual caculations, or due to slightly differences of feeder parameters, not exacly same, depend on the library existence. Among three feeders, the asymmetrical short circuit currents on UZM feeder was the highest compared to the remaining feeders. This case was caused by the shortest distance of UZM feeder.

Based on Tables 22-24, the relay working times would be longer as the positions of faults increased from the substation on each feeder. The relay working times on on the transformer incomings were longer than the working times on the feeders. These cases were caused by the impedances increased due to both the feeder fault distance rose and the transformer incomings. Nevertheless, the relay working times on the feeders for double phase faults were longer than the single phase ones. These cases were caused by the determination of relay settings, which were different between the single phase and double phase faults. Among the three feeders, UZB, UZM and UZU, the longest of relay working time was on UZB feeder, due to the longestin distance, i.e. 0.506 seconds for the feeder and 2.23 seconds for the transformer incoming, both for the double phasefaults and for the fault pistion of 100%. While for the single phase faults were 0.299 seconds and 0.7 seconds for the same case. However, if they were compared between the calculation and simulation results, usually the latters were longer than those the formers with the average differences were 0.1913 or 45.98% for the two phase faults and 0.0997 or 35.68% for the one phase faults, for the three feeders. These differences were probably caused by some value of reactance(s) involved in the simulations, however, they could not be involved in the manual calculations.

5. Conclusions

Based on the calculations, simulations and analysis of 20 kV feeder asymmetrical short circuits, it could be concluded as follows. The magnitudes of asymmetrical short circuit currents would reduce as the distance increased due to the impedances rose. The short circuit current magnitudes for the two phase faults were significantly higher than the one phase faults. The calculation results of asymmetrical short circuit currents were lower than those the simulations, where the average difference was 403.9 A (9.24%) for two phase faults and 48.4 (12.53%) for one phase faults.

The relay working times would be longer as the positions of faults increased from the substation. The relay working times on the feeders for double phase faults were longer than the single phase ones. The different between the calculation and simulation results were 0.1913 seconds or 45.98% for the two phase faults and 0.0997 seconds or 35.68% for the one phase faults, where usually the latters were longer than those the formers.

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